EVALUATION OF TWENTY BERMUDAGRASS CULTIVARS FOR THEIR DROUGHT RESISTANCE

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CHAPTER I

A REVIEW OF SCIENTIFIC LITERATURE ON THE SUBJECT OF TURFGRASS WATER RELATIONS

INTRODUCTION

Bermudagrasses (*Cynodon spp.*) are the most widely used turfgrass in full-sun areas of the Southern United States (Emmons, 1995). They are adapted to the humid and semi-arid tropical, sub-tropical and warmer temperate regions in the world. In certain countries bermudagrass is also known by the common name of couchgrass (Beard, 1973). The other names for bermudagrass are quickgrass, wiregrass and devilgrass (Emmons, 1995). With potential for water savings and many desirable qualities fitting today's turfgrass needs and environmental concerns, bermudagrass use has increased considerably (Keeley and Fagerness, 2001). Common bermudagrass [*Cynodon dactylon* (L.) Pers.] is a highly variable warm season turfgrass species, containing considerable variation in color, texture, density, vigor and environmental adaptation (Turgeon, 2005).

It was introduced to the warmer regions of the United States from Africa and India in the late 1700s (Deputy et al., 1998). Bermudagrasses are widely used on athletic fields, bowling greens, tennis courts, golf courses and home lawns. Because of their high biomass yield and desirable forage qualities, bermudagrasses are also used as forage crops for hay production and grazing. Bermudagrass is widely used along roadsides, waterways and other potential erosion areas to reduce water runoff and soil losses.

Bermudagrass Growth Habit, Distribution and Taxonomy

Bermudagrasses are warm-season, perennial grasses that spread vegetatively by stolons, shoots and rhizomes. Although bermudagrass can now be found on 6 of the 7 continents, the center of origin of the Bermudagrass genus *Cynodon* is believed to be Africa or Southeast Asia (Taliaferro et al., 2003). The genus, *Cynodon*, contains 9 species and 10 botanical varieties within those species (de Wet and Harlan, 1970; Harlan et al., 1970). Within these species there are hundreds of recognized cultivars (synonym = cultivated varieties). The bermudagrass taxon *C. dactylon* var. *dactylon* and African bermudagrass (*C. transvaalensis*) as well as the crosses between the two species (interspecific hybrids or *C. dactylon* X *C. transvaalensis*) are generally considered the most economically important to the golf turf industry (Beard, 1973; Taliaferro, 2003; Taliaferro et al., 2004). *C. dactylon* contains both tetraploid and hexaploids (Wu et al., 2005) while *C. transvaalensis* is a diploid, both with broad genetic variability and high fertility. In the US most turf managers simply refer to *C. dactylon* var. *dactylon* as “bermudagrass” or “common bermudagrass” while *C. transvaalensis* is referred to as

African bermudagrass. *C. dactylon* var. *dactylon* has three races: a tropical race which forms loose turf with short stature; a temperate race which appears to be similar to tropical but they are denser and more winter hardy; and a seleucidus race which have a very coarse texture, thick stolons and rhizomes and are much more cold tolerant than the other two races (Turgeon, 2005).

General Adaptation Features of Bermudagrass

Bermudagrasses grow best on well-drained soils that have a pH between 6.0 – 6.5 (Higgins, 1998). Usually the growth of bermudagrass is stopped below 16^{o}C and they may discolor at 7^{o} C – 10^{o} C (Emmons, 1995). They have a very fast growth rate and therefore are quick to establish and recover from injury due to their ability to spread rapidly by stolons (aboveground stems) and rhizomes (underground stems) (Higgins, 1998). Common bermudagrass establishes a deep root system with vigorous rhizomes making it a troublesome weed in adjacent flowerbeds (Wiecko, 2006). They are relatively resistant to many herbicides and chemicals as well as many adverse environmental conditions (Wiecko, 2006). Because of their prostrate growth habit they have good tolerance to close mowing (Beard, 1973). Most common bermudagrasses used for general purpose can be mowed as low as 1.27 cm (0.5 in.) to 2.54 cm (1 in.) with 1.9 cm (0.75 in.) preferred. Cultivars such as ‘Tifgreen’ (= ‘Tifton 328’), ‘Tifdwarf’, ‘Everglades’(= ‘FB-4’), and ‘Bayshore’(= ‘Gene Tift') hybrid Bermudagrasses tolerate daily mowing at 0.63 cm (0.25 in.) (Beard, 1973). Ultradwarf bermudagrasses can tolerate 3.2 mm (0.125 in.) or less mowing height for long term (McCullough et al., 2007). Bermudagrass is very wear resistant among the warm season turfgrasses and has an excellent recuperative capacity (Turgeon, 2005). It has a good tolerance to wear and compaction but also requires high nitrogen (N) for good quality turf (Christians and Engelke, 1994). The heat and drought tolerance of bermudagrass was appreciated by early golf course superintendents because it required little or no irrigation during summer (Dunn and Diesburg, 2004). Regarded as drought tolerant, bermudagrass requires less water than most other grasses (Keeley and Fagerness, 2001). The ability to become semidormant during severe drought and to recover from stolons and rhizomes when water becomes available makes them drought tolerant (Duble, 1996).

The water requirement of bermudagrass is cultivar-dependent (Christians, 2004). Turfgrasses cannot structurally utilize all the water that is supplied to them by root uptake. In fact only a small portion of the absorbed water is actually structurally utilized in the production of tissue. The typical turfgrass plant has water content ranging from 75 to 85 percent by weight (Beard, 1985). It may be lethal to the grass plant if water content is reduced just as little as 10 % from 75 to 65 % by weight within a short time (Kim, 1983). The hybrid bermudagrasses tend to thin during extended period of drought whereas common types of bermudagrasses are more tolerant to drought (Christians, 2004). However bermudagrass still requires a sufficient amount of water to keep it growing and maintain suitable turfgrass quality during mid-summer. Drought stress can cause serious damage to turfgrasses. Therefore when selecting turfgrass species for arid climates one should consider the drought resistance of a particular species and it’s cultivars.

Drought Resistance and Terminology

Drought is a condition which plants experience after a prolonged period of water deprivation that causes depletion of moisture in the root zone (Younger, 1985). Drought resistance is a complex mechanism that enables plants to withstand dry periods (Kim et al., 1988). The mechanisms of drought resistance include drought escape, drought avoidance and drought tolerance (Kim et al., 1988). The ability to sustain biochemical and physiological processes by a turfgrass plant when there is an internal decrease in water content is drought tolerance, whereas the ability of a plant to sustain internal water levels through morphological and physical features of growth is drought avoidance (Danneberger, 1993). Turfgrasses need sufficient water to maintain vegetative growth which helps them to retain their aesthetic and functional value in a lawn setting. However drought resistance and water use characteristics might differ among plants based upon the growing season. Similarly their water requirements and other cultural requirements might also differ as warm-season turfgrasses are generally more tolerant to drought stress than the cool-season grasses (Gibeault, 1977). Drought stress, if severe and of adequate duration can cause serious damage to or even death of turfgrasses. Water is a limited renewable resource (Watson, 1985) therefore drought tolerance is an extremely important criterion while selecting a turfgrass species where there is scarce supply of water during prolonged periods of inadequate rainfall (Turgeon, 2005). It is equally important to adopt a strategy that reduces turfgrass irrigation needs using drought resistant species and cultivars (Carrow, 1996).

Pathways of Water Flow Leading to Evapotranspiration

The movement of water directly from soil surface to the atmosphere is called evaporation (E). The loss of water from both plant body and soil surface affects the water availability to plants. The loss of water through the plant surface to atmosphere is termed transpiration (T). Both of these processes occur simultaneously in nature. Water use rate is defined as the total amount of water required for turfgrass growth plus the quantity lost by transpiration from the plant and evaporation from the soil surface (Beard, 1973). Thus, evapotranspiration (ET) is a combined loss of water simultaneously from plant and soil surfaces. Less than 1 – 2 % of the total water taken up by a plant is used in growth (structure). Therefore water use rates are essentially (generally considered) equal to ET rates (Jensen, 1968).

Plants exhibit some resistance to transpiration while the water passes through different pathways before it is ultimately diffused in air. Pathways of transpiration may be cuticular or stomatal. Evaporation within the stomatal cavity occurs primarily on the mesophyll cell walls that are exposed to intercellular spaces. Water vapor then diffuses along a gradient through the stomatal cavity outward from the leaf, then through the turfgrass canopy and eventually into the air mass above (Beard, 1985). The water vapor leaving the stomatal cavity then faces additional resistance to diffusion into the bulk atmosphere because of the boundary layer just above the leaf surface. The boundary layer is a thin layer of air that tends to remain stagnant very near the plant or leaf surface which helps to reduce water loss from the leaves. Therefore a wide range of morphological, anatomical and environmental factors affect the resistance of plants to transpiration (Beard, 1985).

Knowledge of drought-resistance mechanisms in turfgrasses facilitates the development of management strategies and aids in selection of turfgrasses with improved drought resistance (Huang et al., 1997b). Turfgrasses may exhibit drought resistance through various strategies, including developing deep root systems, possessing special shoot morphological features and physiological mechanisms that reduce evapotranspiration losses (Huang et al., 1997b). According to Levitt (1980), plants with good drought resistance are those that are able to survive stress by means of drought avoidance, drought tolerance at low leaf water potentials, or both (Qian and Fry, 1997). Osmotic adjustment (OA), defined as the accumulation of solutes in plant tissue in response to dehydration (Turner and Jones, 1980), subsequently reduces osmotic potential. This is an important mechanism of drought tolerance that maintains cellular turgor at a given leaf water potential and thus delays wilting of leaves, enabling sustained growth and productivity at lower levels of water (Huang, 2004). The OA and induction of dehydrin proteins may confer drought tolerance, and abscisic acid (ABA) may contribute to drought avoidance by induction of stomatal closure in turfgrass (Huang, 2004). The mechanisms or changes in the turfgrass metabolism that enable plants to persist and endure internal water stress are important drought tolerance characteristics (Kopec, 1992). When the water is not adequate from either rainfall or irrigation, turfgrasses will roll or fold (depending upon the vernation) their leaf blades to stop transpirational water loss which will defer any new shoot growth and will send their roots deeper into soil in search of water (Trenholm, 1991). Trenholm termed this process “Drought conditioning”. A drought conditioned turf can tolerate water stress more than one that is not drought conditioned (Trenholm, 1991).

Plants may exhibit different adaptive characteristics to deal with water deficit stress such as enhanced root plasticity, root extension deeper into the soil profile for greater extraction of water, decreased leaf growth and/or reduced leaf area, enhanced leaf pubescence, leaf rolling/folding, and reduced number of stomata in response to drought (Huang et al., 1997b; Duncan and Carrow, 1999; Huang, 2008). Another important feature of drought avoiding plants is reduction in the water use rate (Huang, 2008). Dehydration avoidance is one type of drought resistance by which plants avoid tissue-damaging water deficits while maintaining growth during increasing water stress (Sifers and Beard, 1998; Beard, 1989).

In response to progressive drought stress leaves become chlorotic starting at tips and margins, and progress down the leaf which is termed as “Leaf firing” (Carrow and Duncan., 2003). Since visual quality is an important factor in growing utilitarian turfgrass stands, leaf firing during conditions of moderate to severe drought should be taken into consideration when selecting turfgrasses (Kim et al., 1988). Research by Kim et al. (1988) also indicated that leaf firing predicted the potential resistance of warm season turfgrass species (Sifers and Beard, 1998).

Cultural practices may help turf plants survive drought (Harivandi and Gibeault, 1990). Turf that looks brown but possesses a healthy stem system may not be dead and can have potential to initiate new growth within a few days upon receiving a significant rain (Harivandi and Gibeault, 1990). Irrigating frequently and deeply as the signs like spots turning bluish gray color, footprints remaining in the grass for longer time, and folding and rolling of leaves when occur for the first time is helpful (Harivandi and Gibeault, 1990). Uniform irrigation matching the infiltration rate will help avoid runoff thus preventing water runoff (Harivandi and Gibeault, 1990). Applying water in short repeated cycles in early morning or late at night when wind and evaporation losses are lowest is recommended (Harivandi and Gibeault, 1990).

Proper fertilization practices can enhance drought tolerance in turf (Trenholm, 1991). Nitrogen fertilizers enhance the shoot growth, hence enhancing the higher water use which should be avoided to achieve drought resistance during summer (Harivandi and Gibeault, 1990). Potassium fertilizers promote increased root growth and thicker cell walls thus can help increase tolerance to many stresses including drought (Trenholm, 1991). Mowing affects the metabolic activities of grasses which reduce root growth, so the cutting height should be maintained to the highest feasible height to facilitate drought conditioning (Trenholm, 1991). Maintaining higher mowing heights allows increased leaf area resulting in more photosynthesis that helps to develop a deeper and extensive root system; however the turfgrass should not be allowed to grow to more than 1 1/2 times its mowing height (Harivandi and Gibeault, 1990).

Drought Resistance Research

Despite a general consensus concerning bermudagrass being a drought tolerant turfgrass, there has been a minimal effort to exclusively study the differences among bermudagrass cultivars for their drought tolerance (Richardson et al., 2010). In preliminary research conducted at the University of Arkansas, Fayetteville, 15 bermudagrass cultivars were evaluated for drought tolerance under a fixed poly covered rain-out shelter (Richardson et al., 2010). They found no sign of drought stress for the weakest cultivar until 45 days into the drought cycle. Tifway was always in the top statistical group in each evaluation period in their experiments during all the evaluations.

Extensive research by Kim et al. (1988) at College Station, TX involved the study of comparative drought resistance among 11 major warm-season turfgrasses, including 22 bermudagrasses, five St. Augustinegrasses, six zoysiagrass, and four centipedegrass cultivars. The drought resistance measurement criteria were speed of shoot recovery after stress and the leaf firing characteristics following withholding of irrigation and rainfall for 48 days. They found an opposite relationship between leaf firing and shoot recovery for each species and cultivars in that work. Kim et al. (1988) found that turfgrass species/varieties that turned yellow earlier during water deficit stress showed poor shoot recovery after the drought period ended.

Figure 1 excerpted from Kim et al. (1988) ranks the drought resistance and leaf firing of warm-season turfgrass species based on the performance of the most widely used cultivars of each species. Kim et al. (1988) characterized bermudagrass as a low leaf firing and high drought resistant warm season turfgrass.

TABLE 1
Warm-season interspecies drought resistance and leaf firing comparisons representative of the most widely used cultivars of each species.

Relative Classification	Leaf Firing	Drought Resistance (Shoot Recovery)
High	St. Augustinegrass	Zoyziagrass Bermudagrass Centipedegrass
Medium	Seashore paspalum Buffalograss Bahiagrass	Seashore paspalum Buffalograss Bahiagrass
Low	Centipedegrass Bermudagrass Zoysiagrass	St. Augustinegrass

Figure 1. Table showing leaf firing and drought resistance comparisons among warm season turfgrass species. Excerpted from Kim, K.S., James, B. Beard, Samuel I. Sifers. 1988. Drought resistance comparisons among major warm-season turfgrasses. USGA Green Section.

Chalmers et al. (2008) conducted research in San Antonio, TX with the overall purpose of characterizing the drought tolerance of the commonly used turfgrass species/cultivars used in south Texas. They imposed a 60 day drought period on field-grown turfgrasses in 2006 and 2007. Eight cultivars of bermudagrass, 7 cultivars of St. Augustinegrass, 9 cultivars of zoysiagrass and 1 buffalograss were studied in their work. In addition to an unrestricted depth of rooting, Chalmers et al. (2008) also repeated their work in both years in restricted root zones only four inches in depth. Four inches (10 cm) was the minimum soil depth required by construction specifications (San Antonio Water

District) for lawns on new building sites in San Antonio. All work was conducted in the field using a rain shelter. Rainfall sensors were used such that the structure would cover the field plots in the event of rain. Chalmers et al. (2008) imposed drought on the grasses by stopping irrigation for 60 days while the rain-out shelter was operating. After the 60 days of drought had passed, irrigation was supplied (non-limiting) to facilitate turfgrass recovery. The plots were evaluated for turf quality, turf uniformity and leaf firing during drought while in the recovery period they evaluated turf quality, percent living ground cover and uniformity. In both 2006 and 2007, Chalmers et al. (2008) found that no grass was able to survive (100 % kill) the 60 day drought on a shallow 10 cm (4 in) deep soil profile at San Antonio. All turfgrasses were able to survive (at least partial recovery) on native soil where the root zone depth was not restricted.

Among the bermudagrasses ‘Premier’ showed the poorest turf quality by the end of the 60 day drought in 2006 and 2007 and poorest in quality following the 60 day recovery periods in 2006. However Premier ranked higher in quality than a variety not stated ‘Common’ type bermudagrass, ‘Grimes EXP’, and ‘GN1’ by the end of the extended recovery period of 78 days in 2007. ‘Tifway’ showed the best turf quality by the end of the drought recovery period in 2006 and by the end of the extended recovery period of 78 days in 2007. ‘Celebration’ bermudagrass had the second best turf quality after ‘Tex Turf’ during the 2006 drought period and the best turf quality during the 2007 drought period. Premier was most susceptible to leaf firing during drought in both 2006 and 2007. The varieties found most resistant to leaf firing was Tex Turf followed by ‘Tifsport’ in 2006 while in 2007 Celebration was most resistant.

Chalmers et al. (2008) found a strong positive relationship between turfgrass canopy temperature and leaf firing score. Transpiration and management differences between species have been determined using turfgrass canopy temperatures (Steinke et al., 2009). Canopy temperatures are lower in non-water-stressed grasses due to transpirational cooling with higher canopy temperatures occurring as soil moisture is depleted (Steinke et al., 2009). Overall, in 2006 and 2007, the severity of leaf firing was least in bermudagrass followed by St. Augustinegrass and then zoysiagrass (Steinke et al., 2009). Canopy temperature increases at the onset of leaf firing as soon as the water is restricted (Steinke et al., 2009).

It will benefit turfgrass breeding programs and practitioners in cultivar selection if bermudagrass cultivars with superior drought resistance and variability among cultivars are identified (Baldwin et al., 2006). A two year greenhouse study was conducted in years 2003 and 2004 by Baldwin et al. (2006) with the purpose of quantifying drought resistance of six bermudagrass cultivars. Watering treatments imposed were daily, and at 5-, 10-, and 15-d irrigation intervals. Response to deficit irrigation was measured by monitoring Turf Quality (TQ), root weight, ET and soil moisture status. They found that only Celebration and ‘Aussie Green’ had acceptable TQ at the 5-d treatment after 2 weeks in greenhouse environment. All the cultivars quickly declined in TQ when irrigation was less frequent than at a 5-d interval. Celebration had the highest percentage of root weight and the least volumetric soil water content (VSWC). While Aussie Green and Celebration both produced the greatest TQ, the VSWC for both cultivars were lower than that of ‘Tifton No. 3’. However the root weight on Tifton No. 3 was greater than that of Aussie Green. Baldwin assumed that Celebration’s greater root weight helped it extract more water than Tifton No.3. By observing the results of VSWC in Aussie Green and Tifton No.3 we can assume that there may be other factors like root diameter, length, surface area and volume in combination with root weight that may have helped Aussie Green extract more water than Tifton No.3 and maintained good TQ.

In a study conducted by Poudel (2010) at Stillwater, OK, 23 clonal and experimental bermudagrass cultivars were evaluated for drought performance under field conditions. Bermudagrass was irrigated at 0, 33, 66, and 100 % of cumulative evapotranspiration on a two day basis. The work was conducted in the summer under limited rainfall and a tarp was used to exclude rainfall from all plots. After 28 days of irrigation treatment grasses were watered to eliminate further drought stress and recovery proceeded for 60 days. In separate greenhouse studies, 8 bermudagrass cultivars were evaluated for differences in root growth characteristics. Poudel (2010) found Celebration as a good drought performer and Premier as a poor drought performer in terms of LF, TQ and Normalized difference vegetative index (NDVI) in the field study. Based on the results of greenhouse work Poudel (2010) found that Celebration, ‘OKC 1119’ (=’Latitude 36’) and Experimental cultivar # 2 had good genetic potential for improved drought resistance through extensive rooting and high root/shoot ratios.

Bermudagrass is the most commonly used turfgrass for lawns and landscapes in Oklahoma. Water scarcity is one of the greatest long-term problems facing the turf industry worldwide (Sifers and Beard, 1998) and this issue is not new to Oklahoma. A review of literature revealed that only limited information was available concerning the relative drought resistance of bermudagrass cultivars that are either in use or are adapted to Oklahoma. Additional information regarding which commercially available bermudagrasses have the best drought resistance is needed. Such information would allow for improved decision making concerning selection of bermudagrasses that have the best fit under conditions of frequent drought and limited to no supplemental irrigation.

RESEARCH OBJECTIVES

This research includes twenty commercialized and experimental bermudagrass cultivars which were selected based upon their economic and local use values in Oklahoma and the transition zone. The goal of this research was to determine and compare the drought resistance characteristics among those twenty bermudagrass cultivars. The purpose was to generate valuable information that would allow the people of Oklahoma and the transition zone to make informed decisions concerning bermudagrass varietal selection and appropriate management practices. The specific objectives of this research were to i) determine overall relationships amongst turfgrass quality, leaf firing and living cover from bermudagrasses subjected to drought, ii) determine trends in drought resistance amongst bermudagrass cultivars under extended drought, iii) elucidate trends in soil moisture use amongst cultivars during drought, and iv) characterize the recuperation response of bermudagrass cultivars following the cessation of drought.

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CHAPTER II

EVALUATION OF TWENTY BERMUDAGRASS CULTIVARS FOR THEIR DROUGHT RESISTANCE

ABSTRACT

Bermudagrasses (*Cynodon* spps) are the most widely utilized turfgrass in the southern United States. Knowledge of the relative drought tolerance of bermudagrass cultivars is crucial so that turfgrass managers can make informed cultivar selection and use decisions. The objectives of this research were to determine trends in drought resistance of twenty bermudagrasses under extended drought and following the cessation of drought by observing the relationships amongst turfgrass quality, leaf firing and living cover, and trends in soil moisture use amongst cultivars. A greenhouse was used to eliminate interference from natural rainfall. Drought resistance was assessed via measures of turfgrass quality, percent living cover, and leaf firing. The experiment was conducted three times, each as a completely randomized design with five replications of each cultivar. Celebration and Premier were selected as standards of comparison in this research. Visual quality (TQ) as well as leaf firing (LF) were evaluated using a 1-9 scale where 9=excellent quality or no leaf firing. Green cover (LC) was visually estimated

from 0 to 100 % where 100 = the entire surface canopy is green. In Experiments II and III, percent volumetric soil moisture content was measured at an average 5, 10, 38 and 71 cm depths using a time domain reflectometry (TDR) probe. A strong positive correlation was found among LF, TQ and LC in all experiments during drydown and recovery cycles. Non-linear, sigmoidal dose-response equations were fitted to relate LC and days after initiation (DAI) of the drought. The mean number of days to reach 75, 50 and 25 % green cover during the drydown cycles was calculated and used as an index of drought resistance. Drought resistance was also assessed during the recovery phase by separation of mean LC over the various recovery dates. Drought resistance as measured by the mean number of days to reach 50 % LC in drydown cycles and mean LC in recovery cycles varied greatly among the twenty bermudagrasses. Celebration generally showed the highest resistance to drought by resisting LF during drydown and recovering more quickly after the drought. Premier generally had earlier LF and loss of LC which indicated a lower resistance to drought. TifGrand performed nearly as well as Celebration in drought while Latitude 36 had LF and LC performance similar to Premier. Celebration, TifGrand and other cultivars with higher drought resistance showed improved moisture extraction capacity from deeper soil depths. Cultivars with earlier LF and loss of LC had higher levels of moisture remaining deep in the soil profile during the drought. TifGrand may serve as a bermudagrass having improved drought tolerance if additional standards are needed in future drought studies.

INTRODUCTION AND LITERATURE REVIEW

Water is a limited renewable resource (Watson, 1985). To conserve water and fine-tune turfgrass performance it is extremely important that turfgrass managers optimize the amount and timing of irrigation applied to turfgrass (Martin et al., 2005). However, it is equally important to adopt a strategy that reduces turfgrass irrigation needs using drought resistant species and cultivars (Carrow, 1996). Drought resistance is a complex mechanism that enables plants to withstand dry periods (Kim et al., 1988). Drought resistance mechanisms include drought escape, drought avoidance and drought tolerance (Kim et al., 1988). Drought tolerance should be paramount for selecting a turfgrass species for the area with prolonged periods of inadequate rainfall (Turgeon, 2005).

In response to progressive drought stress, leaves become chlorotic starting at tips and margins, and symptoms progress down the leaf which is termed as “Leaf firing” (Carrow and Duncan, 2003). The initial symptoms are yellowing of the leaves which later turn tan/brown color causing death of the tan/brown areas (Carrow and Duncan, 2003). Thus as leaf firing increases, live green turfgrass color decreases. Under field conditions leaf firing and loss of live green cover provides a good assessment of overall turfgrass drought resistance (Carrow and Duncan, 2003). Under similar climatic and soil conditions, grasses varying in leaf firing amongst ecotypes are the result of their characteristic drought avoidance and tolerance mechanisms (Carrow and Duncan, 2003).

In urban areas where water availability is increasingly limited for landscapes (Huang et al., 1997a), drought stress is one of the most important environmental factors that limit turfgrass growth (Beard, 1973). One should have knowledge of variability in drought resistance for selecting grasses to improve management strategies and develop drought resistant turfgrass (Huang et al., 1997a). Water scarcity is one of the greatest long-term problems facing the turf industry worldwide (Sifers and Beard, 1998). Water scarcity issues are not new to Oklahoma. Researchers have been working to identify and develop turfgrasses that require less water and that can survive in drought conditions. Prolonged periods of drought have the capacity to damage turf areas and reduce the aesthetic value of landscapes.

Bermudagrass is the most widely used turfgrass in the southern United States. However there has been minimal effort to study the differences among bermudagrass cultivars for their drought tolerance (Richardson et al., 2010). It will be beneficial in cultivar selection for turfgrass breeding programs and practitioners if bermudagrass cultivars with superior drought resistance and variability among cultivars are identified (Baldwin et al., 2006). Chalmers et al. (2008) evaluated eight bermudagrass cultivars and other grass species in their study with the purpose of characterizing the drought tolerance of the commonly used turfgrass species/cultivars used in south Texas. They found ‘Premier’ as the poorest drought performer among bermudagrass cultivars in their study while ‘Celebration’ was among the best performers. A two year greenhouse study conducted by Baldwin et al. (2006) evaluated drought resistance of six bermudagrass cultivars with different intervals of watering treatments. Response to deficit irrigation was measured by monitoring Turf Quality (TQ), root weight, ET and soil moisture status.

They found that Celebration had the highest percentage of root weight and the lowest volumetric soil water content producing the greatest TQ. Celebration again proved to be a good drought performer and Premier as a poor drought performer in terms of LF, TQ and Normalized difference vegetative index (NDVI) in a field study conducted by Poudel (2010). Based upon the relative differences in drought resistance of Celebration and Premier documented by Chalmers et al. (2008) and Poudel (2010) these grasses would appear to be suitable standards in drought resistance research.

To date, only a small number of bermudagrasses that are commercially available in the US have been characterized for their relative drought resistance. The majority of bermudagrass turf cultivars receiving wide-spread use in Oklahoma have not been characterized for drought resistance. A need exists to characterize the drought resistance of the most commonly used bermuda cultivars in Oklahoma so that more precise recommendations can be made for areas receiving little to no irrigation during periods of drought. More wide spread use of bermudagrass varieties having high turf quality and improved adaptation to a wide array of environmental stress including improved drought resistance is essential to the success of integrated turfgrass management programs and increased water conservation.

OBJECTIVES

The specific objectives of this research were to i) determine overall relationships amongst turfgrass quality, leaf firing and living cover from bermudagrasses subjected to drought, ii) determine trends in drought resistance amongst bermudagrass cultivars under extended drought, iii) elucidate trends in soil moisture use amongst cultivars during drought, and iv) characterize the recuperation response of bermudagrass cultivars following the cessation of drought.

MATERIALS AND METHODS

This research was conducted in the greenhouse facility at the Turfgrass Research Center, Oklahoma State University, Stillwater OK. Twenty cultivars were evaluated for visual quality, leaf firing resistance and percent living (green) cover during exposure to soil moisture deficit as well as their quality and green cover during a recovery period.

Selection of Plant Materials

Cultivars were selected for their importance in the southern great plains region (based on personal communication with Dr. Dennis Martin, Oklahoma State University and National Turfgrass Evaluation Program [NTEP] data) (Table 1). The varieties tested included experimental types with promising features, those that were economically important with unknown drought tolerance and selections that had demonstrated very good performance attributes in the southern great plains region but were not widely utilized and their drought resistance characteristics were largely unknown. ‘NuMex Sahara’ (synonym ‘Sahara’), Celebration and Premier were selected as standards of comparison in this research. Sahara rated high in drought tolerance in Texas as measured by leaf firing and drought resistance using percent shoot recovery as an index (Baltensperger, 1989) while Premier was found to be more drought sensitive than Celebration in work conducted by Chalmers et al. (2008). This study was designed in 2009 to build upon the 2006 and 2007 findings of Chalmers et al. (2008) at San Antonio, TX but differed by using a greenhouse to exclude rainfall.

Containers and Growing Medium

Three similar experiments were conducted to assess turfgrass drought resistance. Plant material evaluated in each experiment consisted of 20 bermudagrass cultivars with five replications of treatment. Polyvinyl chloride (PVC) pipes [7.62 cm (3 in.) diameter green sewer pipe] were used to construct the containers (pots or growing tubes) to grow the cultivars of interest. The PVC pipes were cut to 76 cm (30 inches) in length to ensure suitable depth for root growth. The bottoms of the pipes were closed with a rubber cap secured with a stainless steel clamp. Holes drilled in the bottom of the rubber caps facilitated drainage. The rubber caps were clamped tightly to the pipe from outside to reduce the risk of losing the rooting medium. The bottom inner sides of the tubes were lined with a geotextile porous sheet to prevent any loss of the rooting medium.

The rooting medium used was haydite calcined clay (LITE-WATE™ aggregate, Chandlers Materials, Tulsa, OK 74112), sold as “fines”, without screening to specific size particles. The LITE-WATE™ aggregate had physical and chemical characteristics as described by the Expanded Shale, Clay and Slate Institute, Salt Lake City, Utah 84711. The advantages of calcined clay include 1) high infiltration rate, 2) good moisture holding capacity, 3) good plant available water and 4) rapid drainage (Kopec, 2004).

Establishment and Fertilization

The bermudagrass entries under study were selected from plots maintained under simulated golf course fairway conditions in bermudagrass trials located at the north and south ends (36^{o} 07’ 06.76” N and 97^{o} 06’ 11.60” W) of the Turfgrass Research Center, Oklahoma State University, Stillwater. Plugs measuring 7.62 cm (3 in) in dia. were removed from the field on 11, 12, and 21 - 23 January 2009. Plugs were trimmed to a 5 cm (2 inches) soil depth and were allowed to green up in trays for one month in the greenhouse before planting in the tubes. The plant material was then carefully washed to remove all soil particles while retaining aerial shoots and a substantial amount of rhizomes. Plugs were planted in the PVC tubes filled with calcined clay which was saturated with water prior to planting. Plugs were carefully pressed against the moistened growing medium to ensure a good sod to rooting medium contact. The planted materials were established for six months ensuring extensive rooting depth before grasses were subjected to drought stress in the first experiment. The experiment was conducted a second and third time when grasses in the growth tubes had been established for fifteen and sixteen months.

Cultural Practices

Fertilization

During the first month following placement of sod in February 2009 the grasses were fertilized with 73.2 kg N ha^{-1} (1.5 lbs N 1000 $sq.ft.^{-1}$) by application of Jack's Professional fertilizer 20-20-20 N-P_2O_5-K_2O source (20-8.8-16.6 N-P-K). Nitrogen fertility was increased to 146.4 kg ha^{-1} mo^{-1} (3 lbs N 1000 $sq.ft.^{-1}$) with 36.6 kg (0.75 lbs N 1000 $sq.ft.^{-1}$) split into four equal applications per week for the first two weeks on 5 April 2010. As we could not see enough improvement in growth and turf coverage after the increased fertilization rate was started, the rate and application frequency were increased again to applications twice per week totaling 210 kg N ha^{-1} mo^{-1} (4.3 lbs N 1000 $sq.ft.^{-1}$) on 5 May 2009. After observing the grass condition, it was decided to continue the fertilization program with 30.6 kg N ha^{-1} wk^{-1} (0.63 lbs N 1000 $sq.ft.^{-1}$) on 26 May 2009. The haydite calcined clay rooting medium used in these experiments was not charged with nutrients prior to the start of the experiment. That factor combined with possible leaching of nutrients through the tubes was possibly the reasons behind the high nutrient requirements for these grasses grown on the tubes.

Mor-green AC brand fertilizer (12-0-0-4-6-2 N-P-K-S-Fe-Mn) was applied to supplement micronutrients at a rate of 9.8 kg N, 3.3 kg S, 4.9 kg Fe and 1.6 kg Mn ha^{-1}on 10, 17 and 24 January as well as on 5 March 2010.

No fertilizer was applied during the time period when irrigation was withheld. This was consistent with turfgrass managers being advised not to fertilize in the absence of irrigation during water deficit stress. Fertility during the re-growth phase following the end of the drought stress period was applied at 30.6 kg N ha^{-1} wk^{-1} (0.63 lbs N 1000 $sq.ft.^{-1}$). During the re-growth period of the first experiment we observed yellowing of leaves, including the new growth in the other two sets of experiments in the greenhouse. We associated this with deficit nutrition and pest issues. To address the nutrition problem calcium sulfate was applied at 1800 kg ha^{-1} (10 lbs 1000 ft^{-2}) in four split applications along with magnesium sulfate at 100 kg ha^{-1} (2.4 lbs 1000 ft^{-2}) to supplement the calcium and magnesium that was already being applied.

Irrigation, Mowing and Pest Management

Irrigation was applied to ensure establishment and prevent moisture deficit stress during the establishment phase prior to inducing drought. Turf was watered three to four times a day during the first two months of establishment. A preventative application of imidacloprid was applied on 14 July 2009 during the establishment phase to prevent *Phyllophaga* and *Cyclocephela* taxa grub infestation which could interfere with the study. Weeds were removed by hand. Mowing of the tubes was facilitated by placement of the growth tubes in a frame structure (Fig.2). The structure supported a light-weight electric reel-type mower as well as shielded the tubes from direct heating from exposure to sunlight as only the very top of the tube was exposed (Fig.3). Mowing was performed two times per week at a height of 3.8 cm (1.5 in.) typical of a lawn. Mowing was continued for 45 days after the drought period was started then stopped after turfgrass growth ceased in the first experiment. In the second and third experiments mowing was stopped after 38 and 40 days into the drought cycle, respectively. Once the recovery period started, mowing was again conducted after three weeks and thereafter on a weekly interval. The sides of the tubes were hand-trimmed once a week using an electric shearer.

Figure 2. A frame structure was used to support the PVC growth tubes that contained the bermudagrasses being studied. Fifty growth tubes per present per frame structure

Figure 3. A light-weight electric reel-type mower was used on top of the support frame to clip the bermudagrasses to the 3.8 cm mowing height.

On 22 November 2009 a carbaryl insecticide (trade name Sevin) was applied as a curative measure for controlling cutworms (*Agrostis ipsilon*), fall armyworms (*Spodoptera frugiperda*) and sod webworms (*Crambus teterrellus*). In December other plants inside the greenhouse were found to be infested with mealy bugs (*Pseudococcus spp*.). There was evidence of mealy bugs in some of our research materials so on 15 December 2009 a fenoxycarb (trade name Preclude TR) aerosol bomb was applied in the greenhouse and the application was repeated after two weeks on 29 December 2009. A pyrethrin (trade name Pyrethrum TR) aerosol bomb was applied on 22 December 2009 and the application was repeated after two weeks on 5 January 2010. A bio-insecticide Thuricide (BT) (*bacillus thurengiensis*) was applied on 5 January 2010 to control sod webworm and repeated four times in weekly intervals. Myclobutanil (Eagle 20 EW) was applied on 9 January and 25 February 2010 to prevent fungal leaf spot and crown rot infestation.

Imposing Drought Stress

Seven months after planting, the sod was well established in the first experiment. The drought resistance testing began with a pre-trial stress acclimation treatment. Water was withheld for four days then the tubes were again saturated followed by another four days withholding of water. This pre-trial conditioning treatment was performed to help the grasses acclimate for a long dry down period which they were exposed to later. The first experiment was started on the 18th of August 2009 by withholding water. We observed the first experiment very carefully to ensure a reasonable rate of recovery which gave us a starting point for two similar, later experiments. Our earlier plan was to subject the grass to drought by means of withholding irrigation for 60 days as was performed by Chalmers et al. (2008) but there were many cultivars that still had substantial live green cover remaining after 60 days so we decided to extend the length of the drought until all of the cultivars had a leaf firing rating below a rating of 5 on a scale of 1 – 9 (9 = no firing). The drought period for the first experiment lasted for 93 days (August 18 2009 – November 19 2009). On 28 October 2009 all grass-filled tubes were transferred to another greenhouse facility where high intensity discharge lamps (HID) were available for use. Lights were set up to an automatic 16 hours of day length. Due to insufficient capacity of the greenhouse we could not use HID lamps for the drydown phase of the first experiment. The tubes were randomized and re-randomized once every week. Following the cessation of the drought period irrigation was applied two times per week in an amount to maintain non-water stressed conditions during recovery. The recovery period for Experiment I lasted for 151 days (November 19 2009 – April 19 2010).

The pre-trial acclimation was again performed for Experiments II and III as earlier described. The drought period was started for Experiment II on 4 May 2010 and for Experiment III on 28 June 2010. The visual ratings as well as soil moisture assessment were taken once each week during the drydown and recovery phases of Experiments II and III. The drought period for experiments II and III was concluded after all replicates of each variety had received a green cover rating of below 25 percent. The drydown cycles for Experiment II and III lasted for 101 days (May 4 2010 – August 13 2010) and 67 days (June 28 2010 – September 3 2010) respectively. After the drought period pots were watered every day to maintain an abundant supply of water for the first week of recovery and thereafter pots were watered twice per week. The recovery cycle for Experiment II lasted for 86 days (August 13 2010 – November 7 2010) and that for Experiment III lasted for 65 days (September 3 2010 – November 7 2010).

Data Collection

During the imposed drought period the data for turf visual quality (TQ), leaf firing (LF), leaf wilting (LW) and percent green cover (LC) were recorded using visual rating scales. We observed the visual browning of leaves caused by drought stress and evaluated the LF using a scale of 1-9 where 1 = total leaf firing of all leaves in the canopy and 9 = no leaf firing (Chalmers et al., 2008). The visual ratings were made by the observer while viewing the growth tubes from directly over the top of the turf canopy.

The TQ had components of color, density, texture, and living cover**.** The TQ was evaluated using the NTEP standard 1-9 scale where 9=excellent quality and 1= very poor quality (Morris, 2007). The LC was visually estimated from 0 to 100 % where 0 = no green cover and 100 = the entire surface canopy is green. In this paper "percent green cover" is synonymously used as "green cover", "percent living cover", "percent living green cover" or "living cover". During the recovery period visual ratings were taken for LC and TQ. Grass varieties were rated visually every 3 days during the drought period in Experiment I. As performance features were noted to change slowly in Experiment I, ratings were collected weekly in Experiments II and III. Additionally, digital images of the canopy of each experimental unit were collected once per week for a record of turfgrass performance. Although not an objective of this project at this time these images may prove useful in a later analysis.

Meteorological Conditions

A weather monitoring station (HOBO U30, Onset Computer Corporation 470 MacArthur Blvd. Bourne, MA 02532) device was installed to monitor meteorological conditions. All components were standardized “plug and use” sensors from the manufacturer. Air temperature was measured every 15 minutes at 30.5 cm above the turfgrass canopy level, at canopy level and at 10.2 cm below the wooden deck level outside of the growth tubes using thermister probes (Model S-TMB-M002). Relative humidity was measured every 15 minutes at 30.5 cm above the canopy with an electrical resistance type sensor (Model S-THB-M002), with photosynthetically active radiation (PAR) [Model S-LIA-M003] and incoming solar radiation [Model S-LIB-M003] measured by silicon diode type sensors every 15 minutes at the surface of the canopy.

In Experiments II and III percent volumetric soil moisture content was measured at an average 5, 10, 38 and 71 cm depths using a time domain reflectometry (TDR) probe (Model PICO 32, Trime brand, IMKO Micromodultechnik GmbH, Ettlingen, Germany). The stainless steel rods of the TDR probe were 110 mm in length, 3.5 mm in dia and were mounted in the probe body at 20 mm center to center. Moisture measurement was achieved by insertion of probe rods through two vertically aligned holes in the side of the PVC tube for each designated depth. The moisture contents at each depth were the averages of the moistures of points where the two probes were inserted in the tubes.

Moisture measurements were collected on a weekly basis on 15 dates in Experiments II and on 10 dates in Experiment III.

Statistical Analysis

Correlation analysis using the Proc Corr procedure of Statistical Analysis Systems software (SAS, 2004) [SAS version 9.1.3., SAS Institute Inc., Cary, NC] was used to examine the relationships amongst the various response variables (LF, TQ, LC, days after initiation of drought or recovery [DAI] and percent volumetric soil moisture retention). As highly statistically significant relationships as well as strong positive correlation was found amongst the dependent variables LF, TQ and LC, a decision was made to focus the remaining analyses on LC since it allowed for more individual whole units of measure (0 to 100 by 1 % vs 1 to 9 by 1 unit). A separate analysis of variance (ANOVA) was conducted on LC within the drydown and the recovery cycle of each experiment (Exp) due to different lengths of the drought and recovery cycles. The General Linear Model Procedure (Proc GLM) of SAS software was used to conduct ANOVA. The analytical design of each ANOVA was a completely randomized design with five replications of cultivar. Main effects were cultivar (Cult), the rating date or days after initiation of the drought or days after re-initiation of irrigation (DAI) and their interaction.

Highly significant cultivar, date and interaction effects were present with respect to LC in the drydown and recovery cycles of all three experiments. Following this finding, a drought duration dose-response analysis similar to that conducted by Karcher el al. (2008) was used to describe the LC response to length of the drought in DAI as well as to compare bermudagrass cultivar performance.

Karcher et al. (2008), using the insights of Motulsky and Christopoulos (2003), used a sigmoidal dose response curve for LC of tall fescue as a function of duration of the drought or length of recovery cycle (Eq. 1).

Equation (1): $LC = 100/\{1+10^{[(LD50- DAI)slope]}\}$

Where **LC** = the predicted green turf cover in %, **LD50** = the predicted mean number of days from the start of the drought or beginning of the recovery cycle needed to reach 50 % green turf cover, **DAI** = the independent variable which is the number of days into the drydown or recovery cycle and **slope** = the predicted slope at the LD50 value. Karcher et al. (2008) did not utilize any logarithmic or linear transformations on variables used in their equations and work.

In this research, several non-linear dose-response models presented by Motulsky and Christopoulos (2003) were tested before settling on the best overall model (data not shown). The author used SAS Proc NLIN (the non-linear models procedure) [UCLA Statistics Dept., 2006] to fit these models. Following model fitting, predicted LC points were then plotted against actual LC as a function of DAI for several cultivars. One of these models was identical to that of Eq. 1 utilized by Karcher et al. (2008). Interestingly the R-square values of the various sigmoidal non-linear models that were tested were very similar. Inspection for individual model bias (the over or under estimation of the response variable in a specific portion of the response curve) was conducted. The final criterion used in model selection was a visual qualitative inspection for goodness of fit since very similar R-square values were found amongst the various equations.

Since the R-square values had a good fit in the model used by Karcher et al. (2008), we adopted a variation on Eq. 1 that is shown in Eq. 2.

Equation (2) $\mathbf{LC = 100/ \{1+10^{[(\log_{10} [(LD50t)/ (DAIt)]) slope]}\}}$

Where **LC** = the predicted green turf cover in %, **LD50t** = predicted mean linearly transformed number of days from the start of the drought or beginning of the recovery cycle needed to reach 50 % green turf cover, **DAIt** = the independent variable which is the linearly transformed number of days into the drydown or recovery cycle and **slope** = the predicted slope at the LD50t value. The raw DAI values in the data set were linearly transformed by adding 0.001 days to the raw DAI value. This transformation was necessary to avoid mathematical functions being performed on the value zero.

The models shown in Eq. 1 and 2 are intended to only be used if the LC values fall between 0 and 100 (Motulsky and Christopoulos, 2003). Karcher et al. (2008) utilized Eq. 1 for both the drydown and recovery phase of tall fescue. Although in this research the author chose ANOVA and mean separation (discussed later) for analysis of recovery cycle LC, preliminary testing was conducted using a number of different non-linear dose-response equations, including Eq. 1 and Eq. 2, for estimating mean LC during the recovery cycles of Exp I through III. Since not all LC observations were at or near 0 % green cover at the beginning of the recovery cycles, Eq. 2 required further modification when fit to recovery phase LC data to avoid small but consistent under estimation of LC near a DAI of 0. To solve this problem the author opened the lower limit of Eq. 2

(allowing for predictive estimate of the lower limit) that had originally been fixed at 0. In recovery phase work the upper limit was allowed to remain at 100 as it did not present a biasing problem. However in undertaking this modification, an additional challenge resulted from this change in Eq. 2. Once the lower limit was opened up, the LD50t in Eq. 2 then became an estimate of the mean number of days to reach the midpoint between the predicted lower limit and the upper limit of 100 %, rather than LD50t actually representing the mean number of days to reach 50 % live cover. This problem was solved by additional mathematical operations suggested by Motulsky and Christopoulos (2003) [data not shown]. However, since not all cultivars achieved close to 100 % recovery during the recovery phases, the author ultimately chose ANOVA and mean separation as the method to analyze recovery phase datasets.

Once Eq. 2 was settled upon for description of the LC response to DAI during drydown cycles of the experiments, a sum of squares reduction test was conducted to determine if a single non-linear (global model) or individual cultivar-based non-linear models of similar form accounted for the largest amount of variation present amongst LC observations (UCLA Statistics Dept., 2006). The sum of squares reduction test resulted in rejection of the null hypothesis that a single global equation (shared regression parameters for all varieties) was the most effective analysis. Thus, justification was present for the development of the 20 individual cultivar-based dry down models.

Following the Sum of Square reduction test, Eq. 2 was modified modified using the methods of Motulsky and Christopoulos (2003) to generate Equations 3 and 4, which predicted the mean number of days for LC to reach 75 percent live cover (LD25) and 25 percent live cover (LD75), respectively.

Equation (3) $\mathbf{LC = 100/\ \{1 + 10^{[(Log_{10}(LD25t)-(1/slope)*log_{10}(3))-[log_{10}(DAIt)]\ slope]}\}}$

Equation (4) $\mathbf{LC = 100/\ \{1 + 10^{[(Log_{10}(LD75t)-(1/slope)*log_{10}(1/3))-[log_{10}(DAIt)]\ slope]}\}}$

Where **LC** = the predicted green turf cover in %, **LD25t** = predicted mean linearly transformed number of days from the start of the drought or beginning of the recovery cycle needed to reach 75 % green turf cover, **LD75t** = predicted mean linearly transformed number of days from the start of the drought or beginning of the recovery cycle needed to reach 25 % green turf cover. **DAIt** = the independent variable which is the linearly transformed number of days into the drydown or recovery cycle and **slope** = the predicted slope at the LD25t value for equation (3) and the predicted slope at the LD75t value for equation (4). The raw DAI values in the data set were linearly transformed by adding 0.001 days to the raw DAI value. This transformation was necessary to avoid mathematical functions being performed on the value zero.

Next, a pair wise F-test was conducted using Proc NLIN to conduct the individual 190 tests of individual slopes at LD50t generated from Eq. 2 and the individual LD50t, LD25t and LD75t (generated from Eq. 2, 3 and 4) using the method of the UCLA Statistics Dept (2006). The results of the 190 pair wise F-tests were then summarized and tabulated.

Not all bermudagrass varieties were able to reach 100 % living cover during the recovery cycles. During the recovery cycles of all three experiments the meteorological environment was unable to be held constant in the greenhouse despite the use of a heating and cooling system as well as 16 hour simulated daylight cycles from the HID lamps on a timer. Additionally, some pest problems may have affected turfgrass growth despite intensive intervention. In some cases, some cultivars recovered for several weeks then did not increase in live cover while some cultivars showed a slight decline. In order to effectively use Eq. 2 or similar dose-response analyses, the grasses needed to show a continued improvement in living cover until they approached or achieved 100 % cover. Consequently, a decision was made to utilize the ANOVA method of LC response to cultivar, DAI of recovery period and their interaction as performed for the drydown cycles. Following ANOVA, Fisher's Protected least significant difference (LSD) [p=0.05] test was used to compare the mean percent living cover of the cultivars in the trials.

Correlation analysis of the relationship between cumulative evapotranspiration (ET) i) during the course of the dry down cycle and ii) at the end of the drying cycle of experiment I, was performed with the parameters LF, TQ, LC and DAI. SAS Proc Corr was used for this analysis. Correlation analysis was also conducted amongst LF, TQ, LC, DAI and volumetric soil moisture retention at each of the four depths (and combinations thereof) in Exp II and III. Following correlation analyses, separate ANOVAs were conducted on soil moisture data collected within each of the four soil depths. The effects tested within each depth were cultivar, DAI and their interaction. Fisher's Protected LSD test was used to compare mean cultivar moisture retention values within depths and within dates in Exp II and III during the drydown cycles.

RESULTS

CULTIVAR RESPONSE TO THE DRYDOWN CYCLES

Drydown Cycle Duration and Environmental Conditions

The lengths of the drydown cycles for the three experiments were Exp I, 93 days (18 August – 19 November 2009); Exp II, 101 days (4 May – 13 August 2010) and Exp III, 65 days (28 June – 3 September 2010) respectively. The rate of turfgrass leaf firing and turfgrass recovery was variable amongst the three experiments. This is not surprising since environmental conditions in the greenhouse were not the same during the three trials. The average daily maximum and minimum temperatures during drydown cycles of Experiment I were 32^{o}C and 18^{o}C respectively (Fig. 4), Experiment II were 35^{o}C and 22^{o}C respectively (Fig. 5), and Experiment III were 37^{o}C and 23^{o}C respectively (Fig. 5). The average daily maximum and minimum temperatures during the recovery cycles of Experiment I were 29^{o}C and 15^{o}C respectively (Fig. 4), Experiment II were 33^{o}C and 19^{o}C respectively (Fig. 5), and Experiment III were 32^{o}C and 19^{o}C respectively (Fig. 5).

Correlation Analysis

Visual estimates of leaf firing (LF), turf quality (TQ), percent green cover (LC) and leaf wilting (LW) were recorded during the drydown cycle. The author has defined the strength of correlation relationships of this study as follows: coefficients of 0 to 0.50 or 0 to -0.50 as a weak correlation, 0.5 to 0.69 and -0.5 to -0.69 as a moderately strong correlation and 0.7 to 1.0 and -0.70 to -1.0 as a strong correlation. Pearson's Correlation analysis showed a strong positive correlation among the response variables LF, TQ, and LC (range of r = 0.88*** to r = 0.98***) and a strong negative correlation between each of the response variables LF, TQ, LC and the independent variable DAI (range of r = 0.77*** to r = 0.91***) in all three experiments (Table 2). LF rating values decreased (increased leaf firing), TQ ratings decreased (quality decreased) and LC ratings decreased as the length of the drought in DAI increased.

With this high degree of correlation amongst the three parameters the author chose a single variable, LC, for further analyses because its scale included larger number of individual discrete rating units (0 to 100 scale in 1 unit intervals) as opposed to the 1 to 9 scale in 1 unit intervals for the LF and TQ parameters. The percent live cover ratings may, however, in addition to the effect of LF, reflect the damage caused by biotic (insects, disease, weeds) and abiotic (heat, cold) factors and may also reflect the recuperative abilities of cultivars from prior damage (Han, 2009).

Analysis of Live Cover Ratings

The ANOVA conducted on percent green cover data demonstrated significant differences among cultivar, date and cultivar x date in all three experiments during the drydown cycles (Table 3). Results of a sum of squares reduction test (Table 4) indicated the appropriateness of using multiple non-linear models rather than a single global model to describe cultivar response. Thus, 20 individual drydown models were generated and pair wise F-tests of individual slopes and LD50 values of the cultivar curves were conducted. Pair-wise comparisons were followed by summarization of the pair-wise comparison findings (Tables 5 - 8).

Days To Reach 75 % Live Green Cover

LD25 is the predicted mean number of days of drought to reach 25 % brown cover and a predicted live green cover of 75 %. In Experiment I the cultivar predicted to take the longest number of days to reach 75 % green cover was U3-SIU, which was 29 days (Table 5). This was significantly longer (longer periods suggest greater drought resistance) than other cultivars except TifGrand which was predicted to take 24 days to reach 75 % green cover. These two grasses were predicted to reach 75 % green cover significantly later than the other 18 cultivars. Tifway was predicted to take 20 days to reach 75 % green cover, which was significantly longer than that predicted for U3-SIU but not longer than TifGrand. The cultivar predicted to reached 75 % green cover in the shortest time in Experiment I was U3-TGS which was 8 days (Table 5). The predicted number of days for Quickstand to reach 75 % green cover was not significantly different than that for U3-TGS in Experiment I.

In the Experiment II drydown cycle, TifGrand was predicted to take 31 days to reach 75 % green cover which was the largest LD25 value of any cultivar in the experiment. This was significantly longer than that predicted for all other 19 cultivars (Table 5). Celebration was predicted to take 27 days to reach 75 % green cover in Experiment II. The trend was consistent with TifGrand from Experiment I while it was not consistent in Celebration. Premier was predicted to take the shortest number of days (10) to reach 75 % green cover in Experiment II. This was the expected trend for Premier as it had been chosen as a standard for low drought resistant. The LD25 for U3-TGS and Premier were not significantly different from each other in Experiment II.

Celebration was predicted to take 18 days to reach 75 % green cover in Experiment III which was the longest of any cultivar in that experiment (Table 5) but it was not significantly different from TifGrand and Tifway. This trend was expected, as Celebration had been chosen as a standard in our experiment representing what was believed to be the most drought tolerant bermudagrass. Premier, NuMex Sahara, U3-TGS and U3-NC were all in the lowest ranking statistical group in terms of LD25 values in Experiment II. U3-TGS was in the lowest ranking statistical group in Experiment I and II but in Experiment III Premier was significantly below all other cultivars (Table 5).

Days To Reach 50 % Live Green Cover

LD50 is the predicted mean number of days of drought to reach 50 % brown cover and a predicted live green cover of 50 %. Since Experiment I started in mid August of 2009 and there was no additional lighting supplied in the greenhouse, it took more than 100 (predicted) days for the last cultivar (Tifway) to reach 50 % green cover. Tifway and Tifsport had no significant difference in their predicted LD50 values. Tifway and Tifsport took significantly longer than TifGrand to reach 50 % green cover in Exp I. TifGrand was the last cultivar to reach 50 % predicted green cover in Experiment II and in the group taking the second longest time to reach LD50 in Exp III. U3-TGS was the fastest in reaching 50 % green cover with no significant difference from Latitude 36. U3-NC and Premier were second from the bottom of significance level to take shortest predicted number of days to reach 50 % live green cover.

In both Experiment II and III TifGrand and Celebration were predicted to take longer to reach 50 % green cover than the remaining 18 bermudagrass cultivars. The LD50 values for Premier, U3-TGS, U3-NC and NuMex Sahara were in the bottom statistical group in Experiment II (Table 6) whereas the LD50 values for Premier and U3-TGS were in the bottom significance group in Experiment III. U3-NC was predicted to require only slightly more time than U3-TGS to reach 50 % LC in Experiment III. U3-SIU was predicted to take significantly longer to reach 50 % LC than U3-NC and U-3 TGS in all three Exp. All cultivars reached 50 % green cover within 40 and 30 days of the start of the drydown cycle in Exp II and III.

Response Curve Slopes At 50 % Live Green Cover

During the drydown cycle, as the grasses went more into the drought period they lost more green cover. The slope is the loss of LC per unit of time at the LD50 point on the sigmoidal dose-response curve. The smaller (more negative) slope values shown for any cultivar indicates more rapid changes in predicted live green cover at the LD50 value during the drydown cycle. At the LD50 point Patriot showed the most rapidly declining cover with a slope value of -2.1 in Experiment I. TifGrand was declining more rapidly in

Experiment II with a -4.8 slope value and Tifway was declining more quickly in Experiment III at this point with a -3.6 slope value (Table 7).

Days To Reach 25 % Live Green Cover

LD75 is the predicted mean number of days of drought to reach 75 % brown cover and a predicted live green cover of 25 %. Some of the cultivars in the experiments were still partially green at the termination of the drydown cycles of the three experiments. A large number of cultivars retained substantial green color at the termination of Exp I. Therefore the mean values of LD75 were much higher in some cultivars in Exp I (Table 8). Tifway and Tifsport retained more than 25 % live cover at the completion of the Exp I drydown cycle so the LD75 of these two cultivars could not be calculated without extending the response equations to DAI well beyond the length of actual drydown cycles. Exclusive of Tifway and Tifsport, the cultivar that took the next longest time to reach 25 % predicted green cover was Astro, taking 177 days, which was not significantly different from TifGrand (166 predicted number of days to reach 25 % live green cover). The cultivar that most quickly reached 25 % predicted green cover in Experiment I was U3-TGS (35 days) while Latitude 36 was not significantly different from U3-TGS (Table 8). TifGrand, Celebration, U3-SIU, Astro, OKC 70-18 and Quickstand, all were in the top significance level in Experiment II. NuMex Sahara was predicted to take the longest number of days to reach 25 % live green cover in Experiment III, while it was not significantly different from U3-SIU and Astro. U3-TGS was the fastest to reach 25 % predicted green cover in both Experiment II and III (Table

8). U3-TGS and Premier were both at the bottom of the significance rankings in Experiment III.

CULTIVAR RESPONSE DURING RECOVERY CYCLES

Recovery Cycle Duration and Environmental Conditions

During the recovery cycles visual observations were taken on TQ and LC. Many of the cultivars were still green when the recovery period started while some of them never recovered. The author chose to use in the analysis only the first 96 days of the recovery period in Experiment I although the recovery cycle in Exp I lasted for 151 days. Exp I was initially conducted as a preliminary experiment to test the techniques and to gather information to more effectively conduct the second and third repeat experiments. Only the first 96 days of the Exp I recovery cycle were used in the final analysis because after that period the percent live cover on some cultivars had reached a plateau while a few showed slight declines, presumably from biotic and abiotic stress other than drought. For the same reason, only the first 63 of 86 days of data were used in the recovery analysis in Experiment II. Data from the first 65 days of recovery was used in analysis of the recovery cycle of Experiment III.

Larger maximum and minimum temperature fluctuations were seen during the recovery cycle of Exp I than in Exp II and III. The average daily maximum air temperature recorded during drydown cycle of Exp I was 32^{o}C and the average daily minimum temperature recorded was 18^{o}C (Fig. 2). This variation in growing conditions may have influenced the cultivar response as well responses are compared to those found in Exp II and III where average daily maximum and minimum air temperature were 35^{o}C and 22^{o}C respectively for Exp II and 36^{o}C and 23^{o}C respectively in Exp III (Fig. 5).

Examination of Pearson's correlation coefficients between TQ and LC showed highly significant and strong positive correlation (r = 0.93***, 0.98***, 0.95***) in all three recovery cycles (Table 9). For that reason the author desired to continue to focus analysis on the LC variable. The bermudagrasses recovered slowly over time and a highly significant but variable positive relationship was present between TQ and DAI (r=0.69***, 0.52***, 0.47***) as well as LC and DAI (r=0.58***, 0.49***, 0.44***) in the recovery cycles of the three experiments (Table 9).

Analysis of Live Cover Ratings

Live cover (LC) achieved during the recovery cycle is believed to be a measure of cultivar drought tolerance since all cultivars are known to have faced substantial soil moisture deficit during their drydown cycles and all cultivars showed an injury response reflected in LF, TQ and LC ratings during the drydown cycles. The ANOVA conducted on percent green cover data from recovery cycles indicated highly significant differences (p=0.001) due to main effects of cultivar and date in all three experiments and highly significant cultivar by date effects in Exp I and II (Table 10).

In a preliminary approach, dose-response model fitting similar to that practiced for the drydown cycles using Eq. 2 was conducted for the LC found during the recovery cycles. Results of a sum of squares reduction test (Table 11) indicated the appropriateness of using multiple non-linear models rather than a single global model to describe cultivar response. Thus, 20 individual recovery models were generated, yielding individual slopes (Table 12) and LD50 (Table 13) of the cultivar curves with 2 exceptions. The equations associated with the estimates for the LD50 for Patriot in experiment II and for U3-TGS in Exp III predicted LD50 values at several thousand days. Since these predictions were well beyond the length of the actual recovery cycles conducted the certainty in the validity of such projections was low so the author chose not to display those dates. Because of uncertainty in the estimates of the LD50 values for those two cultivars in Exp II and III the author chose not to pursue use of the Pair-wise F-test to compare slopes and LD50 values but rather to use a more traditional separation of cultivar mean LC using Fisher's protected LSD test.

Fisher's protected least significance difference (LSD) test was conducted using the 95 % certainty (p=0.05) level to analyze the mean LC performance of cultivars by date within each Exp. The LC was analyzed for 13, 10 and 10 dates each in the recovery cycles of Exp I, II and III respectively. In recovery cycles of the experiments DAI stands for days after grasses were re-watered or days after the end of drought cycle.

Experiment I

Celebration demonstrated good recovery which was expected for this cultivar as it was selected as one of the standards for a high level of drought tolerance in this study. On the first measurement date into recovery Tifway had the highest mean percentage living cover followed by Tifsport with no statistical difference (Table 14). Although Celebration did not start with the highest percentage of living cover, its recovery rate increased rapidly by 10 days after the recovery period started (DAI) and reached the highest percentage of green cover (55 %) on that date. However, Celebration recovery was not significantly different from Princess 77, TifGrand, Tifway, Tifsport and U3-SIU at 10 DAI. Celebration recovered quickest among all 20 cultivars with 90 % mean living cover by 96 DAI. Celebration's recovery was significantly different from all other cultivars except TifGrand and Princess 77 by the end of recovery period in Exp I. TifGrand and Princess 77 did not differ significantly from Celebration at 96 DAI, with mean LC of 81 and 80 % on that date (Table 14).

Premier and OKS 2004-2 both started from 1.8 percent LC at DAI 0 in Experiment I (Table 14). This low level of LC for Premier and ranking as lowest LC at the end of the recovery cycle was expected as it had been selected as a standard for being most susceptible to drought based on work by Chalmers et al. (2008). U3-TGS, OKC 70-18, Latitude 36, and Northbridge were at the same significance level as Premier with regard to LC at DAI 0. However, Premier achieved significantly higher LC (53 %) as compared to NorthBridge (40 %) and Latitude 36 (36 %) by the end of the recovery cycle (Table 14) in Exp I. Even though OKS 2004-2 started with the same LC level as Premier, it was significantly higher (65 %) than Premier by the end of the Exp I recovery period.

Experiment II

The coefficients of variation associated with the experimental units increased with each DAI over the course of Exp II. Thus, the LSD values increased with increasing DAI affecting testing power with each successive DAI (Table 15). Much less change in the size of the LSD value was observed over time in the recovery phase of Exp I compared with Exp II. In the recovery cycle of Experiment II, Celebration started at 0 % LC (Table 15). Some of the loss in LC in many of the cultivars in Experiment II may have been due in part to damage caused by insects, despite an intensive intervention with various insecticides. Performance of TifGrand may have been affected by insect feeding. TifGrand had the lowest percent recovery (12 %) at the end of Experiment I. TifGrand had otherwise performed very well in Experiment I and III. Celebration reached 20 % LC by the end of the experiment and Patriot reached 14 % LC, both of which were not significantly higher than TifGrand. Although it started from 0 % LC, U3-NC was able to recover substantially, as it reach 72 % LC, the highest numerical value, tied with U3-SIU, both of which were at the same significance level at the end of the trial.

Premier did surprisingly well during the recovery period in Experiment II, starting with 6 % mean LC and ending with 54 % mean LC, which was not significantly different from U3-SIU and U3-NC. At the same level of significance, U3-SIU and U3-NC both had the highest percent of live green cover (72 %) and Princess 77 had 71 % live green cover by the end of the experiment. The success in recovery achieved by Princess 77 was very consistent with that found in Experiment I. U3-SIU also demonstrated a somewhat consistent trend from Exp I while U3-NC did surprisingly well during the recovery path in Experiment II compared to Experiment I, starting from 0 % LC and reaching the highest percentage by the end. OKS 2004-2 demonstrated substantial recovery in Experiment I and also had suitable recovery in Exp II, achieving 60 % LC by the end of the trial and finishing not significantly less from the trial leaders U3-SIU and U3-NC (Table 15).

Experiment III

The coefficient of variation (CV) increased slightly with each DAI in Exp III, more so than in Exp I, however, the CV's were more stable over time than in Exp II (data not shown). Consequently, slightly more testing power was present in the LSD test in Exp III than in Exp II. Although it did not start with the highest percentage of living green cover in the beginning of recovery cycle (14.2 %), Celebration achieved the highest LC of all the cultivars by the end of the Exp III recovery cycle (92.9 %) (Table 16). This trend in achieving the highest LC was consistent with the results seen in Experiment I for the cultivar. Princess 77 started with 14.9 % LC at the beginning of the recovery cycle and ended up with 80.3 % LC by the end of the trial. This LC was much lower than that of Celebration but not significantly different at the 5 % p-value level. Princess 77 and Contessa trailed in LC but did not significantly differ from Celebration at the end of the experiment. NuMex Sahara had the highest LC (18.2 %) at the beginning of the recovery period but ended up with 75.7 % LC, which was still at the same level of significance with Celebration. U3-SIU showed a very consistent trend of recovery throughout all three experiments. It started with 16.4 % mean green cover at the beginning of the Experiment III recovery cycle and ended with 72.5 % LC which was not significantly different from Celebration. TifGrand did not demonstrate as impressive a trend in recovery as in Exp I but still had good recovery in Exp III. TifGrand started with 8.6 % LC at the beginning of the recovery cycle in Exp III and ended with 64.4 % LC which was not significantly less different than Celebration (Table 16). The cultivars that fell on the top level of significance in Experiment III were Contessa, NuMex Sahara, Princess 77, TifGrand, Riviera, Celebration, U3-SIU and Astro.

Premier, selected as a drought sensitive cultivar, had only 4.2 % LC by the end of the Exp III recovery cycle (Table 16). However, Premier was not the cultivar with the smallest LC at the end. Starting with the least LC at 0.2 %, U3-TGS demonstrated some recovery up to a certain point during the recovery path but declined in recovery to finish at 0.2 %. NorthBridge and Latitude 36 both were somewhat consistent at the recovery trend. They both fell under the same level of significance at 5 % p-value in Experiment I through III. Premier, U3-TGS, NorthBridge and Latitude 36 all were on the same statistical significance level (bottom level) by the end of Experiment III recovery cycle.

MOISTURE RELATIONS

Soil Moisture And Cumulative Evapotranspiration In Experiment I

Evapotranspiration (ET) of bermudagrass cultivars was assessed during the drydown cycle of Experiment I. This was performed by measuring initial total growth tube weight at time zero and on each monitoring date thereafter. An assumption was made that carbon and biomass fixation and loss in the system was negligible during the course of the experiment and that the difference between the earlier and later growth tube weights was due exclusively to ET. The cumulative ET was calculated by subtracting the final observation from the observation taken at time 0. Correlation analyses were performed to yield the relationships amongst cumulative ET and visual parameters (yielding Pearson's correlation coefficients) during the course of the drydown cycle (Table 17) and at the end of drydown cycle (Table 18) in Experiment I.

The cumulative ET (Cumu ET) increased with increasing number of DAI of the drought while LF, TQ and LC readings decreased with increasing number of DAI. The increase in LF and decrease in TQ and LC indicated increasing levels of injury as the drought duration increased. There was no statistically significant correlation amongst the Cumu ET and any visual parameters rated at the end of the drydown cycle (Table 18). However there was significant and moderately strong negative correlation between Cumu ET and the parameters of LF (r = -0.63), TQ (r= -0.68) and LC (r=-0.59) during the course of the drydown cycle (Table 18). The correlation amongst the various visual parameters was strong (r = 0.89*** to r = 0.96***) during the drydown cycle as well as at the end of the drydown cycle (r = 0.83*** to r = 0.96***). Correlation between the various visual parameters and DAI of the dry down cycle was high and negative (r = -0.81*** to r = -0.83***).

Comparison of Soil Moisture Retention of Bermudagrass Cultivars in Experiment I

Analysis of Variance was conducted to determine the cultivar, date and cultivar by date effects on cumulative ET during the drydown cycle of experiment I (Table 19). Highly significant (p =0.001) cultivar and date effects were present while their interaction effect was not significant. The Fisher's LSD (p = 0.05) comparison test was performed to compare the overall trial mean cumulative ET among the cultivars as well as the end of trial cumulative ET means (Table 20). Tifway showed the highest amount of cumulative ET of all cultivars in both the trial mean and end of trial cumulative ET values. Including Tifway there were four cultivars that grouped in the top level of significance in regard to trial mean cumulative ET. TifGrand and Tifway were not significantly different in terms of ET with respect to the trial mean or end of trial cumulative ET. TifGrand and Celebration were not different in their trial mean ET on end of trial cumulative ET mean. Latitude 36 had the lowest cumulative ET trial mean and end of trial cumulative ET. However, U3-TGS and OKC 70-18 did not statistically differ from Latitude 36 in their trial mean ET or end of trial cumulative ET. Premier and NorthBridge had significantly higher trial mean cumulative ET than Latitude 36 but did not differ when end of trial cumulative ET was considered.

Correlations Amongst Soil Moisture Retention Other Response Parameters In Exp II & III

In Experiment II and III volumetric soil moisture content was measured once every week at an average 5.1, 10.2, 38.1 and 71.2 cm depths using a TDR probe. Soil moisture retained at each depth of the profile declined substantially over time as the bermudagrasses extracted water from the soil profile during the drydown cycles of each experiment. Not surprisingly, soil moisture retention declined most rapidly at the shallowest depth of measure (5.1 cm) followed closely with rapid loss of moisture from the 10.2 cm depth. Although root system depth was not measured it is widely known and generally accepted that turfgrasses have the highest volume of roots in the more shallow depths of the soil and this was reconfirmed in bermudagrass by Poudel (2010). Figure 10 provides an overview of the mean volumetric soil moisture retained at various depths in pots of Contessa bermudagrass over time. Similarly, Figure 11 shows the mean soil moisture retention at various depths as well as the mean LC of Contessa bermudagrass during the drydown cycle in Exp II.

Correlation analysis was conducted to determine the relationship between soil moisture retention at each of 4 depths and each of the visual parameters (LF, TQ, and LC) collected in Exp II and III. Pearson's correlation coefficients are displayed in Table 21 and 22 for Exp II and III. No statistically significant correlations were present amongst any the visual parameters and the soil moisture present at the 5.1 or 10.2 cm depths, nor between DAI and soil moisture at these two depths in Exp II (Table 21). This finding is believed to be due to soil moisture being effectively extracted by the root systems of all cultivars at the two most shallow depths so rapidly and early on that visual parameters as measures of drought injury had not responded as yet,

Highly significant, strong positive relationships were generally found amongst the visual parameters and soil moisture measured at the 38.1 and 71.2 cm depths, as well as between various combinations of means of soil moisture at the various depths and the visual parameters collected during the drydown cycle of Exp II (range r = 0.69*** to 0.76***) (Table 21). Also, highly significant, but strong negative relationships were present between soil moisture retention and DAI at 38.1 and 71.2 cm depths as well as between various combinations of means of soil moisture at the various depths (range r =-0.74*** to -0.79***). The visual parameters had just slightly higher correlations with soil moisture measured most deeply in the profile at 71.2 cm and when using the mean soil moisture of both the 38.1 and 71.2 cm depths. This finding suggests that the ability to access soil moisture deep in the profile is very important in order to resist leaf firing, live cover loss and thus loss in turfgrass quality by having the ability to extract soil moisture from deep in the soil profile. Notably, root production characteristics of the cultivars were not studied in this work.

The trend present in correlation coefficients in Experiment III was of declining r values in all the parameters as one went from 5.1 cm down to 10.2 cm. Going further down in the profile from 10.2 cm to 38.1 cm the correlation coefficients between LF, TQ and LC and depth again declined. No significant correlation was present between soil moisture at the 5.1 or 10.2 cm depths but a strong negative correlation was present between soil moisture retention at the 38.1 (r =-0.74***) and 71.2 cm (r = -0.76***) depths and DAI in Exp II (Table 21). When the average soil moisture retained at 4 depths was correlated with LF, TQ, LC and DAI, the correlation was in general slightly higher than the correlation with soil moisture at the 38.1 cm depth and just slightly higher than that achieved with correlation at the 71.2 cm depth.

Based on the trends in correlations amongst the soil moisture depths and visual parameters in both Exp I and II, if a single average depth of mean soil moisture is chosen, the use of the average of all 4 measurement depths seems most reasonable based on this research.

Comparison of Soil Moisture Retention at Four Measurement Depths

Analysis of Variance was performed for the effects of cultivar, sampling date and their interaction on soil moisture retention at 4 depths during drydown cycles of Experiments II and III (Table 23). There were significant Date effects at all four soil depths and cultivar effects were significant at the 38.1 and 71.2 cm depths in Experiment II. The cultivar by date interaction effects was not significant at any soil moisture measurement depth in Exp II.

The results of ANOVA in Experiment III found a significant difference in cultivar, date and cultivar x date interactions at all 4 moisture measurement depths except the cultivar x date interact at the 71.2 cm measurement depth (Table 23).

Mean Moisture Comparisons

The Fisher's LSD test was done to determine and compare the mean moisture contents at 4 depths amongst the bermudagrass cultivars within the dates of data collection in Experiments II and III drydown cycles. The observations are presented in four different tables (Table 24– Table31) for each depth level in each experiment.

5.1 cm Depth

At the 5.1 cm depth the mean moisture level was highest in Celebration, whereas it was lowest in Yukon within 7 DAI in Exp II (Table 24). In Exp II the mean moisture content was around the same level for TifGrand, Premier and OKS 2004-2 at 7 DAI but not significantly different from Celebration. By the 14 DAI Premier, NuMex Sahara and OKS 2004-2 had very little soil moisture remaining at the 5.1 cm depth in Exp II while all other cultivars had a trace amount of water left which was rounded to 0.00 at two decimal points shown in Table 24. All three cultivars were in the same level of statistical significance while NuMex Sahara and OKS 2004-2 were not significantly different from the rest of 17 cultivars at 14 DAI. In Exp II by 21 DAI the soil moisture at 5.1 cm depth for all cultivars reached 0.00 % after the round up to two decimal points (Table 24).

In Experiment III Premier was still holding some significant amount of moisture than all other cultivars except Latitude 36 at 5.1 cm at 35 DAI. Latitude 36 had some moisture left but not significantly higher that other 18 cultivars all of which reached 0.00 % (0.00 % = 0.001 % rounded to two decimal points) soil moisture (Table 28). From 42

DAI till 49 DAI Latitude 36 was the only cultivar which was still holding significant soil moisture at the 5.1 cm depth in Experiment III.

10.2 cm Depth

Premier had the highest percentage of soil moisture at 10.2 cm depth on 7 DAI which was not significantly different from many other cultivars in Experiment II (Table 25). Premier alone was holding significantly higher percentage of soil moisture at the 10.2 cm depth from14 DAI until 43 DAI in Experiment II. Many of the cultivars reached 0.00 % moisture by 14 DAI in Exp II. Soil moisture in the pots of all the cultivars except Premier reached 0.00 % at 21 DAI while Premier reached that level at 50 DAI in Experiment II.

In Experiment III Premier, OKC 70-18 and Latitude 36 had the higher percentage of moisture at the 10.2 cm depth ay 7 DAI (Table 29) all of which were not significantly different from NuMex Sahara, Patriot, NorthBridge and OKS 2004-2. At 42 DAI Premier and Latitude 36 had significantly higher soil moisture retention at 10.2 cm than the other 18 cultivars and this trend held through 67 DAI. Other than in Premier and Latitude 36, the mean moisture retained in pots of NorthBridge at the 10.2 cm depth was significantly higher than the other 17 cultivars except that of Patriot at 42 DAI in Experiment III. NorthBridge retained significantly higher soil moisture than 17 other cultivars at 67 DAI, second only to Premier and Latitude 36 in Experiment III. Many of the cultivars reached 0.00 % moisture by 14 DAI in Exp III.

38.1 cm Depth

The soil moisture in TifGrand at 38.1 cm reached to 0.00 % at 35 DAI while that of Celebration was very close (0.01 %) at 35 DAI but went down to 0.00 % at 43 DAI in Experiment II (Table 26) which was not significantly different than many other cultivars. Premier was holding the highest percentage of water at the 38.1 cm depth by the end of the cycle at 101 DAI in Experiment II but not significantly different from NuMex Sahara, U3-TGS and Latitude 36.

However the moisture of Celebration reached 0.00 % by 35 DAI in Experiment III (Table 30), significantly different from all other cultivars at 35 DAI, was the only one to have 0.00 % moisture till the end at 67 DAI in that depth level. The soil moisture in Latitude 36, U3-TGS and NuMex Sahara at 38.1 cm was not significantly different from Premier at the end of the trial. At the end of the drydown cycle at 67 DAI in Exp III the highest percentage of soil moisture retained at the 38.1 cm level was found in pots of U3-TGS. This amount was not significantly different from that found in pots of Premier, NorthBridge, Latitude 36 and 5 other cultivars.

71.2 cm Depth

All of the cultivars retained good soil moisture at the 71.2 cm depth for a long period until Celebration reached 0.00 % on 72 DAI in Experiment II (Table 27) but it was not significantly different from U3-NC, Astro, Tifsport and TifGrand. None of the other cultivars in Experiment II had soil at that depth that was completely dry until the end of the experiment. Yukon retained the most soil moisture at the end of Experiment II followed by Latitude 36, Premier and U3-TGS respectively in terms of percentage value, which did not significantly different from each other.

The lowest amounts of soil moisture found in pots at the 71.2 cm depth at the end of the 67 day drydown cycle of Exp III (Table 31) was that found in pots of TifGrand followed by U3-SIU and then Celebration, all of which were in the same statistical significance level. The cultivar that retained most soil moisture by the end of Exp III at the 71.2 cm depth was NorthBridge (6.95 %) followed by Latitude 36 (6.77 %) and then OKS 2004-2 (6.03 %) but they were not significantly different from many other cultivars. Premier and U3-TGS also retained a significant amount of moisture at 71.2 cm at the end of the Exp III drydown cycle and this amount was not significantly different from that retained by NorthBridge.

SUMMARY AND CONCLUSION

With the high degree of correlation among leaf firing (LF), turf quality (TQ) and percent living cover (LC) parameters and also considering the fact that LC allowed for more individual whole units of measure (0 to 100 by 1 % vs 1 to 9 by 1 unit) as opposed to the LF and TQ parameters, detailed analytical focus was on LC in all three experiments. Celebration showed higher tolerance consistently in both Experiment II and

III by taking a longer time to reach 50 % green cover. Celebration also had the highest LC by the end of the recovery cycles falling in the top group of statistical significance in Experiment I and III. Selected as a standard for good drought tolerance for inclusion in this research, Celebration's performance in this work was consistent with the findings of Chalmers et al. (2008) in both their 2006 and 2007 trials. Poudel (2010) also found Celebration to have very good drought resistance in a field study.

Premier was selected for use as a standard for poor drought performance in this work. Premier demonstrated poor drought resistance in the Experiment II and III drydown cycles, as was expected. Premier was at the bottom of the cultivar performance list of statistical significance due to it taking the least number of days to reach 50 % green cover during drydown cycles. Chalmers et al. (2008) found that Premier fired first among the bermudagrass cultivars in both 2006 and 2007. The performance of Premier was also consistent with the findings of Poudel (2010).

Although Premier was expected to have a low percentage recovery it was not the lowest by the end of all three recovery cycles. OKC 70-18, NorthBridge and Latitude 36 were at the bottom of significance level where as Premier and U3-TGS were one level higher in Experiment I, however there was no significant difference between Premier and OKS 70-18. The findings of this research were consistent with those of Kim et al. (1998) who reported that cultivars that turned yellow earlier during water deficit stress showed poor shoot recovery after the drought period ended.

This research project began with the purpose of identifying and making a short list of bermudagrass cultivars with improved drought tolerance. Results of this research found TifGrand as a cultivar showing very good drought tolerance and it has potential to be used as one of the reference cultivars (standards) in the future. TifGrand took a larger number of days to fire (measured as days to reach 50 % live cover) during the drydown cycles and its recovery was always close to Celebration during the recovery phase.

While soil moisture was quickly depleted at the 5.1 cm depth, except in Experiment II where Celebration had used up all the soil moisture leaving a trace amount at the 71.2 cm depth, by 72 DAI, there was still some moisture left at the 71.2 cm depth in all the cultivars at the end of drydown cycles in both Experiment II and III. One of the drought survival mechanisms (drought avoidance) of turfgrass is to produce deeper roots in the soil profile for greater extraction of water (Huang et al., 1997b; Duncan and Carrow, 1999; Huang, 2008). More than one drought resistance mechanism can be at work simultaneously. Since we did not perform destructive sampling of the tubes for root depth and mass measurements, one can only speculate that roots were present deep in the profile of cultivars where the soil moisture was complete extracted at the 72.1 cm depth.

Premier, Latitude 36, U3-TGS and NorthBridge still retained substantial amounts of soil moisture at both the 38.1 cm and 71.2 cm depths even at the end of the drydown cycles. While all of these cultivars fired quickly and were slow to recover, the presence of significant amounts of moisture deeper in the profile suggests their inability to extract water from the deeper profile. This also explains why these cultivars fired quickly. Poudel (2010) found that Latitude 36 and NorthBridge had shorter root length and lower dry weight as compared to Celebration bermudagrass.

Celebration and TifGrand were able to maintain higher amounts of live green cover for a long time period during the drydown cycle and they both had the least amount of water present at the lowest level of the soil profile by the end of the drydown in both Experiment II and III. This finding is seemingly due to their ability to extract water from the deeper profile by growing deeper, more extensive roots. This finding is consistent with that of Poudel (2010) where he found that Celebration had the longest root length after that of Patriot at the 30 – 60 cm depth. Additionally, Baldwin et al. (2006) found Celebration had the highest percentage of root weight and the least volumetric soil water content.

There were some inconsistencies in bermudagrass recovery in Experiment II compared with those of Experiments I and III regarding cultivars demonstrating the greatest and least drought resistance. Celebration had depleted all the soil moisture deeper in the profile long before the drydown cycle was terminated. TifGrand also had minimal moisture left by the end of the drydown cycle. All bermudagrass cultivars that depleted soil moisture deeper in the soil profile recovered slower later. Premier had the most water left at a 38.1 cm depth in the profile but not significantly more than that found in pots of U3-TGS and Latitude 36 by the end of the drydown cycle in Experiment II. However these grasses showed better recovery than Celebration and TifGrand. This finding may be due to a long period of exposure to lower amounts of remaining available soil moisture for Celebration and TifGrand after moisture depletion. This may have lead to serious root injury. Moreover, the four other cultivars may have recovered faster because they were speculated to have a healthy root system left due to retention of some water available at the 38.1 cm depth. Additionally, noticeable insect damage was found on some bermudagrasses in Experiment II which may have altered cultivar performance. Inconsistencies in performance found in the Experiment I drydown cycle from Experiments II and III is suspected to have been due to the different environmental conditions present in the Experiment I drydown cycle.

In summary, it can be concluded that Celebration and Premier are suitable standards for use as a good and poor performing bermudagrass under drought. TifGrand's performance was such that it holds potential for use as a drought tolerant bermudagrass. TifGrand should receive additional investigation to further characterize its drought resistance. U3-TGS, NorthBridge and Latitude 36 demonstrated poorer performance under severe drought and hold potential for use as reference cultivars as well in further studies. Based on soil moisture extraction trends found in this work, future research is justified on bermudagrass cultivars that characterize both rooting characteristics and soil moisture extraction trends in the same study.

Percent living cover is perhaps a reasonable and more precise parameter for visually rating turfgrasses as it has both high degree of correlation with LF and TQ but also has a higher number of individual scaled units (0 to 100 scale by 1) as opposed to the (1 to 9 scale) for the LF and TQ parameters. Future studies should involve both soil moisture extraction measurement as well as assessments of root mass and distribution by destructive sample. The technique of using turfgrass pots in a growth box in a greenhouse is a viable technique that can be used in further drought studies for turfgrass throughout the year.

Table 1. Bermudagrass cultivar entries evaluated for drought resistance.

Cultivar†	Propagation Method	Original Source
Contessa (SWI-1045)	Seeded*	Seeds West, Inc.
Numex Sahara (NMS-1)	Seeded*	New Mexico Agricultural Experiment Station (AES)
Princess 77 (FMC-77)	Seeded*	Seeds West, Inc.
TifGrand (Tift No. 4)	Vegetative	Georgia AES
Tifway (Tifton 419)	Vegetative*	Georgia AES
Tifsport (Tifton 94)	Vegetative*	Georgia AES
Riviera (OKS 95-1)	Seeded*	Oklahoma State University
Yukon (OKS 91-11)	Seeded*	Oklahoma State University
Premier (OR 2002)	Vegetative*	Trinity Turf Nursery
Patriot (OKC 18-4)	Vegetative*	Oklahoma State University
OKC 70-18	Vegetative	Oklahoma State University
Celebration	Vegetative*	Sod Solutions
Quickstand	Vegetative*	Kentucky AES
U3 – SIU	Vegetative	Southern Illinois University
U3 – NC	Vegetative*	Northcutt Sod Farm, Lexington, OK
U3 – TGS	Vegetative*	Tulsa Grass and Sod Farms, Inc.
Astro	Vegetative*	Tulsa Grass and Sod Farms, Inc.
NorthBridge (OKC 1134)	Vegetative	Oklahoma State University
Latitude 36 (OKC 1119)	Vegetative	Oklahoma State University
OKS 2004 – 2	Seeded	Oklahoma State University

† Commercial cultivar names are provided when available with experimental designations shown in parentheses.
AES = Agricultural Experiment Station.
* = commercially available in the U.S. in 2008.

Table 2. Pearson's Correlation Analysis for Leaf firing (LF), Turf Quality (TQ), Percent Live Cover (LC) and Days After Irrigation (DAI) for drydown cycles in Experiments I, II and III.

	Experiment I			**Experiment II**			**Experiment III**		
	LF	**TQ**	**LC**	**LF**	**TQ**	**LC**	**LF**	**TQ**	**LC**
TQ	0.92***			0.97***			0.91***		
No. of Samples	2700			1500			1000		
LC	0.88***	0.95***		0.98***	0.98***		0.95***	0.92***	
No. of Samples	2700	3000		1500	1500		1000	1000	
DAI	-0.78***	-0.79***	-0.77***	-0.91***	-0.89***	-0.89***	-0.84***	-0.80***	-0.82***
No. of Samples	2700	3000	3000	1500	1500	1500	1000	1000	1000

*** Significant at $P = 0.001$.

DAI = Days after irrigation. In the drydown cycle DAI stands for days after grasses were saturated before the start of drought cycle.

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

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

LC = Percent Living Cover was rated on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.

Table 3. Analysis of variance for the effects of cultivar (Cult), date and their interaction, on green cover response during the drydown cycles from three experiments (Exp).

	Exp I				Exp II				Exp III			
Source	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**
Total	2999	2679783			1499	1750630			999	1242171		
Cultivar	19	409398	21547	156.2***	19	19654	1034	12.19***	19	61846	3255	21.36***
Date	29	1778607	61331	444.6***	14	1573240	112374	1324***	9	1015274	112808	740.4***
Cult x Date	551	160707	292	2.11***	266	55914	210	2.48***	171	43168	252	1.66***
Error	2400	331070	138		1200	101821	85		800	121884	152	

*** Significant at $P \leq 0.001$.

Table 4. Hypothesis test summaries for bermudagrass cultivar effects on green turf coverage during dry-down cycles of three experiments (Exp).

	Dry-Down Cycles		
Sum of Squares reduction test	**Exp I**	**Exp II**	**Exp III**
Null hypothesis	Shared regression parameters (slope and LD50)† for all varieties		
Alternative hypothesis	Different regression parameters for each variety		
Numerator df	38	38	38
Denominator df	2960	1460	960
F value	90.78	18.81	17.83
P value	<0.001	<0.001	<0.001

† Slope is that of the non-linear regression equation. LD50 is the linearly transformed number of days required to reach 50 percent live green cover.

Table 5. Pair-wise comparison of mean LD25 values of non-linear equations fit to live cover measured during the drydown cycles of experiments (Exp) I, II and III.

		Exp I		Exp II		Exp III	
Entry	**Cultivar**	**Mean LD25†**	**Significance‡**	**Mean LD25**	**Significance**	**Mean LD25**	**Significance**
1	Contessa	12.5	fo	15.7	ijklm	13.6	bce
2	NuMex Sahara	9.6	nr	10.8	p	7.4	klr
3	Princess 77	13.4	fhl	19.5	ce	13.0	bcg
4	TifGrand	24.4	ab	30.9	a	15.8	ab
5	Tifway	20.2	bc	19.5	cdi	15.4	ac
6	Tifsport	17.0	cf	18.5	cg	13.3	bcf
7	Riviera	14.6	efghi	17.4	defghj	8.1	jklp
8	Yukon	17.4	ce	13.5	mno	8.1	klo
9	Premier	13.1	fhm	9.5	ps	4.5	t
10	Patriot	17.9	cd	17.6	efghi	10.3	fghk
11	OKC 70-18	16.8	cg	18.7	cf	10.1	hl
12	Celebration	14.4	efghj	27.7	bd	18.4	a
13	Quickstand	8.7	qrs	14.9	ijkln	10.8	defghj
14	U3 - SIU	29.2	a	16.3	fghl	12.3	ch
15	U3 - NC	10.3	noq	10.7	pq	8.0	klq
16	U3 - TGS	8.4	qr	9.6	pr	6.5	eopqrs
17	Astro	12.6	fn	20.5	c	11.6	defghi
18	NorthBridge	16.0	chn	18.4	ch	9.9	hmopqr
19	Latitude 36	11.4	lmnop	16.4	fghk	8.9	ijklmn
20	OKS 2004-2	14.0	fhk	13.9	klot	13.7	bcd

†LD25 is the average number of linearly transformed days required to reach 75 percent live green cover.
‡Means in an LD25 column sharing any letter in the corresponding significance column are not statistically different by a pairwise F test at P = 0.05.

Table 6. Pair-wise comparison of mean LD50 values of non-linear equations fit to live cover measured during the drydown cycles of experiments (Exp) I, II and III.

		Exp I		Exp II		Exp III	
Entry	**Cultivar**	**Mean LD50†**	**Significance‡**	**Mean LD50**	**Significance**	**Mean LD50**	**Significance**
1	Contessa	28.5	ikm	26.2	ek	20.5	cdefgi
2	NuMex Sahara	29.0	ikl	19.3	q	19.1	cdefgj
3	Princess 77	39.8	g	29.0	cf	22.1	bd
4	TifGrand	63.7	c	38.7	a	24.2	b
5	Tifway	109.2	a	27.8	defg	20.8	cdefgh
6	Tifsport	99.9	ab	26.4	ej	21.3	bg
7	Riviera	27.0	lmn	26.5	efi	17.0	jk
8	Yukon	36.7	gh	23.1	mnop	14.7	kq
9	Premier	23.4	op	18.3	q	7.9	s
10	Patriot	30.0	jk	29.0	ce	16.7	jkl
11	OKC 70-18	31.9	i	29.3	cdh	14.9	kp
12	Celebration	42.1	efg	36.9	ab	28.9	a
13	Quickstand	19.1	qs	24.9	hijkn	16.5	jkm
14	U3 - SIU	58.8	cd	27.6	efh	23.1	bc
15	U3 - NC	20.5	qr	19.9	q	14.4	kr
16	U3 - TGS	17.1	t	17.9	q	9.5	s
17	Astro	47.2	e	31.0	c	21.6	bf
18	NorthBridge	30.5	ij	25.6	ghijkl	15.1	ko
19	Latitude 36	20.6	q	23.9	ko	15.1	kn
20	OKS 2004-2	24.4	o	24.9	hijkm	21.9	be

†LD50 is the average number of linearly transformed days required to reach 50 percent live green cover.
‡Means in an LD50 column sharing any letter in the corresponding significance column are not statistically different by a pairwise F test at P = 0.05.

Table 7. Pair-wise comparisons of slopes at the mean LD50 values of non-linear equations fit to live cover measured during the drydown cycles of experiments (Exp) I, II and III.

		Exp I		Exp II		Exp III	
Entry	**Cultivar**	**Slope†**	**Significance**	**Slope**	**Significance**	**Slope**	**Significance**
1	Contessa	-1.3	gh	-2.1	bcdefh	-2.6	gqt
2	NuMex Sahara	-1.0	cd	-1.9	ae	-1.2	a
3	Princess 77	-1.0	ce	-2.8	kn	-2.1	cdefgi
4	TifGrand	-1.1	defg	-4.8	s	-2.6	gn
5	Tifway	-0.7	ab	-3.1	lmnoq	-3.6	nopqrt
6	Tifsport	-0.6	a	-3.1	lmnop	-2.3	cdefgl
7	Riviera	-1.8	klmp	-2.6	hijkl	-1.5	ab
8	Yukon	-1.5	hij	-2.0	af	-1.8	be
9	Premier	-1.9	lmr	-1.7	a	-1.9	bg
10	Patriot	-2.1	pqr	-2.2	defj	-2.3	cdefgj
11	OKC 70-18	-1.7	jklmo	-2.4	fk	-2.8	gr
12	Celebration	-1.0	cf	-3.8	pqrs	-2.4	efgm
13	Quickstand	-1.4	gi	-2.2	bcdefi	-2.6	efgo
14	U3 - SIU	-1.6	hil	-2.1	bcdefg	-1.7	bc
15	U3 - NC	-1.6	him	-1.8	ac	-1.8	bf
16	U3 - TGS	-1.5	hik	-1.7	ab	-3.0	h-s
17	Astro	-0.8	bc	-2.7	km	-1.8	bd
18	NorthBridge	-1.7	jklmn	-3.3	dmnor	-2.6	efgp
19	Latitude 36	-1.9	lmq	-2.9	ko	-2.1	cdefgh
20	OKS 2004-2	-2.0	nopqrs	-1.9	ad	-2.3	cdefgk

†Means in slope column sharing any letter in significance column are not statistically different by a pairwise F test at P = 0.05.

Table 8. Pair-wise comparison of mean LD75 values of non-linear equations fit to live cover measured during the drydown cycles of experiments (Exp) I, II and III.

		Exp I		Exp II		Exp III	
Entry	Cultivar	Mean LD75†	Significance‡	Mean LD75	Significance	Mean LD75	Significance
1	Contessa	64.7	h	43.9	cdeh	31.1	ghij
2	NuMex Sahara	87.9	f	34.5	nos	49.5	a
3	Princess 77	118.3	ce	43.1	dei	37.5	cde
4	TifGrand	166.3	ab	48.5	ab	37.2	cdf
5	Tifway	.	.	39.6	hil	28.3	jk
6	Tifsport	.	.	37.7	jkln	34.0	di
7	Riviera	50.1	kl	40.4	ghijk	35.9	cdg
8	Yukon	77.7	fg	39.6	hijm	26.8	jm
9	Premier	42.0	mo	35.3	lmnq	14.0	s
10	Patriot	50.2	k	47.8	ac	26.8	jl
11	OKC 70-18	60.6	hi	46.0	bcdef	22.1	mnr
12	Celebration	122.9	c	49.1	af	45.2	be
13	Quickstand	42.1	mn	41.4	fghijq	25.2	klmnp
14	U3 - SIU	118.6	cd	47.0	ad	43.4	abfg
15	U3 - NC	40.8	mp	37.1	jlopr	26.1	jn
16	U3 - TGS	35.0	q	33.6	no	13.7	s
17	Astro	177.2	a	46.7	ae	40.2	abd
18	NorthBridge	58.1	hj	35.7	mnp	22.9	lmnq
19	Latitude 36	37.2	npq	34.7	nr	25.9	klmno
20	OKS 2004-2	42.5	m	44.7	cdeg	35.1	dh

† LD75 is the average number of linearly transformed days required to reach 25 percent live green cover. Non-linear equations for Tifway and TifSport were highly unstable and the resultant LD75 mean is not presented.

‡ Means in an LD75 column sharing any letter in the corresponding significance column are not statistically different by a pairwise F test at P = 0.05

Table 9. Pearson's Correlation Analysis for Turf Quality (TQ)†, Percent Live Cover (LC)‡ and Days After Irrigation (DAI)§ for recovery cycles in Experiments I, II and III.

	Exp I		Exp II		Exp III	
	TQ	**LC**	**TQ**	**LC**	**TQ**	**LC**
LC	0.93***		0.98***		0.95***	
No. of Samples	1300		1300		1000	
DAI	0.69***	0.58***	0.52***	0.49***	0.47***	0.44***
No. of Samples	1300	1300	1300	1300	1000	1000

*** Significant at $P \leq .0001$

†DAI = Days after irrigation commenced. In the recovery cycle of the experiments DAI stands for days after grasses were re-watered or days after the end of drought cycle.

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

§LC = Percent Living Cover was rated on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.

Table 10. Analysis of variance for the effects of cultivar (Cult), date and their interaction, on live green cover response during the recovery cycles from three experiments (Exp).

	Exp I				Exp II				Exp III			
Source	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**
Total	1299	589341			1099	966556			999	803353		
Cultivars	19	201934	10628	102.8***	19	160180	8430	15.08***	19	293069	15425	42.39***
Dates	12	248365	20697	200.1***	10	267016	26702	47.78***	9	153527	17059	46.88***
Cult x Dates	228	31495	138	1.34***	190	47532	250	0.45***	171	65675	384	1.06†
Error	1040	107547	103		880	491828	559		800	291084	364	

*** Significant at P ≤ 0.001.
† Non-significant at P ≤ 0.001.

Table 11. Hypothesis test summaries for bermudagrass cultivar effects on live coverage during recovery cycles of three experiments (Exp).

	Recovery Cycles		
Sum of Squares reduction test	**Exp I**	**Exp II**	**Exp III**
Null hypothesis	Shared regression parameters (slope and LD50)† for all varieties		
Alternative hypothesis	Different regression parameters for each variety		
Numerator df	55	36	54
Denominator df	1242	1007	893
F value	13.48618	9.609278	17.14691
P value	<0.0001	<0.0001	<0.0001

† Slope is that of the non-linear regression equation. LD50 is the average number of linearly transformed days required to reach 50 percent live green cover.

Table 12. Slopes at the mean LD50 values of non-linear equations fit to live cover measured during the recovery cycles of experiments (Exp) I, II and III.

		Slopes†		
Entry	**Cultivar**	**Exp I**	**Exp II**	**Exp III**
1	Contessa	0.93	1.40	1.96
2	NuMex Sahara	0.82	1.47	1.62
3	Princess 77	0.76	1.49	1.70
4	TifGrand	0.77	1.30	1.88
5	Tifway	1.39	1.26	2.21
6	Tifsport	1.30	1.82	1.60
7	Riviera	0.84	1.30	1.18
8	Yukon	0.81	1.30	1.42
9	Premier	1.24	1.13	4.98
10	Patriot	0.37	-	2.04
11	OKC 70-18	0.87	1.10	0.99
12	Celebration	0.84	0.95	1.93
13	Quickstand	0.79	1.07	1.24
14	U3 - SIU	0.55	1.41	1.86
15	U3 - NC	0.74	1.03	0.61
16	U3 - TGS	0.60	0.84	-
17	Astro	0.70	0.90	1.98
18	NorthBridge	0.74	0.82	1.98
19	Latitude 36	0.77	0.82	1.13
20	OKS 2004-2	0.73	0.94	0.95

†Slopes with higher values indicate faster recovery rate. Non-linear equations for Patriot in Exp II and U3-TGS in Exp III were highly unstable and the resultant slope at mean LD50 is not presented.

Table 13. Number of days to reach the LD50 for percent live green cover during recovery cycles of experiments (Exp) I, II and III.

		LD50†		
Entry	**Cultivar**	**Exp I**	**Exp II**	**Exp III**
1	Contessa	40.52	47.28	36.47
	NuMex			
2	Sahara	52.43	45.87	37.60
3	Princess 77	29.66	34.39	42.60
4	TifGrand	19.09	276.30	57.67
5	Tifway	127.90	70.04	174.50
6	Tifsport	0.00	66.23	137.40
7	Riviera	47.16	44.01	45.28
8	Yukon	50.66	47.95	66.38
9	Premier	76.33	61.37	131.00
10	Patriot	28.67	-	145.20
11	OKC 70-18	126.10	54.46	198.60
12	Celebration	17.76	262.00	29.11
13	Quickstand	44.81	34.45	66.90
14	U3 - SIU	38.13	36.76	50.19
15	U3 - NC	51.11	25.45	172.70
16	U3 - TGS	33.23	87.68	-
17	Astro	153.30	68.45	40.62
18	NorthBridge	150.60	256.00	152.30
19	Latitude 36	156.30	150.50	356.30
20	OKS 2004-2	29.72	44.50	38.93

†LD50 is the average number of days required to reach 50 percent live green cover as analyzed using Newton Method, for recovery cycles.

Table 14. Comparison of mean living cover amongst bermudagrass cultivars during the experiment I recovery cycle.

		Mean Living Cover (%)												
Entry	**Cultivar**	**0 DAI †**	**10 DAI**	**17 DAI**	**25 DAI**	**32 DAI**	**40 DAI**	**49 DAI**	**57 DAI**	**64 DAI**	**70 DAI**	**77 DAI**	**87 DAI**	**96 DAI**
1	Contessa	7.2 de	24.0 d-g	34.0 def	44.0 c	52.0 cd	57.0 cd	55.0 c	62.0 bcd	63.0 bc	60.0 bc	61.0 cd	72.0 bcd	74.0 bcd
2	NuMex Sahara	26.2 bc	37.0 bcd	43.0 b-f	52.0 c	61.0 bc	62.0 bc	62.0 bc	64.0 bcd	66.0 bc	65.0 ab	66.0 bcd	71.0 cd	69.0 c-f
3	Princess 77	27.2 bc	43.0 abc	52.0 ab	68.0 ab	69.0 ab	72.0 ab	73.0 ab	68.0 ab	70.0 ab	73.0 a	73.0 abc	76.0 bc	80.0 abc
4	TifGrand	28.2 bc	54.0 a	57.0 a	72.0 a	75.0 a	76.0 a	79.0 a	78.0 a	79.0 a	75.0 a	81.0 a	85.0 ab	81.0 ab
5	Tifway	52.0 a	52.0 a	50.0 abc	55.0 bc	58.0 bcd	61.0 bc	58.0 c	65.0 bc	63.0 bc	66.0 ab	68.0 bcd	70.0 cd	68.0 def
6	Tifsport	50.0 a	49.0 ab	48.0 abc	54.0 bc	58.0 bcd	62.0 bc	60.0 c	62.0 bcd	64.0 bc	63.0 ab	64.0 bcd	71.0 cd	70.0 b-e
7	Riviera	6.4 de	17.0 fgh	30.0 fg	47.0 c	49.0 cd	53.0 cd	53.0 c	55.0 cd	59.0 bc	59.0 bc	57.0 def	66.0 cd	63.0 d-h
8	Yukon	11.4 de	19.2 e-h	33.0 d-g	47.0 c	50.0 cd	56.0 cd	56.0 c	58.0 bcd	62.0 bc	58.0 bc	59.0 de	62.0 de	61.0 e-h
9	Premier	1.8 e	3.4 i	10.2 h	18.0 d	23.0 e	32.0 f	39.0 de	43 .0ef	47.0 de	48 .0c-e	48.0 e-g	51.0 ef	53.0 hi
10	Patriot	2.8 e	36.0 bcd	45.0 a-e	52.0 c	59.0 bcd	58.0 cd	56.0 c	55.0 cd	58.0 cd	59.0 bc	56.0 def	61.0 de	58.0 fgh
11	OKC 70-18	11.0 de	12.0 ghi	20.0 gh	27.0 d	33.0 e	37.0 ef	36.0 e	40.0 f	43.0 ef	44.0 de	45.0 fg	46.0 f	44.0 ij
12	Celebration	27.0 bc	55.0 a	57.0 a	74.0 a	76.0 a	77.0 a	80.0 a	79.0 a	79.0 a	75.0 a	76.0 ab	92.0 a	90.0 a
13	Quickstand	7.4 de	31.0 c-e	33.0 d-g	45.0 c	50.0 cd	54.0 cd	52.0 c	58.0 bcd	60.0 bc	60.0 bc	60.0 de	68.0 cd	70.0 b-e
14	U3 - SIU	18.2 cd	46.0 ab	46.0 a-d	54.0 bc	61.0 bc	62.0 bc	59.0 c	63.0 bcd	66.0 bc	65.0 ab	67.0 bcd	69.0 cd	68.0 def
15	U3 - NC	5.4 de	26.0 def	32.0 e-g	44.0 c	47.0 d	48.0 de	51.0 cd	53.0 de	56.0 cd	58.0 bc	58.0 de	62.0 de	65.0 d-g
16	U3 - TGS	3.4 e	32.0 c-e	37.0 c-f	51.0 c	58.0 bcd	58.0 cd	54.0 c	59.0 bcd	63.0 bc	60.0 bc	58.0 de	70.0 cd	62.0 e-h
17	Astro	33.0 b	36.0 bcd	39.0 b-f	49.0 c	56.0 bcd	58.0 cd	54.0 c	57.0 bcd	56.0 cd	54.0 bcd	56.0 def	61.0 de	56.0 gh
18	NorthBridge	2.8 e	7.4 hi	14.0 h	22.0 d	27.0 e	35.0 f	34.0 e	33.0 f	35.0 f	36.0 e	38.0 g	38.0 f	40.0 j
19	Latitude 36	2.6 e	6.4 hi	12.2 h	19.2 d	26.0e	32.0 f	30.0 e	33.0 f	35.0 f	37.0 e	36.0 g	38.0 f	36.0 j
20	OKS 2004-2	1.8 e	22.0 e-g	39.0 b-f	51.0 c	61.0 bc	59.0 cd	61.0 bc	63.0 bcd	66.0 bc	63.0 ab	63.0 cd	66.0 cd	65.0 d-g
	LSD‡	**14.1**	**13.6**	**13.2**	**14.5**	**13.8**	**11.4**	**12.2**	**11.6**	**11.6**	**12**	**12.3**	**13.7**	**11.7**

† DAI = Days after irrigation commenced. In the recovery cycle of the experiments DAI stands for days after grasses were re-watered or days after the end of drought cycle.

‡ 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 living cover amongst bermudagrass cultivars during the experiment II recovery cycle.

		Mean Living Cover (%)									
Entry	**Cultivar**	**0 DAI †**	**7 DAI**	**14 DAI**	**21 DAI**	**28 DAI**	**35 DAI**	**42 DAI**	**49 DAI**	**56 DAI**	**63 DAI**
1	Contessa	5.0 abc	8.0 bcd	17.0 b-e	22.0 a-e	28.0 b-f	40.0 ab	49.0 abc	54.0 ab	58.0 a-d	58.0 abc
2	NuMex Sahara	3.0 abc	8.0 bcd	19.0 a-e	25.0 a-d	29.0 b-e	35.0 abc	46.0 a-d	54.0 ab	63.0 ab	60.0 abc
3	Princess 77	0.6 bc	9.8 a-d	23.0 a-d	32.0 abc	40.0 ab	46.0 ab	58.4 a	66.0 a	73.0 a	71.0 a
4	TifGrand	1.0 bc	2.0 d	4.0 e	3.0 e	4.0 f	6.0 d	7.0 e	10.0 c	12.0 e	12.0 e
5	Tifway	3.0 abc	6.8 bcd	15.0 b-e	18.0 b-e	22.0 b-f	27.0 bcd	34.0 a-e	39.0 abc	42.0 a-e	47.0 a-e
6	Tifsport	0.0 c	2.6 cd	7 .0de	10.0 de	15.0 c-f	23.8 bcd	29.0 a-e	40.0 abc	44.0 a-e	49.0 a-e
7	Riviera	5.0 abc	9.0 bcd	22.0 a-e	27.0 a-d	32.0 a-d	40.0 ab	51.0 abc	53.0 ab	61.0 abc	63.0 ab
8	Yukon	4.0.6 abc	11.0 a-d	21.0 a-e	25.0 a-d	30.0 a-e	36.0 abc	45.0 a-d	55.0 ab	58.0 a-d	60.0 abc
9	Premier	6.0 ab	10.4 a-d	18.0 b-e	22.0 a-e	27.0 b-f	32.0 a-d	38.0 a-e	45.0 abc	50.0 a-e	54.0 a-d
10	Patriot	7.0 a	8.4 bcd	12.0 cde	6.0 de	6.2.0 ef	10.2 cd	12.2 de	13.2 c	14.0 e	14.0 de
11	OKC 70-18	2.0 abc	8.4 bcd	22.0 a-e	26.0 a-d	30.0 a-e	35.0 abc	46.0 a-d	55.0 ab	51.0 a-e	52.0 a-e
12	Celebration	0.0 c	2.0 d	6.0 de	8.0 de	9.0 def	12.0 cd	18.0 cde	18.0 bc	20.0 de	20.0 cde
13	Quickstand	4.0 abc	14.4 ab	31.0 ab	38.0 ab	42.0 ab	45.0 ab	55.0 ab	63.0 a	65.0 ab	66.0 a
14	U3 - SIU	7.0 a	16.0 ab	26.0 abc	32.0 abc	33.0 a-d	40.0 ab	53.0 ab	61.0 a	67.0 ab	72.0 a
15	U3 - NC	0.0 c	20.0 a	37.0 a	43.0 a	54.0 a	58.0 a	61.0 a	66.0 a	73.0 a	72.0 a
16	U3 - TGS	5.0 abc	11.0 a-d	20.0 a-e	22.0 a-e	26.0 b-f	29.0 bcd	37.0 a-e	39.0 abc	43.0 a-e	44.0 a-e
17	Astro	4.0 abc	13.0 abc	22.0 a-e	24.0 a-e	31.0 a-e	37.0 abc	40.0 a-e	44.0 abc	46.0 a-e	49.0 a-e
18	NorthBridge	0.0 c	3.6 cd	7.0 de	10.0 de	13.0 c-f	19.0 bcd	22.0 b-e	22.0 bc	22.0 cde	23.0 b-e
19	Latitude 36	5.0 abc	7.6 bcd	13.0 b-e	14.0 cde	18.0 b-f	25.0 bcd	29.0 a-e	30.0 abc	31.0 b-e	33.0 a-e
20	OKS 2004-2	4.0 abc	12.0 a-d	29.0 abc	34.0 abc	37.0 abc	42.0 ab	50.0 abc	53.0 ab	55.0 a-d	60.0 abc
	LSD‡	**5.7**	**10.5**	**18.3**	**21.2**	**24.9**	**27.0**	**34.1**	**37.1**	**40.0**	**40.5**

† DAI = Days after irrigation commenced. In the recovery cycle of the experiments DAI stands for days after grasses were re-watered or days after the end of drought cycle.

‡ 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. Comparisons of mean living cover amongst bermudagrass cultivars during the experiment III recovery cycle.

		Mean Living Cover (%)									
Entry	**Cultivar**	**0 DAI †**	**7 DAI**	**14 DAI**	**21 DAI**	**28 DAI**	**35 DAI**	**42 DAI**	**49 DAI**	**57 DAI**	**65 DAI**
1	Contessa	10.8 a-f	11.4 a-d	25.8 a-d	34.2 abc	41.9 abc	52.5 ab	60.6 abc	69.3 ab	72.2 ab	80.3 ab
2	NuMex Sahara	18.2 a	23.5 a	33.6 a	41.8 ab	49.0 ab	55.2 ab	62.6 ab	68.8 ab	74.1 ab	75.7 ab
3	Princess 77	14.9 abc	19.9 abc	31.8 ab	34.2 abc	48.2 ab	47.5 ab	53.9 abc	62.3 abc	65.8 abc	80.3 ab
4	TifGrand	8.6 a-g	11.6 a-d	22.5 a-f	24.2 bcd	29.8 b-e	31.5 b-e	41.3 a-d	50.2 a-d	52.8 a-d	64.4 abc
5	Tifway	5.0 c-g	6.7 cd	7.2 e-g	7.9 de	8.2 e-g	9.5 def	8.8 fg	11.9 fg	12.9 ef	16.3 fgh
6	Tifsport	10.0 a-g	11.8 a-d	13.1 c-g	16.0 cde	18.8 c-g	20.3 c-f	20.8 d-g	25.5 d-g	28.1 def	33.3 d-g
7	Riviera	16.9 ab	21.5 a	29.4 abc	42.8 ab	48.9 ab	51.1 ab	55.4 abc	59.6 abc	63.0 abc	65.2 abc
8	Yukon	11.5 a-e	14.0 a-d	23.9 a-e	25.4 a-d	33.0 a-d	35.0 bcd	40.5 a-e	48.4 a-d	49.7 bcd	57.1 bcd
9	Premier	1.1 fg	1.1 d	2.1 g	1.1 e	2.1 fg	1.1 f	1.1 g	2.5 g	3.0 f	4.2 gh
10	Patriot	4.7 d-g	4.6 d	10.8 d-g	8.7 de	11.2 d-g	10.5 def	11.4 fg	16.5 e-g	16.0 ef	23.7 e-h
11	OKC 70-18	4.6 d-g	5.1 d	8.1 e-g	14.8 cde	13.4 d-g	17.7 def	22.8 d-g	24.1 d-g	25.7 def	24.3 e-h
12	Celebration	14.2 a-d	20.2 abc	32.9 ab	46.4 a	56.2 a	63.0 a	67.7 a	76.4 a	80.8 a	92.9 a
13	Quickstand	3.4 e-g	6.8 bcd	15.5 b-g	23.7 bcd	26.5 b-f	32.5 b-e	36.3 b-f	44.0 b-e	46.0 bcd	50.7 b-e
14	U3 - SIU	16.4 ab	23.4 a	29.2 abc	30.5 abc	38.5 abc	47.8 ab	53.7 abc	56.0 abc	63.0 abc	72.5 ab
15	U3 - NC	6.9 b-g	14.3 a-d	23.4 a-e	27.7 a-d	31.7 a-e	32.5 b-e	32.5 c-f	36.6 c-f	37.5 cde	37.7 c-f
16	U3 - TGS	0.2 g	1.1 d	1.1 g	1.1 e	1.1 g	0.9 f	0.4 g	0.4 g	0.4 f	0.2 h
17	Astro	10.8 a-f	11.8 a-d	24.8 a-e	31.1 abc	38.2 abc	45.5 abc	56.7 abc	68.4 ab	68.4 ab	75.5 ab
18	NorthBridge	6.1 c-g	3.2 d	4.0 g	6.8 de	8.2 e-g	7.5 ef	12.8 e-g	14.1 fg	15.5 ef	19.4 fgh
19	Latitude 36	5.2 c-g	4.0 d	5.2 fg	8.2 de	9.2 d-g	10.2 def	13.2 d-g	14.2 fg	14.2 ef	15.3 fgh
20	OKS 2004-2	9.5 a-g	21.2 ab	31.7 ab	40.3 ab	49.9 ab	56.9 ab	57.0 abc	58.3 abc	60.1 abc	61.5 bcd
	LSD‡	**10.1**	**14.5**	**17.7**	**21.3**	**24.6**	**25.9**	**28.4**	**28.6**	**28.8**	**31.0**

† DAI = Days after irrigation commenced. In the recovery cycle of the experiments DAI stands for days after grasses were re-watered or days after the end of drought cycle.

‡ 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 coefficients from relationships amongst evapotranspiration (ET) and visual parameters during the course of the drydown cycle in experiment I.

	CumuET‡	**LF**	**TQ**	**LC**
LF	-0.63***			
No. of Samples	1300			
TQ	-0.68***	0.93***		
No. of Samples	1500	1300		
LC	-0.59***	0.89***	0.96***	
No. of Samples	1500	1300	1500	
DAI	0.72***	-0.83***	-0.83***	-0.81***
No. of Samples	1500	1300	1500	1500

*** Significant at $P \leq .0001$
‡CumuET = accumulated ET from time 0 to the end of drydown cycle.
LF = Leaf Firing was rated on a scale from 1-9 during drydown cycles where 1= all leaves fired and 9 = no leaf fired.
TQ = Turf Quality was rated on a scale from 1-9 during both drydown and recovery cycles where 1 = lowest quality and 9 = excellent quality.
LC = Percent Living Cover was rated on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.
DAI = Adjusted Days After Irrigation are the number of days after irrigation was stopped during the drydown cycles. The DAI was adjusted by adding 0.001 to each date to avoid complications while running the data analysis.

Table 18. Pearson's correlation coefficients from relationships amongst final total cumulative evapotranspiration (ET) and visual parameters at the end of the drydown cycle in experiment I, (n=100).

	CumuET‡	**LF**	**TQ**
LF	0.26		
TQ	0.30	0.83***	
LC	0.28	0.85***	0.96***

*** Significant at $P \leq .0001$

‡ CumuET = accumulated ET from time 0 to the end of drydown cycle.

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

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

LC = Percent Living Cover was rated on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.

Table 19. Analysis of variance for cumulative evapotranspiration (Cumu ET) of bermudagrass cultivars during drydown cycle of experiment I. †

Source	df	SS	MS	F
Cultivar (Cult)	19	4305950.9	226629.0	7.92***
DAI ‡	14	117232890.4	8373777.9	292.75***
Cult*DAI	266	4909648.6	18457.3	0.65

*** Significant at $P \leq 0.001$.

† Cumu ET was calculated by subtracting the final weight observation of growth tubes from the weight taken on the very first day of drydown cycle in experiment I.

‡ DAI = Adjusted Days After Irrigation are the number of days after irrigation was stopped during the drydown cycles. The DAI was adjusted by adding 0.001 to each date to avoid complications while running the data analysis.

Table 20. Comparison of trial means and total end of trial cumulative evapotranspiration (ET) of 20 bermudagrass during the drydown cycle of Experiment I.

		Cumulative ET in grams	
Entry	Cultivar	Trial Mean	Total at End of Trial
1	Contessa	801 c-g	1115 abc
2	NuMex Sahara	855abc	1166 abc
3	Princess 77	755 ghi	1069 abc
4	TifGrand	856 ab	1205 ab
5	Tifway	875 a	1234 a
6	Tifsport	781d-h	1061 abc
7	Riviera	764 e-h	1090 abc
8	Yukon	754 e-h	971 cd
9	Premier	757 f-j	989 bcd
10	Patriot	769 e-h	996 bcd
11	OKC 70-18	702 ijk	963 cd
12	Celebration	805 b-g	1113 abc
13	Quickstand	739 hij	1015 a-d
14	U3 - SIU	829 a-d	1062 abc
15	U3 - NC	737 hij	1087 abc
16	U3 - TGS	700 jk	977 cd
17	Astro	743 hij	1057 a-d
18	NorthBridge	810 b-f	1022 a-d
19	Latitude 36	669 k	836 d
20	OKS 2004-2	814 b-e	1081 abc
	LSD‡	54	225

‡ 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 21. Pearson's correlation coefficients for relationships amongst soil moisture at various depths and the parameters leaf firing, turfgrass quality, living cover and days without irrigation in experiment II, (n=1500).

Volumetric Moisture At†	LF‡	TQ	LC	DAI
5.1 cm	0.50	0.53	0.51	-0.46
10.2 cm	0.53	0.55	0.54	-0.49
38.1 cm	0.71***	0.71***	0.69***	-0.74***
71.2 cm	0.76***	0.74***	0.74***	-0.76***
Avg of all depths	0.73***	0.73***	0.72***	-0.72***
Avg of 38.1 and 71.2 cm	0.77***	0.76***	0.74***	-0.79***
Avg of 10.2, 28.1, and 71.2 cm	0.76***	0.76***	0.74***	-0.76***

*** Significant at $P \leq 0.001$.
†Percent volumetric soil moisture was measured at the 5.1 10.2, 38.1 and 71.2 cm depths. Averages (Avg) were calculated for various combinations of depths and used in correlation analysis.
‡LF = Leaf Firing was rated on a scale from 1-9 during drydown cycles where 1= all leaves fired and 9 = no leaf fired.
TQ = Turf Quality was rated on a scale from 1-9 during both drydown and recovery cycles where 1 = lowest quality and 9 = excellent quality.
LC = Percent Living Cover was rated on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.
DAI = Adjusted Days After Irrigation (length of drought) are the number of days after irrigation was stopped during the drydown cycles.
The DAI was adjusted by adding 0.001 to each date to avoid mathematical operations on 0 DAI.

Table 22. Pearson's correlation coefficients for relationships amongst soil moisture at various depths and the parameters leaf firing, turfgrass quality, living cover and days without irrigation in experiment III, (n=1000).

Volumetric Moisture At†	LF‡	TQ	LC	DAI
5.1 cm	0.68***	0.61***	0.69***	-0.62***
10.2 cm	0.65***	0.56	0.64***	-0.61***
38.1 cm	0.51***	0.42	0.47	-0.65***
71.2 cm	0.57	0.49	0.54	-0.72***
Avg of all depths	0.71***	0.61***	0.69***	-0.77***
Avg of 38.1 and 71.2 cm	0.59	0.50	0.56	-0.75***
Avg of 10.2, 28.1, and 71.2 cm	0.67***	0.57	0.64***	-0.77***

*** Significant at $P \leq .001$.
†Percent volumetric soil moisture was measured at the 5.1 10.2, 38.1 and 71.2 cm depths. Averages (Avg) were calculated for various combinations of depths and used in correlation analysis.
‡ LF = Leaf Firing was rated on a scale from 1-9 during drydown cycles where 1= all leaves fired and 9 = no leaf fired.

TQ = Turf Quality was rated on a scale from 1-9 during both drydown and recovery cycles where 1 = lowest quality and 9 = excellent quality.
LC = Percent Living Cover was rated on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.

DAI = Adjusted Days After Irrigation are the number of days after irrigation was stopped during the drydown cycles.
The DAI was adjusted by adding 0.001 to each date to avoid mathematical operations on 0 DAI.

Table 23. Analysis of variance for the effects of cultivar, sampling date and their interaction on soil moisture retention measured weekly at four depths during the drydown cycles of experiments II and III.

		Experiment II (cm)					Experiment III (cm)			
Source	**df**	**5.1**	**10.2**	**38.1**	**71.2**	**df**	**5.1**	**10.2**	**38.1**	**71.2**
Cultivar (Cult)	19	NS	NS	***	***	19	***	***	***	***
Date (D)	14	***	***	***	***	9	***	***	***	***
C X D	266	NS	NS	NS	NS	171	***	***	***	NS
Error	1200					800				

*** Significant at $P \leq 0.001$.
NS = not significant at $P \leq 0.001$.

Table 24. Comparison of mean volumetric soil moisture retention of twenty bermudagrass cultivars at the 5.1 cm depth during the drydown cycle in experiment II.

		Mean Volumetric Moisture (%) at 5.1 cm depth													
Entry	**Cultivar**	**7 DAI†**	**14 DAI**	**21 DAI**	**28 DAI**	**35 DAI**	**43 DAI**	**50 DAI**	**57 DAI**	**64 DAI**	**71 DAI**	**79 DAI**	**86 DAI**	**93 DAI**	**101 DAI**
1	Contessa	0.95 a-d	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	NuMex Sahara	1.26 abc	0.17 ab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Princess 77	0.90 a-d	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	TifGrand	1.44 ab	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Tifway	0.42 bcd	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Tifsport	0.79 a-d	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Riviera	0.70 bcd	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Yukon	0.09 d	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Premier	1.45 ab	0.46 a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Patriot	0.98 a-d	0.04 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	OKC 70-18	1.24 abc	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Celebration	1.80 a	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Quickstand	0.24 cd	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	U3 - SIU	0.69 bcd	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	U3 - NC	0.55 bcd	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	U3 - TGS	0.52 bcd	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	Astro	0.42 bcd	0.06 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	NorthBridge	0.56 bcd	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Latitude 36	0.92 a-d	0.01 b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	OKS 2004-2	1.40 ab	0.30 ab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	LSD‡	1.08	0.36	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† DAI = Days after irrigation. In drydown cycles DAI stands for days after grasses were saturated and subjected to drought by withholding water.
‡ 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 25. Comparison of mean volumetric soil moisture retention of twenty bermudagrass cultivars at the 10.2 cm depth during the drydown cycle in experiment II.

Entry	Cultivar	Mean Volumetric Moisture (%) at 10.2 cm depth													
		7 DAI†	14 DAI	21 DAI	28 DAI	35 DAI	43 DAI	50 DAI	57 DAI	64 DAI	71 DAI	79 DAI	86 DAI	93 DAI	101 DAI
1	Contessa	1.17 b-e	0.16 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
2	NuMex Sahara	1.75 a-e	0.51 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
3	Princess 77	2.28 ab	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
4	TifGrand	1.92 a-d	0.29 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
5	Tifway	0.69 de	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
6	Tifsport	1.09 b-e	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
7	Riviera	1.23 b-e	0.03 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
8	Yukon	1.26 b-e	0.09 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
9	Premier	2.62 a	1.56 a	1.15 a	0.69 a	0.38 a	0.19 a	0.00	0.08 a	0.00	0.00	0.00	0.00	0.00	0.00
10	Patriot	1.77 a-e	0.17 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
11	OKC 70-18	1.51 a-e	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
12	Celebration	1.92 a-d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
13	Quickstand	0.62 e	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
14	U3 - SIU	2.10 abc	0.28 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
15	U3 - NC	0.92 cde	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
16	U3 - TGS	1.07 b-e	0.24 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
17	Astro	1.14 b-e	0.16 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
18	NorthBridge	1.47 a-e	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
19	Latitude 36	1.61 a-e	0.42 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
20	OKS 2004-2	1.73 a-e	0.07 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00 b	0.00	0.00	0.00	0.00	0.00	0.00
	LSD‡	1.27	0.79	0.45	0.34	0.24	0.12	NS	0.05	NS	NS	NS	NS	NS	NS

† DAI = Days after irrigation. In drydown cycles DAI stands for days after grasses were saturated and subjected to drought by withholding water.

‡ 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 26. Comparison of mean volumetric soil moisture retention of twenty bermudagrass cultivars at the 38.1 cm depth during the drydown cycle in experiment II.

		Mean Volumetric Moisture (%) at 38.1 cm depth													
Entry	**Cultivar**	**7 DAI†**	**14 DAI**	**21 DAI**	**28 DAI**	**35 DAI**	**43 DAI**	**50 DAI**	**57 DAI**	**64 DAI**	**71 DAI**	**79 DAI**	**86 DAI**	**93 DAI**	**101 DAI**
1	Contessa	5.07 ef	5.41 a-d	4.90 abc	3.68 abc	2.80 b-f	2.47 b-g	1.66 cde	1.80 bcd	1.45 b-e	0.80 cd	0.69 b-f	0.34 de	0.27 b	0.07 c
2	NuMex Sahara	5.86 b-e	5.72 ab	4.95 abc	4.65 a	3.85 a-d	3.48 a-d	3.31 abc	1.78 bcd	2.47 ab	2.08 abc	2.31 abc	1.83 a-d	1.44 ab	1.25 abc
3	Princess 77	5.48 c-f	5.11 a-d	5.21 ab	1.86 cd	1.33 fg	1.09 d-g	0.81 de	0.33 cd	0.29 de	0.00 d	0.11 f	0.02 e	0.19 b	0.00 c
4	TifGrand	5.33 c-f	5.01 a-d	3.75 d	0.12 d	0.00 g	0.00 g	0.00 e	0.00 d	0.00 e	0.00 d	0.00 f	0.00 e	0.00 b	0.00 c
5	Tifway	5.84 b-e	4.80 d	5.42 ab	4.75 a	3.90 a-d	2.89 b-f	2.36 cde	2.37 abc	1.59 a-e	1.42 a-d	1.45 a-f	1.22 b-e	1.12 ab	0.87 bc
6	Tifsport	5.09 def	5.31 a-d	3.69 d	1.87 cd	0.07 g	0.00 g	0.00 e	0.00 d	0.00 e	0.00 d	0.00 f	0.00 e	0.00 b	0.00 c
7	Riviera	6.02 abc	5.75 a	5.12 ab	3.80 abc	3.90 a-d	3.19 b-e	2.42 cd	2.42 ab	2.36 abc	2.20 abc	1.98 a-e	1.37 a-e	1.07 ab	1.01bc
8	Yukon	6.77 a	5.34 a-d	5.87 a	5.29 a	4.90 ab	3.85 abc	2.12 cde	2.03 a-d	1.38 b-e	0.50 cd	0.20 ef	0.00 e	0.00 b	0.00 c
9	Premier	5.92 a-e	5.47 a-d	5.55 ab	5.24 a	5.27 a	5.72 a	5.41 a	3.99 a	3.37 a	2.69 ab	2.67 a	2.90 a	2.48 a	2.55 a
10	Patriot	5.82 b-e	5.19 a-d	5.26 ab	4.66 a	4.38 abc	3.46 a-d	2.46 bcd	2.49 ab	1.64 a-e	1.07 bcd	0.62 c-f	0.18 de	0.13 b	0.00 c
11	OKC 70-18	5.31 c-f	5.11 a-d	4.10 abc	4.87 a	3.55 a-f	2.34 b-g	1.89 cde	1.27 bcd	0.58 cde	0.00 d	0.00 f	0.00 e	0.00 b	0.00 c
12	Celebration	4.83 f	4.74 d	3.10 cd	1.93 bcd	0.01 g	0.00 g	0.00 e	1.08 bcd	0.00 e	0.00 d	0.00 f	0.00 e	0.00 b	0.00 c
13	Quickstand	5.11 def	4.92 bcd	4.87 abc	3.94 a	2.10 d-g	0.38 g	0.32 de	0.16 d	0.00 e	0.00 d	0.00 f	0.00 e	0.00 b	0.00 c
14	U3 - SIU	5.57 b-f	5.04 a-d	4.64 bcd	3.57 abc	1.46 efg	0.87 efg	0.74 de	0.96 bcd	0.74 b-e	0.69 cd	0.48 d-e	0.42 cde	0.00 b	0.00 c
15	U3 - NC	5.43 c-f	5.28 a-d	5.39 ab	3.81 abc	1.62 d-g	0.61 gf	0.15 de	0.12 d	0.11 e	0.00 d	0.00 f	0.00 e	0.00 b	0.00 c
16	U3 - TGS	5.59 b-f	4.90 cd	4.59 bcd	5.11 a	4.50 abc	4.01 abc	3.22 abc	2.56 ab	1.95 a-d	2.17 abc	2.16 a-d	2.13 ab	1.88 a	1.88 ab
17	Astro	5.73 b-e	5.39 a-d	4.99 abc	3.85 ab	2.23 c-g	1.22 d-g	0.73 de	0.56 bcd	0.37 de	0.21 d	0.20 ef	0.00 e	0.00 b	0.00 c
18	NorthBridge	5.97 a-d	5.64 abc	5.05 abc	4.94 a	3.71 a-e	3.53 a-d	2.37 cde	2.07 a-d	1.76 a-e	1.46 a-d	1.57 a-f	1.39 a-e	1.46 ab	0.87 bc
19	Latitude 36	5.84 b-e	5.29 a-d	5.20 ab	4.90 a	5.26 a	4.78 ab	4.82 ab	4.10 a	3.28 a	3.05 a	2.47 ab	2.01 abc	1.58 ab	1.85 ab
20	OKS 2004-2	6.46 ab	5.54 a-d	5.36 ab	3.95 a	2.76 b-f	2.29 c-g	1.41 cde	1.07 bcd	1.14 b-e	0.67 cd	0.00 f	0.00 e	0.28 b	0.00 c
	LSD‡	0.89	0.81	1.11	1.98	2.29	2.47	2.38	2.09	1.82	1.79	1.18	1.66	1.59	1.51

† DAI = Days after irrigation. In drydown cycles DAI stands for days after grasses were saturated and subjected to drought by withholding water.
‡ 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 27. Comparison of mean volumetric soil moisture retention of twenty bermudagrass cultivars at the 71.2 cm depth during the drydown cycle in experiment II.

		Mean Volumetric Moisture (%) at 71.2 cm depth													
Entry	**Cultivar**	**7 DAI†**	**14 DAI**	**21 DAI**	**28 DAI**	**35 DAI**	**43 DAI**	**50 DAI**	**57 DAI**	**64 DAI**	**72 DAI**	**79 DAI**	**86 DAI**	**93 DAI**	**101 DAI**
1	Contessa	9.48 b	8.2 abc	7.14 b-e	7.07 a-e	4.94 a-d	4.21 a-d	3.36 cde	3.17 d-g	2.56 a-e	2.63 a-d	2.59 b-g	2.31 b-g	2.09 b-g	2.01 c-g
2	NuMex Sahara	10.55 ab	8.88 ab	7.87 a-d	7.70 ab	6.79 ab	5.44 abc	6.28 a	4.25 a-e	3.74 a-d	4.30 abc	4.31 a-e	3.74 a-d	3.65 a-e	3.41 a-e
3	Princess 77	9.74 b	7.53 abc	7.93 a-d	5.34 b-f	4.40 cde	3.98 bcd	3.48 b-f	3.17 c-g	2.43 def	2.76 a-d	2.53 c-g	2.30 b-g	2.01 b-g	1.63 d-g
4	TifGrand	10.87 ab	7.42 abc	6.45 de	4.77 ef	3.69 de	2.17 de	1.55 f	1.15 g	0.87 fg	0.73 de	0.82 gh	0.54 fg	0.65 g	0.18 g
5	Tifway	9.36 b	8.16 abc	8.14 a-d	6.82 a-e	5.88 abc	5.53 abc	5.33 abc	5.58 a	4.51 a	4.33 abc	4.63 abc	3.87 a-d	3.49 a-e	3.77 a-d
6	Tifsport	10.11 b	7.8 abc	5.33 e	4.33 f	2.90 e	1.82 e	1.72 ef	1.13 g	0.81 fg	0.85 de	0.73 gh	0.52 fg	0.51 g	0.47 g
7	Riviera	9.30 b	8.48 abc	7.57 a-e	7.54 abc	6.85 ab	5.64 abc	5.47 abc	4.52 a-d	3.88 a-d	4.56 ab	4.19 a-e	3.52 a-e	3.18 a-f	3.09 a-f
8	Yukon	10.87 ab	8.73 abc	9.53 ab	7.36 abc	5.69 a-d	5.36 abc	5.40 abc	5.05 a-d	4.40 ab	4.79 a	5.03 ab	4.87 a	4.18 ab	4.42 a
9	Premier	10.27 ab	8.67 abc	10.01 a	8.67 a	7.16 a	6.23 a	6.21 a	5.31 ab	4.28 abc	4.85 a	5.24 a	4.43 ab	4.41 a	4.32 abc
10	Patriot	12.49 a	8.67 abc	7.25 b-e	6.21 b-f	6.05 abc	5.09 abc	4.94 abc	4.80 a-d	3.53 a-d	2.99 a-d	2.70 b-g	2.24 b-g	1.87 c-g	2.22 a-g
11	OKC 70-18	9.38 b	7.48 abc	6.58 cde	6.78 a-e	5.46 a-d	4.81 abc	4.20 a-d	3.43 b-f	2.78 a-e	2.62 a-d	2.42 c-h	2.07 b-g	1.80 c-g	0.87 fg
12	Celebration	10.42 ab	6.79 c	6.24 de	4.96 def	4.24 cde	2.24 de	1.46 f	1.97 fg	0.27 g	0.00 e	0.00 h	0.00 g	0.00 g	0.001 g
13	Quickstand	10.06 b	7.5 abc	6.99 cde	5.97 b-f	5.52 a-d	5.09 abc	4.60 a-d	4.04 a-f	2.82 a-e	2.29 bcd	1.90 fgh	1.67 d-g	1.54 efg	1.32efg
14	U3 - SIU	10.82 ab	8.11 abc	8.42 a-d	6.45 a-f	6.17 abc	5.27 abc	5.27 abc	5.30 abc	4.52 a	4.04 abc	3.53 a-f	2.84 a-f	2.01 b-g	1.92 d-g
15	U3 - NC	8.72 b	8.33 abc	7.73 a-e	5.88 b-f	5.17 a-d	4.73 abc	4.28 a-d	4.00 a-f	3.22 a-e	2.11 cde	1.61 fgh	1.30 efg	0.94 g	1.00 fg
16	U3 - TGS	10.65 ab	8.09 abc	7.29 b-e	7.29 a-d	6.79 ab	6.05 ab	5.47 abc	5.16 a-d	4.17 a-d	4.34 abc	4.37 a-e	4.12 abc	3.79 a-d	3.82 a-d
17	Astro	8.75 b	7.26 bc	6.20 de	5.22 c-f	4.61 cde	3.59 cde	2.58 def	2.19 efg	1.57 d-g	1.51 de	1.38 fgh	1.34 efg	1.04 fg	0.85 fg
18	NorthBridge	8.88 b	8.59 abc	6.93 cde	6.24 b-f	5.61 a-d	5.64 abc	5.03 abc	5.10 a-d	4.14 a-d	4.71 a	4.39 a-d	4.03 a-d	3.99 abc	3.67 a-d
19	Latitude 36	10.48 ab	8.68 abc	8.99 abc	7.32 a-d	5.96 abc	5.63 abc	5.70 ab	5.18 a-d	4.06 a-d	4.69 a	4.77 abc	4.37 ab	4.37 a	4.39 ab
20	OKS 2004-2	10.19 ab	9.44 a	7.71 a-e	5.88 b-f	5.21 a-d	4.55 abc	3.99 a-e	3.38 b-f	2.48 c-f	2.37 bcd	2.05 d-h	1.95 c-g	1.76 d-g	2.05 b-g
	LSD‡	2.33	2.08	2.51	2.38	2.1	2.14	2.31	2.14	1.99	2.27	2.45	2.40	2.23	2.35

† DAI = Days after irrigation. In drydown cycles DAI stands for days after grasses were saturated and subjected to drought by withholding water.

‡ 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 28. Comparison of mean volumetric soil moisture retention of twenty bermudagrass cultivars at the 5.1 cm depth during the drydown cycle in experiment III.

Entry	Cultivar	Mean Volumetric Moisture (%) at 5.1 cm depth								
		7 DAI†	14 DAI	21 DAI	28 DAI	35 DAI	42 DAI	49 DAI	60 DAI	67 DAI
1	Contessa	1.73 f	0.00 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
2	NuMex Sahara	3.87 a-d	1.95 abc	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
3	Princess 77	2.47 def	0.00 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
4	TifGrand	3.46 a-e	0.87 dc	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
5	Tifway	2.07 ef	0.02 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
6	Tifsport	1.38 f	0.00 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
7	Riviera	2.75 cde	0.05 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
8	Yukon	2.49 def	0.00 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
9	Premier	3.74 a-d	1.18 dc	0.48 ab	0.47 ab	0.57 a	0.00 b	0.00 b	0.00	0.00
10	Patriot	4.10 abc	2.64 ab	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
11	OKC 70-18	4.41 a	1.88 bc	0.10 a	0.091 b	0.00 b	0.00 b	0.00 b	0.00	0.00
12	Celebration	2.49 def	0.00 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
13	Quickstand	2.78 b-f	0.35 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
14	U3 - SIU	2.46 def	0.00 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
15	U3 - NC	2.05 f	0.00 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
16	U3 - TGS	1.55 f	0.00 d	0.76 ab	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
17	Astro	2.15 ef	0.13 d	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
18	NorthBridge	4.67 a	2.12 abc	0.59 ab	0.37 b	0.00 b	0.00 b	0.00 b	0.00	0.00
19	Latitude 36	4.55 a	3.37 a	1.39 a	0.97 a	0.24 ab	0.12 a	0.20 a	0.00	0.00
20	OKS 2004-2	4.19 ab	0.92 dc	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00	0.00
	LSD‡	1.41	1.42	1.99	0.51	0.39	0.07	0.13	NS	NS

† DAI = Days after irrigation. In drydown cycles DAI stands for days after grasses were saturated and subjected to drought by withholding water.
‡ 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 29. Comparison of mean volumetric soil moisture retention of twenty bermudagrass cultivars at the 10.2 cm depth during the drydown cycle in experiment III.

Entry	Cultivar	Mean Volumetric Moisture (%) at 10.2 cm depth								
		7 DAI†	14 DAI	21 DAI	28 DAI	35 DAI	42 DAI	49 DAI	60 DAI	67 DAI
1	Contessa	2.86 fe	0.00 f	0.00 e	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
2	NuMex Sahara	4.59 abc	3.38 ab	1.72 cd	1.15 cd	0.81 bc	0.27 c	0.07 c	0.00 c	0.00 c
3	Princess 77	2.37 f	0.00 f	0.00 e	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
4	TifGrand	3.73 b-e	1.24 cde	0.00 e	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
5	Tifway	3.52 c-f	0.00 f	0.00 e	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
6	Tifsport	2.56 ef	0.00 f	0.00 e	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
7	Riviera	3.70 b-e	1.68 cd	0.52 cde	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
8	Yukon	3.63 b-e	0.30 ef	0.00 e	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
9	Premier	5.18 a	4.52 a	4.25 a	3.66 a	3.76 a	3.76 a	3.88 a	3.45 a	3.42 a
10	Patriot	4.63 abc	3.74 a	2.19 bc	1.60 c	1.02 bc	0.74 bc	0.29 c	0.4 c	0.03 c
11	OKC 70-18	5.32 a	4.31 a	3.65 ab	1.14 cd	0.55 c	0.45 c	0.48 c	0.00 c	0.00 c
12	Celebration	3.57 b-e	0.13 ef	0.00 e	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
13	Quickstand	3.36 def	0.32 def	0.00 e	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
14	U3 - SIU	3.72 b-e	0.10 c-f	0.00 e	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
15	U3 - NC	2.94 ef	0.00 f	0.00 e	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
16	U3 - TGS	3.40 def	0.42 def	1.20 cde	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
17	Astro	3.65 b-e	1.48 cde	0.19 de	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
18	NorthBridge	4.75 ab	4.00 a	1.53 cde	2.28 bc	2.08 b	1.82 b	1.99 b	1.72 b	1.65 b
19	Latitude 36	5.45 a	4.40 a	4.28 a	4.31 a	4.12 a	3.47 a	3.87 a	3.08 a	3.48 a
20	OKS 2004-2	4.23 a-d	2.31 bc	0.79 cde	0.00 d	0.00 c	0.00 c	0.00 c	0.00 c	0.00 c
	LSD‡	1.18	1.37	1.71	1.45	1.32	1.14	1.11	0.93	0.94

† DAI = Days after irrigation. In drydown cycles DAI stands for days after grasses were saturated and subjected to drought by withholding water.
‡ 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 30. Comparison of mean volumetric soil moisture retention of twenty bermudagrass cultivars at the 38.1 cm depth during the drydown cycle in experiment III.

Entry	Cultivar	Mean Volumetric Moisture (%) at 38.1 cm depth								
		7 DAI†	14 DAI	21 DAI	28 DAI	35 DAI	42 DAI	49 DAI	60 DAI	67 DAI
1	Contessa	8.18 a-d	7.52 a-d	6.36 b-h	5.10 e	3.34 dc	2.71 ef	1.87 ef	1.60 d-e	1.79 fgh
2	NuMex Sahara	8.17 a-d	7.31 a-f	6.60 a-g	6.46 b-f	5.39 a-d	4.67 b-f	3.92 b-e	3.08 bcd	3.41 b-f
3	Princess 77	8.74 a	7.24 a-f	5.85 d-h	5.12 efg	4.31 bcd	2.88 ef	1.38 ef	0.62 ef	0.63 gh
4	TifGrand	7.27 b-e	5.77 f	4.57 ghi	4.00 g	3.22 d	2.72 ef	3.34 cde	2.84 b-e	2.34 e-h
5	Tifway	7.82 a-e	6.66 a-f	6.04 c-h	5.53 d-g	4.17 bcd	3.26 def	2.45 def	2.96 b-e	2.87 c-g
6	Tifsport	7.07cde	6.13 c-f	5.04 ghi	4.67 fg	3.95 dc	2.89 ef	2.88 de	1.99 c-f	1.96 e-h
7	Riviera	7.78 a-e	7.36 b-f	6.50 a-g	6.16 c-g	5.36 a-d	4.51 b-f	3.65 cde	2.78 b-e	2.63 d-h
8	Yukon	7.23 b-e	7.31 a-f	7.19 a-f	7.71 a-d	6.62 ab	5.92 abc	4.92 a-d	5.17 ab	5.35 abc
9	Premier	8.00 a-e	8.03 a	7.97 ab	6.94 a-e	7.51 a	5.73 a-d	6.49 ab	6.35 a	5.93 ab
10	Patriot	8.44 ab	8.01 a	8.36 a	8.45 ab	7.29 a	6.15 abc	5.58 abc	5.19 ab	5.29 abc
11	OKC 70-18	8.77 a	8.11 a	8.07 ab	7.92 abc	7.83 a	6.40 ab	6.44 ab	6.22 a	6.19 a
12	Celebration	8.06 a-d	5.96 def	3.37 i	0.59 h	0.00 e	0.00 g	0.00 f	0.00 f	0.00 h
13	Quickstand	6.92 de	5.80 ef	5.83 d-h	6.18 c-g	5.71 abc	5.2 a-e	4.98 a-d	4.74 ab	5.07 a-d
14	U3 - SIU	8.78 a	7.80 ab	6.78 a-g	6.26 b-g	4.65 bcd	2.48 gf	2.28 ef	1.30 def	0.95 fgh
15	U3 - NC	6.75 e	5.91 ef	5.40 fgh	5.05 e	4.50 bcd	3.76 c-f	3.48 cde	3.56 bcd	3.22 c-g
16	U3 - TGS	8.09 a-d	6.83 a-f	7.77 abc	7.11 a-e	7.47 a	7.44 a	6.77 a	6.54 a	6.92 a
17	Astro	7.46 b-e	6.34 b-f	5.73 e-h	5.15 efg	4.35 bcd	2.78 ef	2.61 de	2.72 b-e	2.63 d-h
18	NorthBridge	8.26 abc	8.17 a	7.66 a-d	8.86 a	7.51 a	7.29 a	7.01 a	6.48 a	6.41 a
19	Latitude 36	8.77 a	8.01 a	7.46 a-e	8.37 abc	6.54 ab	7.23 a	5.61 abc	6.19 a	6.04 ab
20	OKS 2004-2	7.23 b-e	7.60 abc	7.71 abc	7.08 a-e	5.67 a-d	4.29 b-f	4.91 a-d	4.50 a-8c	4.54 a-e
	LSD‡	1.28	1.57	1.86	2.27	2.49	2.49	2.59	2.62	2.64

† DAI = Days after irrigation. In drydown cycles DAI stands for days after grasses were saturated and subjected to drought by withholding water.
‡ 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 31. Comparison of mean volumetric soil moisture retention of twenty bermudagrass cultivars at the 71.2 cm depth during the drydown cycle in experiment III.

Entry	Cultivar	Mean Volumetric Moisture (%) at 71.2 cm depth								
		7 DAI†	14 DAI	21 DAI	28 DAI	35 DAI	42 DAI	49 DAI	60 DAI	67 DAI
1	Contessa	11.75 abc	12.42 b-e	8.93 f	6.18 f	5.90 efg	4.89 d-e	5.37 c-f	5.71 a-d	5.13 b-e
2	NuMex Sahara	12.40 abc	13.59 a-e	12.04 b-f	9.09 c-f	6.56 d-g	5.60 c-f	5.38 c-f	5.19 a-d	4.97 b-e
3	Princess 77	11.21 abc	12.41 b-e	11.18 c-f	8.12 def	6.20 efg	5.21 c-f	5.46 c-f	5.41 a-d	5.22 a-e
4	TifGrand	11.18 abc	13.43 a-e	9.60 ef	7.62 def	5.55 fg	4.34 ef	4.76 ef	4.81 bcd	4.19 e
5	Tifway	11.48 abc	13.31 a-e	10.37 def	6.78 ef	5.57 fg	5.63 c-f	5.88 a-f	6.01 a-d	5.76 a-e
6	Tifsport	11.95 abc	15.68 a-e	10.79 def	6.54 f	6.08 efg	5.83 c-f	5.68 b-f	5.59 a-d	5.15 a-e
7	Riviera	12.23 ab	14.83 a-e	11.96 b-f	8.88 c-f	6.79 c-g	5.66 c-f	5.21 def	5.34 a-d	5.73 a-e
8	Yukon	10.41 bc	14.38 a-e	12.79 a-f	10.65 b-e	6.69 d-g	5.31 c-f	5.53 c-f	6.34 ab	5.41 a-e
9	Premier	13.13 a	16.21 b-e	16.82 a	12.62 abc	10.08 ab	6.95 a-d	6.27 a-e	5.69 a-d	5.83 a-e
10	Patriot	11.88 abc	17.08 a	15.59 ab	12.28 abc	8.84 a-e	6.53 b-e	6.44 a-e	6.15 abc	5.58 a-e
11	OKC 70-18	11.66 abc	13.17 a-e	13.03 a-f	11.25 a-d	9.53 a-d	6.57 b-e	6.71 a-d	6.11 a-d	5.91 a-e
12	Celebration	12.31 ab	13.58 a-e	10.04 ef	6.12 f	4.12 g	4.06 f	4.26 f	4.58 cd	4.30 de
13	Quickstand	10.80 abc	11.82 de	9.52 ef	8.30 d-e	5.86 efg	4.52 def	5.24 def	5.6 a-d	5.39 a-e
14	U3 - SIU	12.28 ab	15.74 a-d	13.33 a-e	9.47 cde	7.37 b-f	5.49 c-f	5.23 def	5.43 a-d	4.26 de
15	U3 - NC	9.69 c	11.26 e	9.99 ef	7.65 def	6.53 d-g	5.73 c-f	5.11 def	5.49 a-d	6.22 abc
16	U3 - TGS	11.57 abc	14.59 a-e	14.74 a-d	13.68 ab	9.84 abc	7.39 abc	7.01 abc	6.35 ab	5.88 a-e
17	Astro	11.30 abc	12.32 cde	9.57 ef	6.38 f	5.47 fg	4.36 ef	4.31 f	4.36 d	4.42 cde
18	NorthBridge	12.07 abc	16.73 abc	15.20 abc	14.06 ab	10.42 ab	8.41 ab	7.35 ab	6.34 ab	6.95 a
19	Latitude 36	12.22 ab	16.45 abc	16.65 a	14.78 a	11.35 a	9.28 a	7.55 a	6.76 a	6.77 ab
20	OKS 2004-2	12.37 ab	16.82 ab	15.97 ab	11.29 a-d	7.39 b-f	6.66 b-e	6.6 a-d	5.95 a-d	6.03 a-d
	LSD‡	2.40	4.45	4.39	3.92	3.13	2.44	1.75	1.75	1.81

† DAI = Days after irrigation. In drydown cycles DAI stands for days after grasses were saturated and subjected to drought by withholding water.

‡ 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.

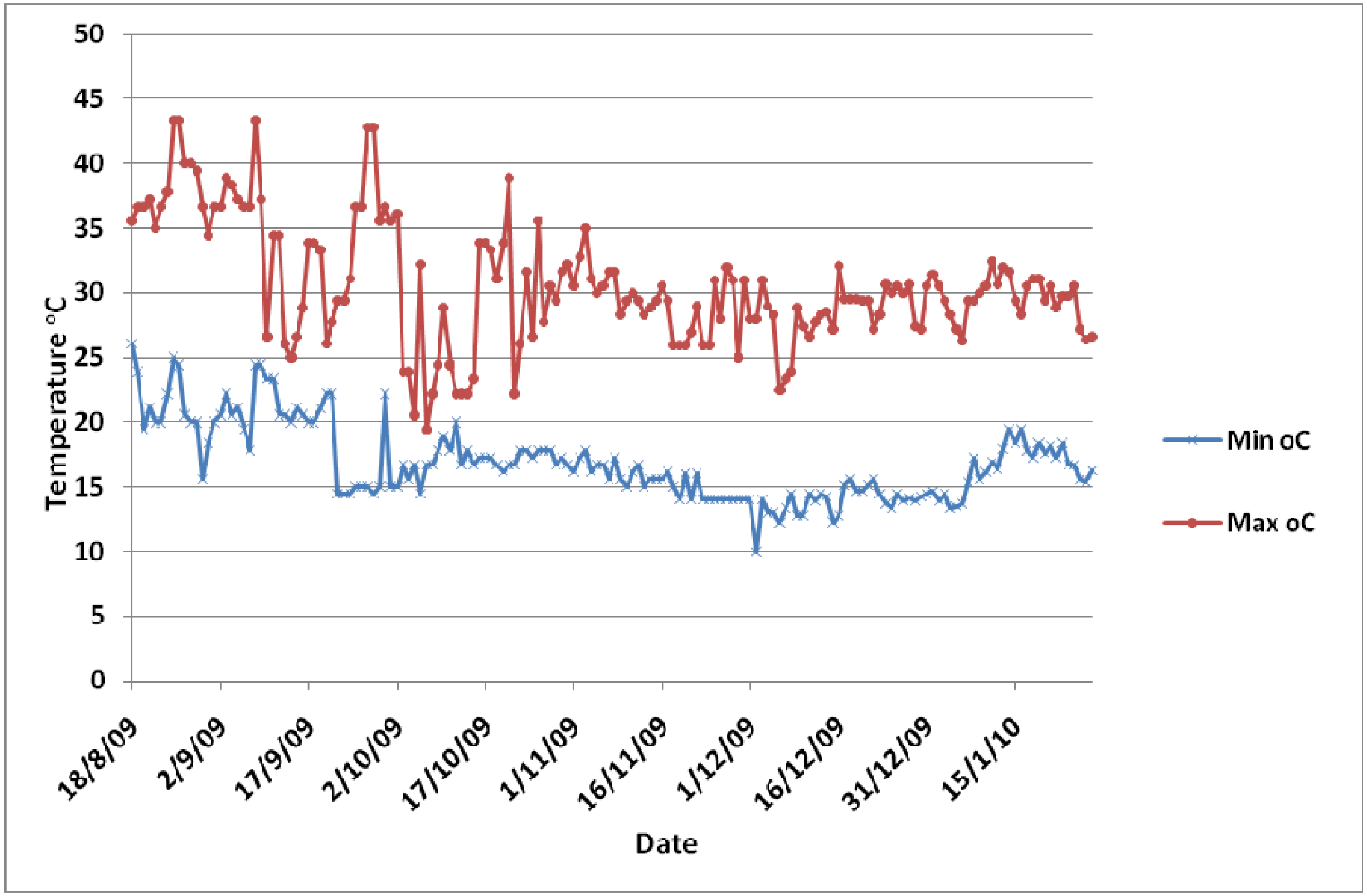

Figure 4. Minimum and maximum daily greenhouse air temperature at 30 cm above the turfgrass canopy during drydown and recovery cycles in Experiment I (18 August 2009 to 28 January 2010).

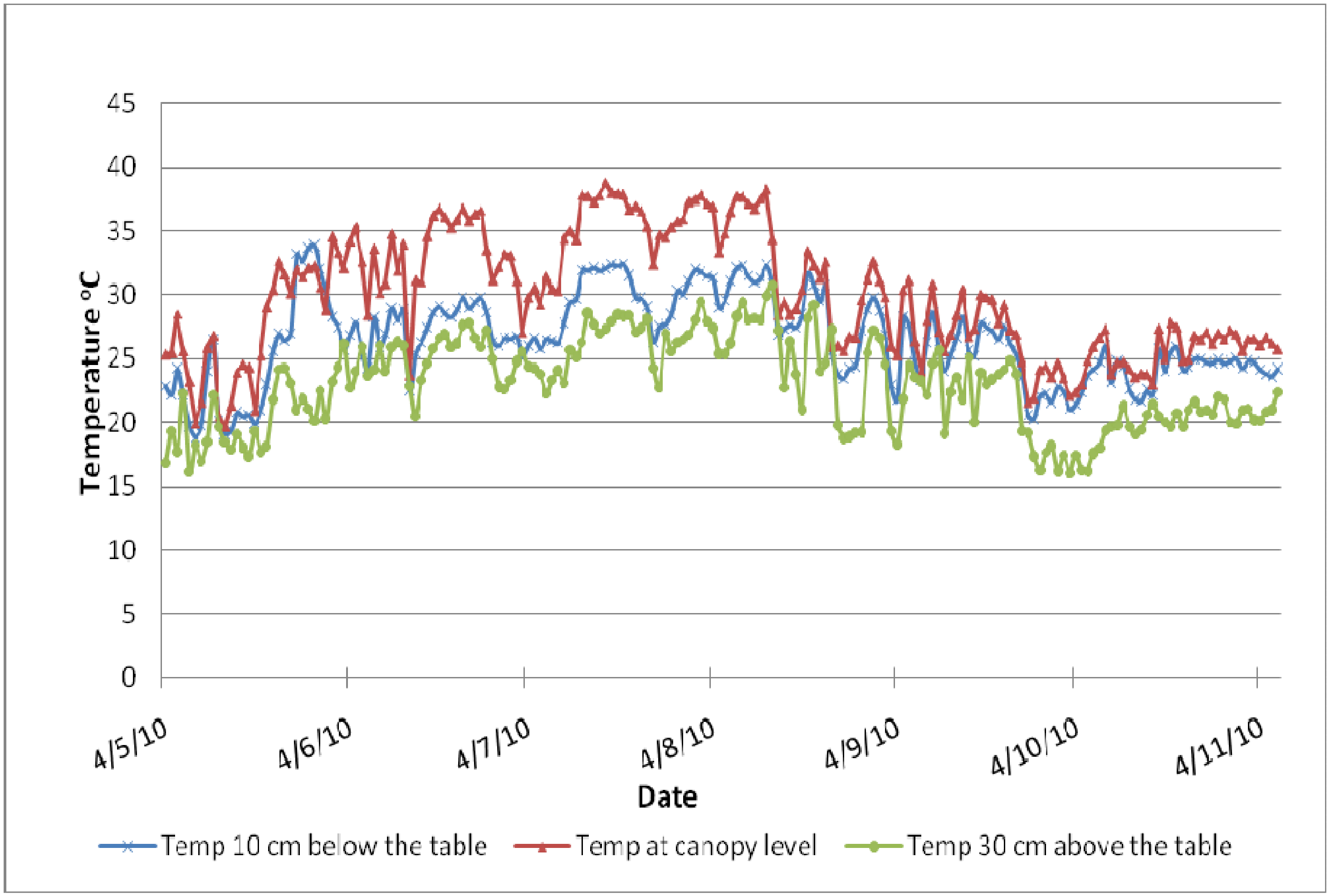

Figure 5. Daily average greenhouse air temperature (Temp) 10 cm below the drought table surface, at the turfgrass canopy level and 30 cm above the turfgrass canopy during drydown cycles and recovery cycles of Experiment II and III (4 May 2010 – 7 November 2010).

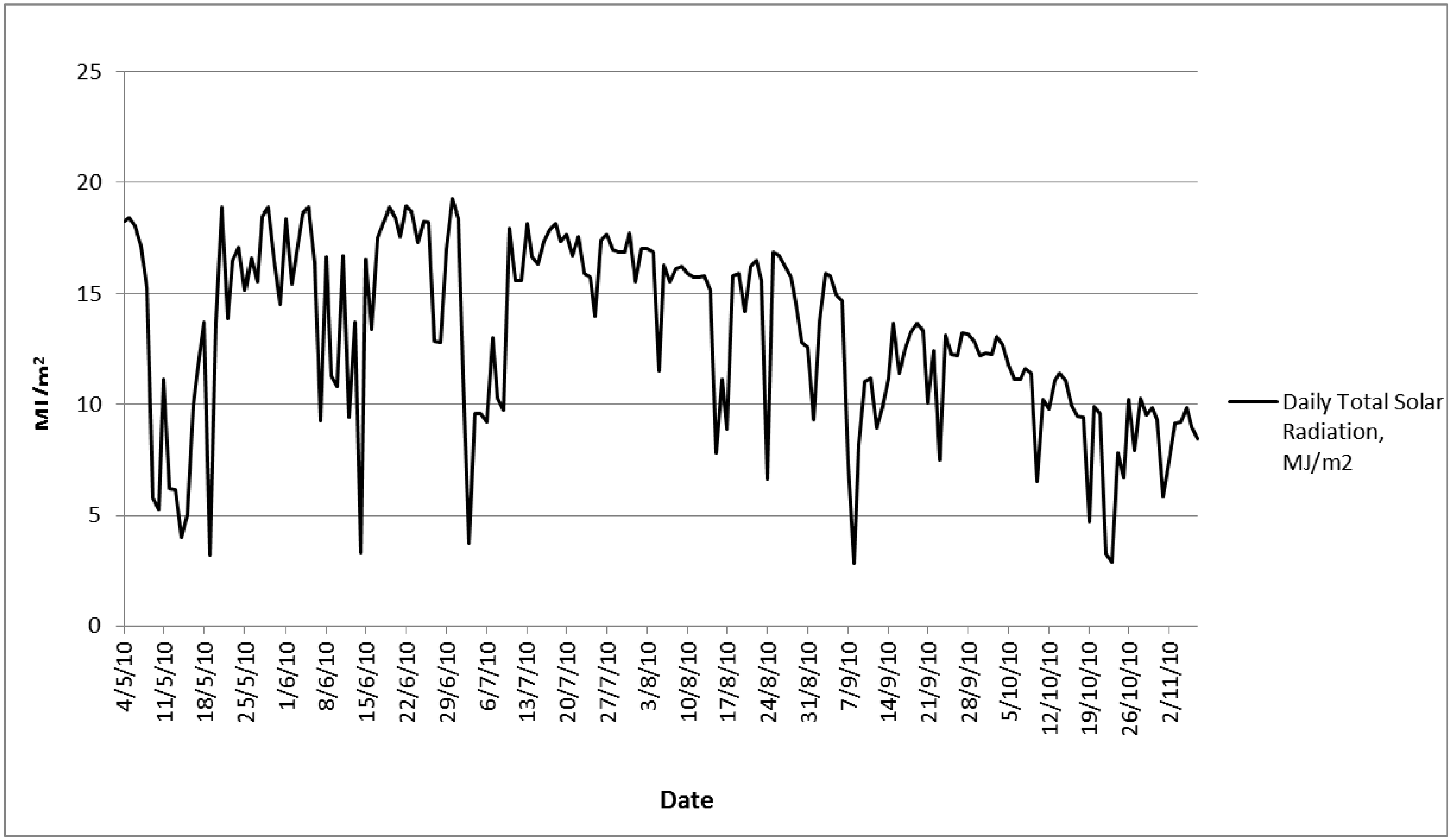

Figure 6. Total daily solar radiation (MJ m^{-2}) at turfgrass canopy level recorded in Experiment II during 4 May through 7 November 2010.

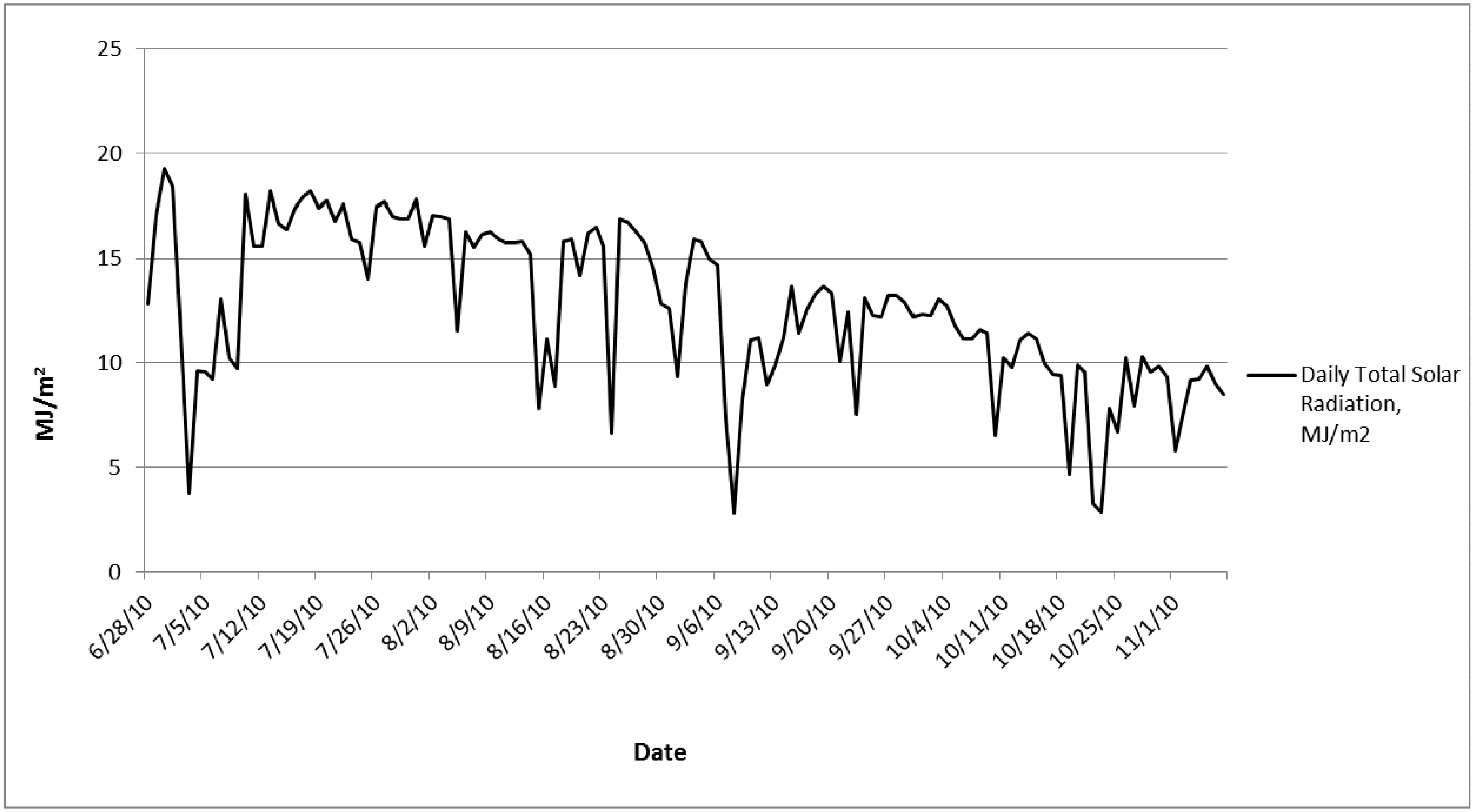

Figure 7. Total daily solar radiation (MJ m^{-2}) at turfgrass canopy level recorded in Experiment III from 28 June through 7 November 2010.

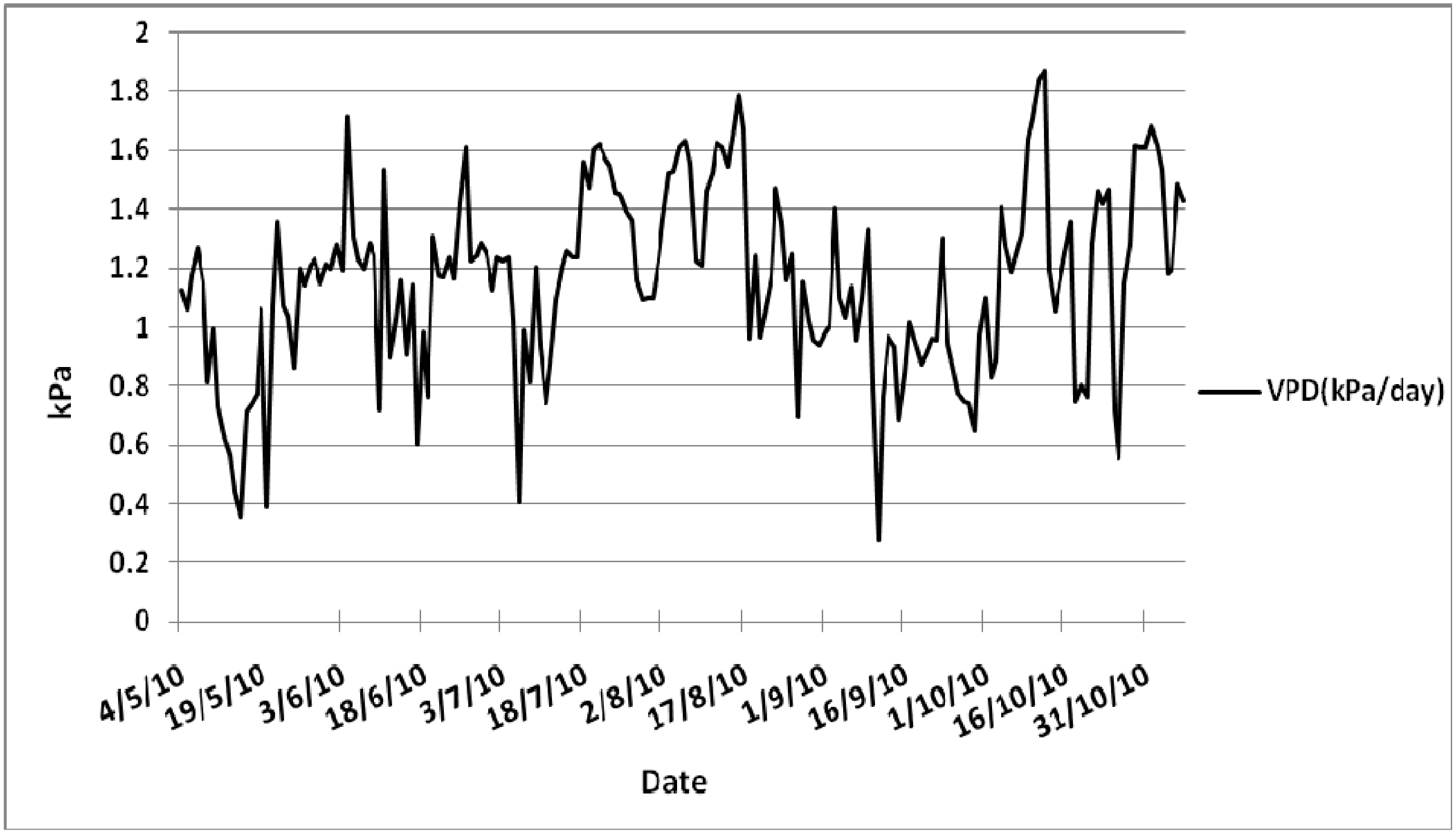

Figure 8. Daily average vapor pressure deficit (VPD) of the greenhouse air at 30 cm above the turfgrass canopy in kilopascals (kPa) recorded throughout Drydown and Recovery cycles of Experiments II and III.

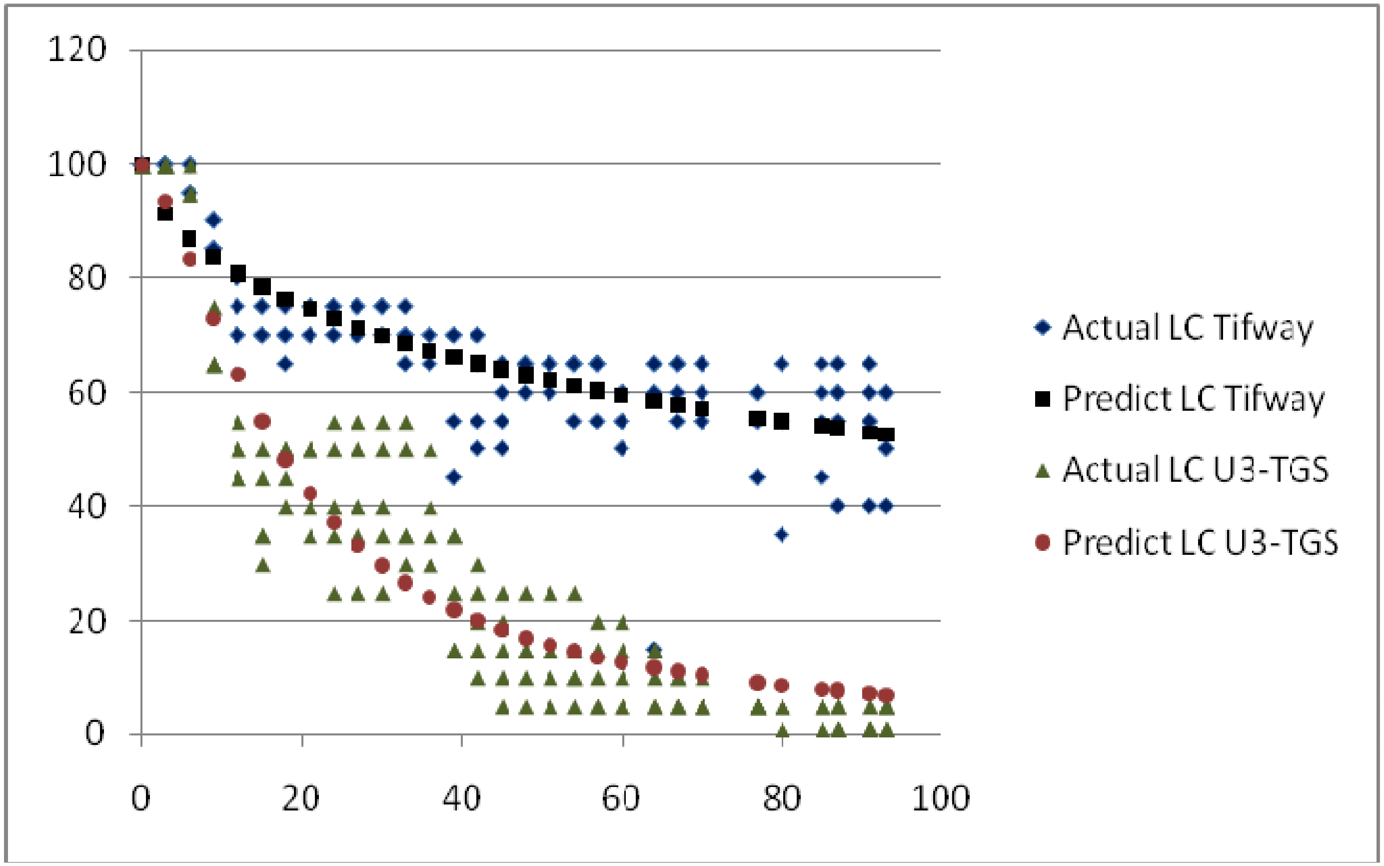

Figure 9. Actual and predicted live green cover (LC) for Tifway and U3-TGS bermudagrasses during the drydown cycle in Experiment I.

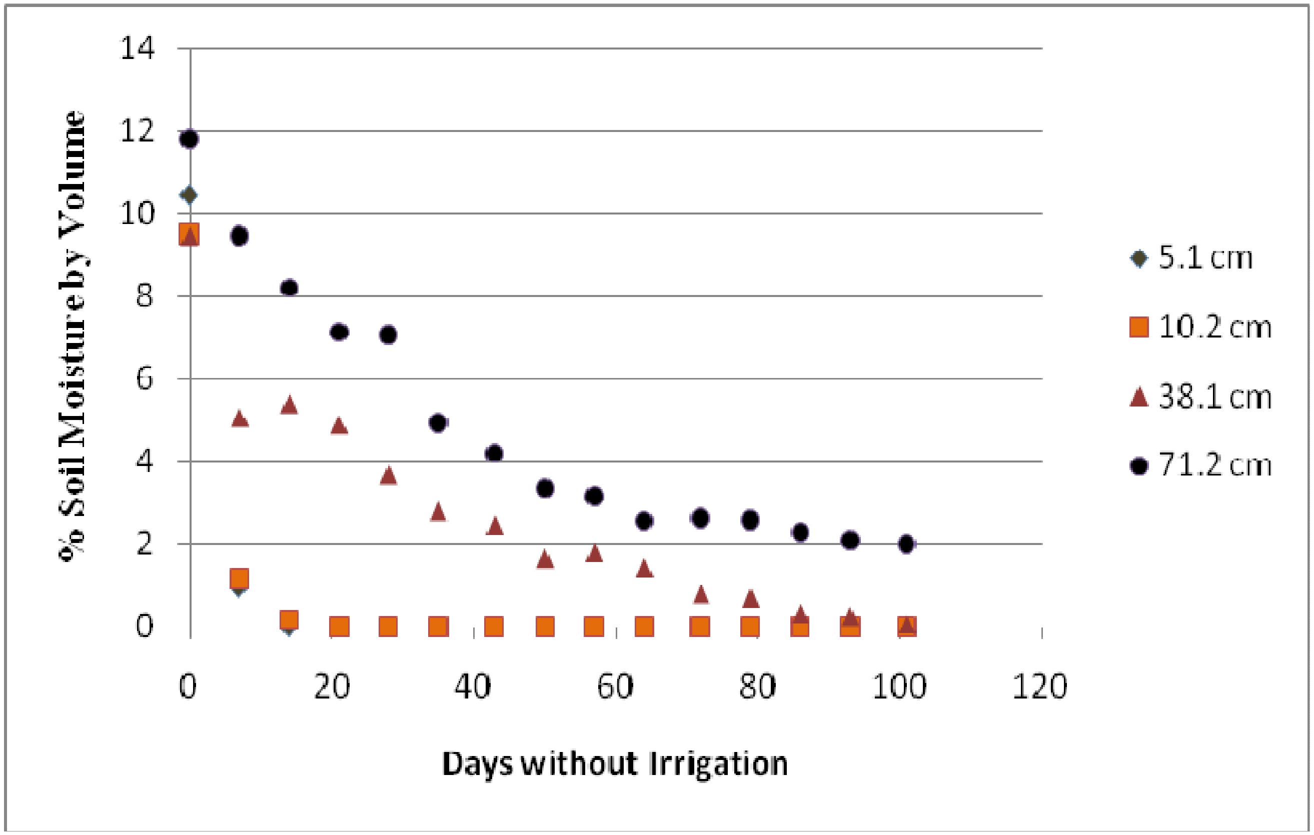

Figure 10. Mean percent volumetric soil moisture in pots of Contessa bermudagrass during the drydown cycle of Experiment II. Moisture was measured at 5.1, 10.2, 38.1 and 71.2 cm depths.

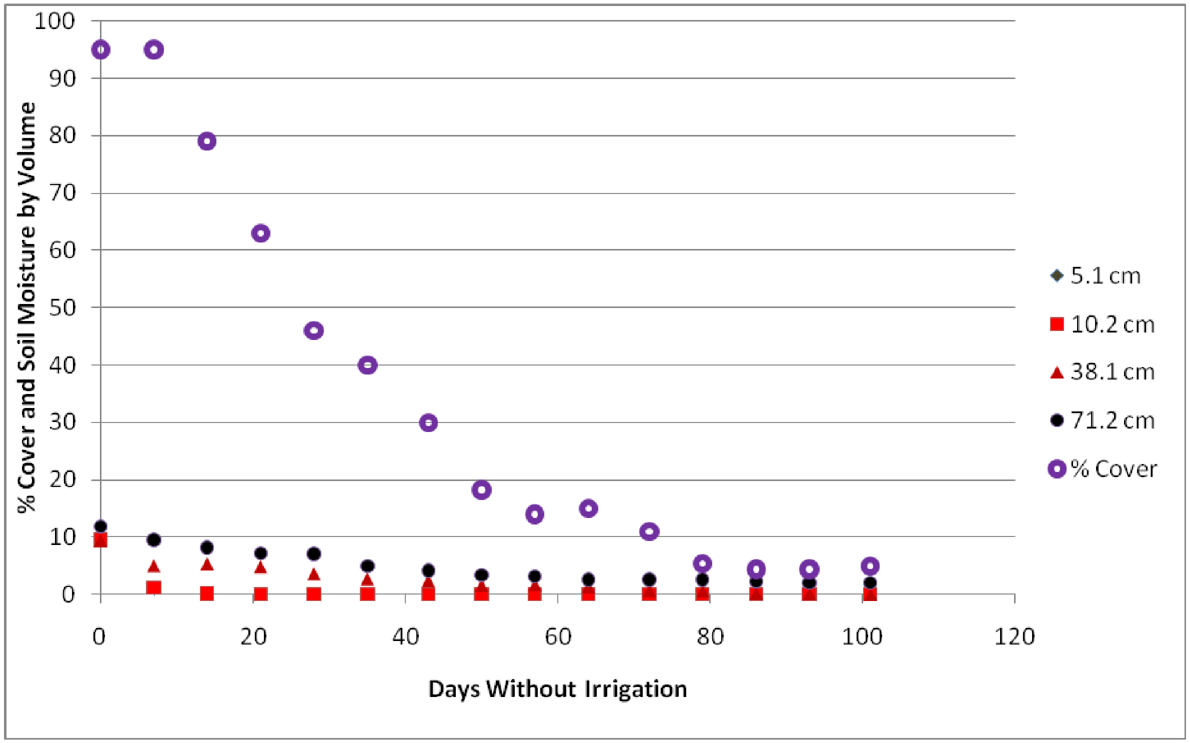

Figure 11. Mean percent living cover of Contessa bermudagrass and percent volumetric soil moisture during the drydown cycle of Experiment II. Moisture was measured at 5.1, 10.2, 38.1 and 71.2 cm depths.

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VITA

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Scope and Method of Study: Twenty cultivars were evaluated for visual quality, leaf firing resistance and percent live green cover during exposure to soil moisture deficit as well as during a recovery period. The experiment was replicated three times. Celebration and Premier were selected as standards of comparison in this research. Visual quality (TQ) as well as leaf firing (LF) were evaluated using a 1-9 scale where 9 = excellent quality and no leaf firing. Green cover (LC) was visually estimated from 0 to 100 % where 100 = the entire surface canopy is green. In Experiment II and III percent volumetric soil moisture content was measured at an average 5, 10, 38 and 71 cm depths using a time domain reflectometry (TDR) probe. Air temperature was measured at the turfgrass canopy level, 30.5 cm above and at 10.2 cm below the wooden deck level outside of the growth tubes. Relative humidity was measured at 30.5 cm above the canopy with an electrical resistance type sensor. Photosynthetically Active Radiation (PAR) and incoming solar radiation were measured by silicon diode type sensors at the surface of the canopy.

Findings and Conclusions: The visual parameters: TQ, LF and LC were strongly positively correlated in all experiments during drydown and recovery cycles. Drought resistance as measured by LC varied greatly among the twenty bermudagrasses in each experiment. In general, Celebration showed the highest resistance to drought by resisting LF and loss of LC during drydown and recovering faster after the drought. Premier showed lower drought resistance as indicated by more rapid LF and earlier loss of LC. TifGrand performed nearly as well as Celebration in drought while Latitude 36 had LF and LC performance similar to Premier. Generally, Celebration, TifGrand and other cultivars with higher drought resistance had improved moisture extraction capacity at deeper soil depths. Cultivars with earlier LF and loss of LC had higher levels of moisture remaining deep in the soil profile during the drought. TifGrand may serve as a bermudagrass having improved drought tolerance if additional standards are needed in future drought studies.

ADVISER’S APPROVAL: Dr. Dennis L. Martin