TESTING OF CLONAL BERMUDAGRASS CULTIVARS AND EXPERIMENTAL GENOTYPES FOR DIFFERENCES IN DROUGHT PERFORMANCE

By

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CHAPTER I

INTRODUCTION

Bermudagrass [*Cynodon dactylon* (L.) Pers.] is used in many parts of the world as a forage crop and as turfgrass on sports fields, golf courses and lawns. Bermudagrass is a warm season perennial grass species best adapted to tropical and subtropical climates with high temperatures, mild winters and high rainfall (Taliaferro et al., 2004b). It was introduced to the United States from Africa by 1751 A. D. (Hanson, 1972). Bermudagrass is native to Africa and Southeast Asia and is currently found all over the world (Harlan and de Wet, 1969; de Wet and Harlan, 1970; de Wet and Harlan, 1971; Taliaferro et al., 2004b). Bermudagrasses are drought tolerant and are adapted to many soil conditions (McCarty and Miller, 2002) but little is known concerning bermudagrass cultivar differences in drought performance. Selection and identification of drought resistant bermudagrass cultivars under acute or chronic drought stress is important for sustainable turfgrass management and water conservation.

Warm-season grasses are often referred to as C-4 grasses, due to their photosynthetic pathway termed the photosynthetic dicarboxylic acid cycle which results in production of a four carbon (C) anion called oxaloacetate (Hull, 1992). In general, C-4 grasses are efficient users of water, especially compared to cool-season or C-3 grasses (Hull, 1992). Bermudagrass is a C-4 grass and is a proficient water user (Feldhake et al., 1983). Evaporation refers to the process where liquid water is converted to water vapor and is thus lost from the evaporative surface, such as soil or vegetation. Transpiration refers to the process where water in plant tissue is converted to water vapor and is thus lost from a plant to the atmosphere primarily through leaf stomata. Evapotranspiration (ET) refers to the sum of water losses through evaporation from the soil and vegetation and plant water loss through transpiration (Allen et al., 1998). The ET rate is plant and site specific and depends on the specific micro-climate of a given area or region. Nitrogen (N) rate, mowing height and solar energy affects the site specific ET rates of turf. The ET rate also varies by season and by year. Irrigation to replace the calculated ET loss of water is dependent upon the quantity of natural precipitation that normally occurs during a growing season. The irrigation requirements of turfgrasses vary by species, region, and season. For instance, in a study of the irrigation requirements of bentgrasses (*Agrostis* spp.) in New Jersey, it was reported that irrigation applied at 60-80% of actual ET was sufficient to maintain acceptable turf quality during the summer while application at 40% of actual ET was sufficient in the fall of the same year (DaCosta and Huang, 2006a).

Potential evapotranspiration (ET_p) refers to the rate of water loss from a short, uniform green crop that is completely shading the soil and with adequate soil moisture for plant growth (Allen et al., 1998). Reference evapotranspiration (ET_o) refers to the rate of water loss from a short reference crop, such as grass, with a height of 0.12 m, a fixed surface resistance of 70 sec m^{-1}, and an albedo of 0.23 (Allen et al., 1998). Reference evapotranspiration is synonymous with reference crop evapotranspiration. A crop coefficient (K_c) can be used to more closely estimate the ET rate of a given crop under normal conditions as it takes into account specific crop characteristics such as plant height and leaf area (Allen et al., 1998). Crop coefficient values vary by growth stage, season and management level (Devitt et al., 1992). Irrigation scheduling using local ET_o data and proper crop coefficients for a specific turfgrass is ideal for irrigating turfgrass areas (Carrow et al., 1995).

Fu et al. (2004) at Manhattan, KS found that minimal annual irrigation as low as 224 mm is enough to maintain acceptable turf quality in bermudagrass. September ratings had unacceptable turf quality when irrigated at 40% of ET (163 mm) in the first year of their two year study. Bermudagrasses were able to tolerate low leaf relative water content (RWC) and resistance to leaf electrolyte leakage (EL) in comparison to other grasses allowing them to maintain leaf turgor and membrane stability under acute drought stress (Fu et al, 2004). Similarly, the irrigation requirement calculated as a percentage of total pan evaporation to maintain acceptable turf quality for different turf species in Texas was: ‘Meyer’ zoysiagrass (*Zoysia japonica* Steud) (68 %), ‘Rebel II’ tall fescue [*Schedonorus phoenix* (Scop.) Holub; synonym *Festuca arundinacea* Schreb] (67%), ‘Nortam’ St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] (44 %), ‘Tifway’ hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. × Cynodon *transvalensis* Burtt. Davy] bermudagrass (35 %), and ‘Prairie’ buffalograss [*Bouteloua dactyloides* (Nutt.) J.T. Columbus; synonym *Buchloe dactyloides* (Nutt.) Englem] (26 %) (Qian and Engelke, 1999).

Golf courses in the United States occupy approximately 1,198,381 acres of irrigated turfgrass areas and use 2,312,701 acre-feet of water per year of which only 12 % is recycled water (Throssell et al., 2009). Current research in many parts of the United States has focuses on turfgrass water use and conservation. Jurisdiction in some regions of the United States has mandated improvements in water use, water quality and/or replacement of traditional turfgrass areas with other plant materials. Inclusion of drought resistant entries would be a proper approach to conserve water in the landscape while maintaining beneficial turfgrass areas. Also, the potential ban on use of potable water for irrigation of turfgrass has stimulated interest in using alternative non-potable water sources. Proper application can provide acceptable turf quality (Hayes et al., 1990a) but management problems due to total soluble salts or boron toxicity is a concern (Hayes et al., 1990b). The use of municipal effluent for irrigation can add nutrients to the soil, which in some cases may be excessive and result in unwanted environmental effects (Thomas et al., 2006). Recycled effluent water can be used for irrigation but N fertilization practices need to be adjusted to account for N in the water (Devitt et al., 2008). Grasses may tolerate poor quality irrigation water as long as evaporative demand does not become excessively high (Dean et al., 1996). In using alternative water sources for turf irrigation, a system of soil, plant, and atmospheric monitoring should be incorporated (Lockett et al., 2008).

Inclusion of drought resistant turfgrass cultivars in urban landscapes is essential to save money and conserve water resources in the United States. These potential drought resistant turfgrass cultivars can help reduce the quantity of municipally treated water used for turfgrass irrigation purposes. It could save thousands of dollars and gallons of water for other daily uses. Development of more drought resistant bermudagrasses for Oklahoma holds promise for conserving Oklahoma water resources.

Literature Review

Drought

Drought is a major limiting factor for crop production. Research evaluating crop cultivars for drought performance characteristics is a priority. Development and selection of potential drought resistant turfgrass cultivars is needed. Future turfgrass research must focus on cultivar improvements for drought resistance along with specific management factors affecting drought performance such as nutritional requirements and nutrient uptake.

Management of environmental stress such as drought in turfgrass is challenging. Drought has long been recognized as a primary constraint for turf management (Beard, 1973). Although warm-season turfgrasses are considered relatively drought resistant, the ability to withstand severe moisture stress if grown under non-irrigated conditions is desirable (McCarty and Miller, 2002). In order to sustain growth, to maintain proper shoot density and to get better turf quality, sufficient soil moisture is required (Taliaferro, 2003; Taliaferro, 1995). Moisture stress in turf is generally due to uneven and/or inadequate precipitation, rapid drainage on coarse soils and rolling topography. In plants, moisture stress inside plant tissue is the major cause for poor plant growth. Plants subjected to drought stress show leaf firing or injury to upper leaves, reduced leaf area, slow leaf development, slowed internode elongation and overall stunted growth (Taliaferro et al., 2004a).

Drought stress in plants decreases their rate of transpiration, which is co-related to reduced nutrient uptake. Drought stress also increases weed competition because some weeds exceed turfgrass plants in their ability to maintain suitable plant water potential in their tissues during drought stress. Some weeds can maintain growth and production during drought periods. Thus, selection and identification of prominent drought resistant turfgrass cultivars is a priority (Kim and Beard, 1988).

Drought and Turfgrass Research

Turfgrass and its application in American life is an age old trend. Turfgrass covers millions of hectares of home lawns, commercial landscapes, roadside vegetation, parks, athletic fields and golf courses in the United States. Rapid urbanization resulted in development of an extensive turfgrass industry. In 2002, the green industry generated revenue in the amount of $147 billion in the United States (Hall et al., 2005) with golf courses accounting for $33.2 billion in gross economic output impacts (Haydu et al., 2008).

A 2002 USDA census of agriculture showed the turfgrass sod industry generated revenue of over $1 billion dollars annually. This demonstrates the turfgrass industry generates significant economic impact as an industry, and it is generally overlooked in American agriculture. Limited knowledge about plant-water relationships and the effects of multiple environmental factors on plant growth mandates the undertaking of research in this arena. To establish an efficient and sustainable drought management system, suggested strategic research initiatives include evaluation of potential drought tolerant turfgrass entries for parameters such as tolerance to soil salinity, root tissue hydraulic conductivity, minimal irrigation requirements and improved stand survival in areas ranging from low to high ET rate.

In several parts of the United States, severe drought prevails and climatologists fear worsening condition in the future. The situation is severe in the South and Southwestern United States regions during the month of July through August each year. These regions experience drought, at times exposing large lake beds and/or shrinking reservoirs with extremely low water levels. In the future, similar drought conditions are projected to extend due to dry seasons and may be exacerbated by poorly managed water sources and increasing demand due to a growing human population. This condition will likely create severe limitations in recreational water use. Already, recycled water or grey water is being used on many golf courses and some lawns to minimize the fresh water consumption in urban areas (Sammon, 2007). The proposed research would help to alleviate these problems associated with water use for turfgrass management.

Drought and Bermudagrass Response

Drought resistance refers to the ability of a plant to avoid dehydration or tolerate dehydration in plant tissue (Levitt, 1980). Plants survive water stress with mechanisms of drought avoidance and/or drought tolerance. Typical mechanisms of drought avoidance include deep, extensive root growth. Typical mechanisms of drought tolerance include cell membrane stability and increased or decreased hormone production under drought stress. Turfgrass cultivars with shoot characteristics for efficient transpiration and extensive root systems for proper moisture absorption are considered drought resistant (Youngner, 1985).

Qian and Fry (1997) found that ‘Midlawn’ bermudagrass and ‘Prairie’ buffalograss drought symptoms were similar and performed better than ‘Meyer’ zoysiagrass. Bleaching of lower leaves and rolling of leaf blade tips were distinct indicators of decreased soil water (SWC) content. It was distinct when SWC dropped near 16%. Drought symptoms were visible in warm season grasses after 25 days of drought stress and they appeared dormant after 40-45 days, suggesting that dormancy is a drought avoidance strategy (Turner and Jones, 1980). After a two-week re-watering period following severe drought, Midlawn bermudagrass showed 14% green coverage. Overall, Midlawn bermudagrass showed rooting characteristics and an ET rate similar to ‘Prairie’ buffalograss. Midlawn bermudagrass also showed increased osmotic adjustment and survival rate after a severe drought period and performed inferior to ‘Prairie’ buffalograss but better than Meyer zoysiagrass (Qian and Fry, 1997).

Drought Avoidance and Root Systems

Extensive root systems allow turfgrasses to avoid drought, enabling them to extract water from deeper in the soil profile during severe moisture stress (Hurd, 1975). To prevent moisture stress and to get better turfgrass establishment within the upper soil profiles, periodic precipitation or irrigation is required. Under-developed root systems may limit plant growth (Madison, 1971). Boeker (1974) felt that development of bermudagrasses capable of avoiding drought through extracting water from deeper soil layers by extensive root systems would be important in the future.

In comparison to cool season grasses, warm season grasses possess better turf quality during periods of drought. Cultivar performance and their selection for factors like vertical root distribution, soil water depletion, leaf firing and turf quality is essential. In a drought study of various bermudagrass genotypes, total root mass at the depths of 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm was correlated with turf quality with coefficients of r = 0.72, 0.86, 0.80, and 0.81, respectively (Hays et al., 1991). Qian et al. (1997) reported that there was no significant difference in total root length (TRL) among bermudagrass, buffalograss and zoysiagrass. At 30-60 cm and 60-90 cm depth bermudagrass was equal to buffalograss but greater than zoysiagrass for root length density.

In areas of irregular rainfall, greater root size (diameter) and length are desirable traits for drought resistant bermudagrasses. It is important to screen genotypes for their rooting characteristics including high root/shoot ratios within controlled environment (Bonos et al., 2004). Sometimes, deficient irrigation can enhance root growth through pre-stress conditioning (Fu et al., 2007). Bermudagrasses which have a great potential for establishing a deep root systems should respond well to deficit irrigation without declining to unacceptable turf quality (Fu et al., 2007). For example, Karcher et al. (2008) selected tall fescue cultivars found to have high root/shoot ratios by Bonos et al (2004) and planted them in field trials for drought performance analysis. These selections performed well under field drought conditions and exhibited improved drought performance compared to their parental lines (Karcher et al., 2008).

Drought Stress and Recovery

Karcher et al. (2008) reported that tall fescue entries selected for high root/shoot ratios in green house condition showed improved field drought performance. Entries that had high root/shoot ratio were the first to green-up or recover upon re-watering. Nobel and Huang (1992) reported that drought stress was a prime factor for root death but the ability of entries to develop extensive, deep root systems or sustainable root plasticity helped them to survive or persist through chronic drought events and to eventually recover after sufficient moisture was present.

Achieving drought resistance in grasses through genetic manipulation requires the assessment of intra-specific variation in their ability to develop and maintain an extensive root system at deeper soil depths (Duncan, 1994). Huang et al. (1997b) reported that recovery in root dry weight upon re-watering after drought treatment was equal to well-watered control plants in 'Tif-Blair' centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.] and Adalayd (Austrila), PI 299042 (Zimbabwe), PI 509018-1 (Argentina), and AP 14 (Florida) seashore paspalum (*Paspalum vaginatum* Sw.), but not for common bermudagrass or 'Emerald' (*Zoysia japonica* x *Z. tenuifolia*) zoysiagrass. The researchers attributed the superior drought tolerance of 'Tif-Blair' centipedegrass with characteristics such as extensive root growth, root water uptake from deeper soil layers, proper root viability at dry soil surfaces, and effective root regeneration on re-watering. Therefore, selection of bermudagrass with these characteristics could improve bermudagrass drought performance under chronic drought stress conditions.

Drought Stress and Shoot Response

Turfgrass resistance to leaf firing is different than drought resistance based on ET rate (Carrow, 1995). Leaf fire measures the ability of the turfgrass to remain green as dry conditions worsen but drought resistance is a measure of survival. Identifiable shoot growth responses to drought include reduced clipping production, wilting, leaf firing and increases in canopy temperature. Turfgrass wilting and leaf firing were direct indicators of drought severity (Carrow, 1996). Leaf canopy temperature and normalized difference vegetative index (NDVI) may also be useful tools for identifying turfgrass shoot responses to drought and potentially for prescribing irrigation need in turfgrasses (Carrow, 1993; Jiang et al., 2009).

Huang et al., (1997a) reported that the greatest variation in shoot growth was due to turfgrass genotype. At 20 cm soil surface drying, there were significant differences in soil-moisture interaction and reduced shoot dry matter production in common bermudagrass. There was a strong correlation between species performance and soil moisture for shoot growth. At 40 cm soil drying, the differences in drought resistant between bermudagrass and ‘Emerald’ zoysiagrass were indicated by reduced chlorophyll content and increased canopy temperature (Huang et al., 1997a). The water use rate of a species or cultivar may not be a major factor for consideration of drought tolerance potential. Cultivar or species selection for leaf firing and wilting is an important factor. In that case, days to unacceptable leaf firing or wilting for a given turfgrass selection should be considered (Ebdon and Kopp, 2004).

Turfgrass Species Performance Rankings Under Drought Stress

Baldwin et al. (2006) conducted a greenhouse study that included six bermudagrass entries ‘SWI-1012’, ‘Arizona Common’, ‘Tift No.3’, ‘Tifsport’, ‘Aussie Green’ and ‘Celebration’ with four irrigation treatments. They found that ‘Aussie Green’ and ‘Celebration’ produced the highest turf quality ratings in the well-watered control treatment. ‘Aussie Green’ and ‘Celebration’ produced higher turf quality ratings compared to ‘Arizona Common’ and ‘Tift No. 3’ after four weeks of successive water stress with a five day irrigation interval. ‘Celebration’ also produced 114% and 97% greater root weight than ‘Tifsport’ and ‘Aussie Green’. Among all treatments, drought tolerance was highest in ‘Celebration followed by ‘SWI-1012’, ‘Aussie Green’, ‘Tifsport’ and ‘Tift No. 3’.

Garrot and Mancino (1994) suggested that bermudagrass as a fairway in an arid environment can be maintained at an annual rainfall of 834-930 mm while maintaining acceptable turf quality, stand density and color. Carrow (1996) reported drought resistance performance rankings of turfgrass for wilting and leaf firing in the order of common bermudagrass = ‘Tifway’ bermudagrass > ‘Raleigh’ St. Augustinegrass =

common centipedegrass > ‘Rebel II’ tall fescue > ‘Kentucky 31’ tall fescue > ‘Meyer’ zoysiagrass, indicating the ability of some common and hybrid bermudagrass to resist wilt and maintain color under dry conditions.

Huang et al. (1997a) studied the drought resistance of turf entries on soil drying at depths of 0-20 cm and 0-40 cm for parameters including canopy temperature, leaf chlorophyll content, relative water content, and shoot dry matter production. The entries ranked in order: Seashore paspalum (PI 509018) = ‘Tif-Blair’ centipedegrass > common bermudagrass = ‘Emerald’ zoysiagrass. During severe drought conditions, 30 days without water, turf canopy temperatures were more than 40° F higher than air temperatures (Steinke et al., 2009). Bermudagrass showed less leaf firing than St. Augustinegrass or zoysiagrass under drought stress (Steinke et al., 2009). Up to 60 % ET_o deficit irrigation may be practiced at certain locations without detrimental effects on turf quality (DaCosta and Huang, 2006a; DaCosta and Huang, 2006b). Common and hybrid bermudagrass demonstrated more drought tolerance than zoysiagrass (Beard and Sifers, 1997). Differences between bermudagrass and zoysiagrass drought response were attributed to differences in root system and ET rate (Beard and Sifers, 1997).

Goals and Objectives

The goals of this research were to test and select more drought resistant cultivars of bermudagrass for turfgrass use in Oklahoma. The objectives of this research were to:

1. Evaluate and explain differences in overall field drought performance of selected industry standard and OSU experimental bermudagrass entries.
2. Evaluate and explain differences in root growth characteristics of selected industry standard and OSU experimental bermudagrass entries.

Research hypotheses:

Hypothesis I: There is no significant difference in vegetative bermudagrass entries for their field drought performance.

Hypothesis II: There is no significant difference in vegetative bermudagrass entries for root growth characteristics.

Literature Cited

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration – guidelines for computing crop water requirements – FAO irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations. Rome, Italy.

Baldwin, C.M., H. Liu, L.B. McCarty, W.L. Bauerle, and J.E. Toler. 2006. Response of six bermudagrass entries to different irrigation intervals. HortTechnology 16(3):466-470.

Beard, J.B. 1973. Turfgrass science and culture. Prentice Hall, Englewood Cliffs, NJ.

Beard, J.B. and S.I. Sifers. 1997. Genetic diversity in dehydration avoidance and drought resistance within the *Cynodon* and *Zoysia* species. Int. Turfgrass Soc. Res. J. 8:603-610.

Boeker, P. 1974. Root development of selected turfgrass species and entries. P 55-61. *In* E.C. Roberts (ed.) Proc. 2nd Int. Turfgrass Res. Conf. ASA and CSSA, Madison, WI.

Bonos, S. A., D. Rush, K. Hingnight, and W.A. Meyer. 2004. Selection for deep root production in tall fescue and perennial ryegrass. Crop Sci. 44:1770-1775.

Carrow, R.N. 1995. Drought resistant aspect of turfgrasses in the southeast: Evapotranspiration and crop coefficients. Crop Sci. 35:1685-1690.

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

Carrow, R.N. 1993. Canopy temperature irrigation scheduling indices for turfgrasses in humid climates. Int. Turfgrass Soc. Res. J. 7:594-599.

Dacosta, M. and B. Huang. 2006a. Deficit irrigation on water use characteristics of bentgrass species. Crop Sci. 46:1779-1786.

DaCosta, M. and B. Huang. 2006b. Minimum water requirements for creeping, colonial, and velvet bentgrass under fairway conditions. Crop Sci. 46:81-89.

de Wet, J. M. J. and J. R. Harlan. 1970. Biosynthesis of *Cynodon dactylon* in relation to ecological condition. Taxon 19:565-569.

de Wet, J.M.J. and J.R. Harlan. 1971. South African species of *Cynodon* (Gramineae). J. S. Afr. Bot. 37:53-56.

Dean, D.E., D.A. Devitt, L.S. Verchick, and R.L. Morris. 1996. Turfgrass quality, growth, and water use influenced by salinity and water stress. Agron J. 88:844-849.

Devitt, D.A., L. Wright, D.C. Bowman, R.L. Morris, and M. Lockett. 2008. Nitrate-N concentration in the soil solution below reuse irrigated golf course fairways. HortScience 43(7):2196-2202.

Devitt, D.A., L. Wright, R.L. Morris, and D.C. Bowman. 1992. Evapotranspiration, crop coefficient, and leaching fractions of irrigated desert turfgrass systems. Agron. J. 84:717-723.

Duncan, R.R. 1994. Seashore paspalum may be grass for the year 2000. Southern Turf Mgmt. 5:31-32.

Ebdon, J.S. and K.L. Kopp. 2004. Relationships between water use efficiency, carbon isotope discrimination, and turf performance in genotypes of Kentucky bluegrass during drought. Crop Sci. 44:1754-1762.

Fu, J., J. Fry, and B. Huang. 2004. Minimum water requirements of four turfgrasses in the transition zone. HortScience 39 (7):1740-1744.

Fu, J., J. Fry., and B. Huang. 2007. Tall fescue rooting as affected by deficit irrigation. HortScience 42(3): 688-691.

Feldhake, C.M., R.E. Danielson, and J.D. Butler. 1983. Turfgrass evapotranspiration. I. Factors influencing rate in urban environments. Agron. J. 75: 824-830.

Garrot, D.J., and C.F. Mancino. 1994. Consumptive water use of three intensively managed bermudagrass growing under arid conditions. Crop Sci. 34:215-221.

Hall, C. R., A.W. Hodges, and J.J. Haydu. 2005. Economic impact of the green industry in the United States. Available at www.hbin.tamu.edu/greenimpact.html. Verified 2/13/2009.

Hanson, A.A. 1972. Breeding of grasses. p. 36-52. *In* V.B. Youngner and C.M. McKell (ed.). The biology and utilization of grasses. Academic Press, New York.

Harlan, J.R., and J.M.J. de Wet. 1969. Sources of variation in *Cynodon dactylon* (L.) Pers. Crop Sci. 9:774-778.

Haydu, J.J., A.W. Hodges, and C.R. Hall. 2008. Estimating the economic impact of the U.S. golf course industry: challenges and solutions. HortScience 43(3):759-763.

Hayes, A.R., C.F. Mancino, W.Y. Forden, D.M. Kopec, and I.L Pepper. 1990a. Irrigation of turfgrass with secondary sewage effluent: II. Turf quality. Agron. J. 82:943-946.

Hayes, A.R., C.F. Mancino, and I.L. Pepper. 1990b. Irrigation of turfgrass with secondary sewage effluent: I. Soil and leachate water quality. Agron. J. 82:939-943.

Hays, K.L., J.F. Barber, M.P. Kenna, and T.G. McCollum. 1991. Drought avoicence mechanism of selected bermudagrass genotype. HortScience 26 (2):180-182.

Huang, B., R.R. Duncan, and R.N. Carrow. 1997a. Drought resistant mechanism of seven warm season turfgrasses under surface soil drying: Shoot response. Crop Sci. 37:1858-1863.

Huang, B., R.R. Duncan, and R.N. Carrow. 1997b. Drought resistant mechanism of seven warm season turfgrasses under surface soil drying: Root aspect. Crop Sci. 37:1863-1869.

Huang, B., and J.D. Fry. 1998. Root anatomical, physiological, and morphological response to drought stress for tall fescue entries. Crop Sci. 38:1017-1022.

Hull, R.J. 1992. Energy relations and carbohydrate partitioning in turfgrass. *In* D.V. Waddington et al. (ed.) Turfgrass. Agron. Monogr. 32. ASA, CSSA, and SSSA, Madison, WI.

Hurd, E. A. 1975. Phenotype and drought tolerance in wheat. P 39-55. *In* J.F. stone (ed.) Plant modification for more efficient water use. Elsevier Sci. Publ. Co., Amsterdam.

Jiang, Y. and B. Huang. 2000. Effects of drought or heat stress alone and in combination on Kentucky bluegrass. Crop Sci. 40:1358-1362.

Jiang, Y., H. Liu., and V. Cline. 2009. Correlations of leaf relative water content and spectral reflectance in perennial ryegrass under water deficient conditions. HortScience. 44(2):459-462.

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

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

Levitt, J. 1980. Response of plants to environmental stress. 2nd ed., Vol 2. Academic Press, New York.

Lockett, A.M., D.A. Devitt, and R.L. Morris. 2008. Impact of reuse water on golf course soil and turfgrass parameters monitored over a 4.5 year period. HortScience 43(7):2210-2218.

Madison, J.J. 1971. Principles of turfgrass culture. Van Nostrand Reinhold Co., New York, NY.

McCarty, L.B. and G. Miller. 2002. Managing bermudagrass turf: Selection, construction, cultural practices and pest management strategies. Sleeping Bear Press, Chelsea, Mich.

Nobel, P.S. and B. Huang. 1992. Hydraulic and structural changes for lateral roots of two desert succulent in response to soil drying and rewetting. Int. J. Plant. Sci. 153:163-170.

Qian, Y. and J.D. Fry. 1997. Water relations and drought tolerance of four turfgrasses. J. Amer. Soc. HortScience 122(1):129-133.

Qian, Y. L., J.D. Fry, and W.S. Upham. 1997. Rooting and drought avoidance of warm-season turfgrasses and tall fescue in Kansas. Crop Sci. 37:905-910.

Qian, Y.L. and M.C. Engelke. 1999. Performance of five turfgrasses under linear gradient irrigation. HortScience 34(5):893-896.

Sammon, R. 2007. Water scarcity will change how we live and work. *In* The Kiplinger Letter. Available at www.kiplinger.com. Verified online Feb. 13, 2009.

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

Taliaferro, C.M. 1995. Diversity and vulnerability of bermudagrass as a turfgrass species. Crop Sci. 35:327-332.

Taliaferro, C.M. 2003. Bermudagrass (*Cynodon* (L.) Rich). P. 235-256. *In* M.D. Casler and R. Duncan (ed.) Turfgrass Biology, genetics and breeding. Sleeping Bear Press. Chelsea, MI.

Taliaferro, C.M., D.L Martin, J.A. Anderson, M.P. Anderson, and A.C. Guenzi. 2004a. Broadening the horizons of turf bermudagrass. USGA Turfgrass and Environmental Research Online 3(20):1-9.

Taliaferro, C.M., F.M. Rouquette, Jr., and P. Mislevy. 2004b. Bermudagrass and stargrass. *In* L.E. Moser et al. (ed.) Warm-season (C4) grasses. Agron. Monogr. 45. ASA, CSSA, and SSSA, Madison, WI.

Throsell, C.S., G.T. Lyman, M.E. Johnson. 2009. Golf course environmental profile measures water use, source, cost, quality, and management and conservation strategies. Online. App. Turfgrass Sci. doi: 10.1094/ ATS-2009-0129-01-RS.

Thomas, J.C., R.H. White, J. T. Vorheis, H.G. Harris, and K. Diehl. 2006. Environmental impact of irrigating turf with type I recycled water. Agron. J. 98:951-961.

Turner, N.C., and M.M. Jones. 1980. Turgor maintenance by osmotic adjustment: A review and evaluation, p. 87-103. *In* N.C. Turner and P.J. Kramer (ed.). Adapatation of plants to water and high temperature stress. Wiley- InterScience, New York.

USDA. 2002. United States Departments of Commerce and Agriculture, Census of agriculture. Washington, D.C.

Youngner, V. B. 1985. Physiology of water use and water stress, p. 37-43. *In* V.A. Gibeault and S.T. Cocker ham (ed.) Turfgrass water conservation. Univ. of Calif., Riverside, Coop. Ext. Publ. 21405.

CHAPTER II

Drought Performance of Clonal Bermudagrass Cultivars and Experimental Selections in the Transition Zone

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Abstract. Bermudagrass is used in many parts of the world as a forage crop and a turfgrass in sports fields, golf courses and lawns. Selection and identification of drought resistant bermudagrass cultivars under acute or chronic drought stress is important for sustainable turfgrass management and water conservation. The objective of this research was to identify differences in overall field drought performance of selected industry standard and OSU experimental bermudagrass entries. This research was conducted at the Oklahoma State University (OSU) Turfgrass Research Center in Stillwater, OK. Twenty-three clonal standard cultivars and experimental genotypes were used for this study including: Celebration, Premier, Tifway, Tifsport, SIU U-3 (Southern Illinois University source), TGS U-3 (Tulsa Grass and Sod farm source), NC U-3 (Northcutt sod farm source), Patriot and OSU experimental OKC 70-18, OKC 1119, OKC 1134, #2, #4, #12, #16, #17, #18, #20, #22, #24, #25, #26, and #27. The experimental design was a strip-plot with four replications, 23 bermudagrass entries and four irrigation treatments. The irrigation treatments were applied to the vertical strips in a reverse linear gradient design while the bermudagrass entries were randomly applied to the horizontal strips. Four levels of irrigation were used according to reference evapotranspiration (ET_o) where: 0% ET_o, 33% ET_o, 66% ET_o, 100% ET_o, control treatment. A consecutive 28 days of drought stress was applied, and 60 days of recovery period was observed upon re-watering. Leaf firing is a prominent visual rating for bermudagrass drought response and was measured

using 1-9 scale where: 1 = total or complete leaf firing and 9 = no leaf firing. In addition, turf quality was assessed using a 1-9 scale where: 1 = completely brown, dormant, or dead grass, 6 = acceptable visual turf quality, and 9 = excellent turf quality. Leaf firing and turf quality ratings were collected once per week throughout the study period. Turfgrass color was measured using FieldScout CM1000 NDVI (normalized difference vegetative index) meter (Spectrum Technologies, Plainfield, IL). All statistical analysis was completed at a P=0.05 significance level. Based on the overall results from this study, the hypothesis that there were no differences in vegetative bermudagrass entries for their field drought performance was rejected. At the 0% ET_o irrigation level, the OSU experimental bermudagrasses that performed lower than Celebration but better than all other entries for leaf firing, turf quality, % living cover, turf quality recovery, and NDVI were #2, #12, #16, #24, and #27. At the 33% ET_o irrigation level, Celebration, #2, #12, and #27 performed better for leaf firing, turf quality, % living cover, turf quality recovery, and NDVI than all other bermudagrass entries. Future work should assess the drought tolerance and/or drought avoidance mechanisms of these entries.

Bermudagrass is used in many parts of the world as a forage crop and as turfgrass in sports fields, golf courses and lawns. Bermudagrass is a warm-season perennial grass species best adapted to tropical and subtropical climates with high temperatures, mild winters and high rainfall (Taliaferro et al., 2004b). Bermudagrass is native to Africa and Southeast Asia and is currently found all over the world (Harlan and de Wet, 1969; de Wet and Harlan, 1970; de Wet and Harlan, 1971; Taliaferro et al., 2004b). Selection and identification of drought resistant bermudagrass cultivars under acute or chronic drought stress is important for sustainable turfgrass management and water conservation.

Evaporation refers to the process where liquid water is converted to water vapor and is thus removed from the evaporative surface, such as soil or vegetation. Transpiration refers to the process where water in plant tissue is converted to water vapor and is thus removed from a plant to the atmosphere primarily through leaf stomata. Evapotranspiration (ET) refers to the sum of water losses through evaporation in soil and vegetation and plant water loss through transpiration (Allen et al., 1998). The ET rate is site specific and depends on the specific micro-climate of a given area or region. Nitrogen (N) rate, mowing height and solar energy affects site specific ET rates. The ET rate varies by season and by year. Irrigation replacement of the ET loss of water may be adjusted depending on the quantity of natural precipitation during the growing season. The irrigation requirements of turfgrasses vary by species, region, and season. For instance, in a study of the irrigation requirements of bentgrasses (*Agrostis* spp.) in New Jersey, it was reported that 60-80% of actual ET was sufficient to maintain acceptable turf quality during the summer while 40% of actual ET was sufficient in the fall of the same year (DaCosta and Huang, 2006a).

Potential evapotranspiration (ET_p) refers to the rate of water loss from a short, uniform green crop that is completely shading the soil and with adequate soil moisture for plant growth (Allen et al., 1998). Reference evapotranspiration (ET_o) refers to the rate of water loss from a short reference crop, such as grass, with a height of 0.12 m, a fixed surface resistance of 70 sec m^{-1}, and an albedo of 0.23 (Allen et al., 1998). Reference evapotranspiration is synonymous with reference crop evapotranspiration. A crop coefficient (K_c) can be used to more closely estimate the ET rate of a given crop under normal conditions as it takes into account specific crop characteristics such as plant height and leaf area (Allen et al., 1998). Crop coefficient values vary by growth stage, season and management level (Devitt et al., 1992). Irrigation scheduling using local ET_o data for turfgrass is ideal for irrigating turfgrass areas (Carrow et al., 1995).

Fu et al. (2004) at Manhattan, KS found that minimal annual irrigation as low as 224 mm is enough to maintain acceptable turf quality in bermudagrass. September ratings had unacceptable turf quality when irrigated at 40% of ET (163 mm) in the first year of their two year study. Bermudagrasses were able to tolerate low leaf relative water content (RWC) and resistance to leaf electrolyte leakage (EL) in comparison to other grasses allowing them to maintain leaf turgor and membrane stability under acute drought stress (Fu et al, 2004). Similarly, the irrigation requirement calculated as a percentage of total pan evaporation to maintain acceptable turf quality for different turf species in Texas was: ‘Meyer’ zoysiagrass (*Zoysia japonica* Steud) (68 %), ‘Rebel II’ tall fescue [*Schedonorus phoenix* (Scop.) Holub; synonym *Festuca arundinacea* Schreb] (67%), ‘Nortam’ St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] (44 %), ‘Tifway’ hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. × Cynodon *transvalensis*

Burtt. Davy] bermudagrass (35 %), and ‘Prairie’ buffalograss [*Bouteloua dactyloides* (Nutt.) J.T. Columbus; synonym *Buchloe dactyloides* (Nutt.) Englem] (26 %) (Qian and Engelke, 1999).

Baldwin et al. (2006) conducted a greenhouse study for six bermudagrass entries ‘SWI-1012’, ‘Arizona Common’, ‘Tift No.3’, ‘Tifsport’, ‘Aussie Green’ and ‘Celebration’ with four irrigation treatments including well-watered control, and treatments irrigated every 5, 10, or 15 days. They found that ‘Aussie Green’ and ‘Celebration’ produced the highest turf quality ratings in the well-watered control treatment. ‘Aussie Green’ and ‘Celebration’ produced the highest turf quality ratings compared to ‘Arizona Common’ and ‘Tift No. 3’ after four weeks of successive water stress with a five day irrigation interval. ‘Celebration’ also produced 114% and 97% greater root weight than ‘Tifsport’ and ‘Aussie Green’. Among all treatments, drought tolerance was higher in ‘Celebration’ followed by ‘SWI-1012’, ‘Aussie Green’, ‘Tifsport’ and ‘Tift No. 3’.

Huang et al. (1997a) studied drought resistance performances of turf entries on soil drying at 0-20 cm and 0-40 cm depths for parameters including canopy temperature, leaf chlorophyll content, relative water content, and shoot dry matter production. The entries ranked in order: Seashore paspalum (PI 509018) = ‘Tif-Blair’ centipedegrass > common bermudagrass = ‘Emerald’ zoysiagrass. Carrow (1996) reported that a drought resistance performance ranking of turfgrass for wilting and leaf firing was in the order: common bermudagrass = ‘Tifway’ bermudagrass > ‘Raleigh’ St. Augustinegrass = common centipedegrass > ‘Rebel II’ tall fescue > ‘Kentucky 31’ tall fescue > ‘Meyer’ zoysiagrass. Similarly, bermudagrass showed less leaf firing than St. Augustinegrass or zoysiagrass under drought stress (Steinke et al., 2009).

Up to 60% ET_o deficit irrigation may be practiced at certain locations without detrimental effects on turf quality (DaCosta and Huang, 2006a; DaCosta and Huang, 2006b). Common and hybrid bermudagrass demonstrated more drought tolerance than zoysiagrass (Beard and Sifers, 1997). Differences between bermudagrass and zoysiagrass drought response were attributed to differences in root system and ET rate (Beard and Sifers, 1997).

Bermudagrasses are drought tolerant and are adapted to many soil conditions (McCarty and Miller, 2002) but little is known concerning bermudagrass cultivar differences in drought performance. There is a great extent of genetic diversity in bermudagrass germplasm (Taliaferro et al., 2004a). The Oklahoma State University (OSU) holds numerous accessions from across the world including much germplasm from China which could contribute to the development and release of bermudagrass cultivars with improved drought tolerance (Wu et al., 2009).

The objective of this research was to identify differences in overall field drought performance of selected industry standard and OSU experimental bermudagrass entries. It was hypothesized that there would be differences in vegetative bermudagrass entries for their field drought performance.

Materials and Methods

This research was conducted at the Oklahoma State University (OSU) Turfgrass Research Center in Stillwater, OK. The former crop at the site was ‘L-93’ creeping bentgrass. The ‘L-93’ was removed with a sod cutter in Feb. 2009 and topsoil was uniformly added and mixed into the existing sand based root zone. After mixing, composite soil samples were collected and analyzed for soil texture using the hydrometer method (Gee and Or, 2002). The final soil texture analysis was 80% sand, 18% clay, and 2% silt and was classified as a sandy loam. An automatic irrigation system was used to irrigate bermudagrass entries during the establishment period. The site was constructed with a 1% slope for proper drainage of the plot area. Prior to planting, steel landscape edging (31 cm height) was installed as a plot border to deter irrigation water from entering into adjacent plot areas. The bottom 26 cm of the steel edging was buried below ground and the remaining 5 cm of the steel edging remained above ground. Twenty-three vegetative standard cultivars and experimental genotypes were selected for this study (Table 1). Uniform sod pieces of each entry were collected from the OSU Turfgrass Research Center field plots from prior research studies (Han, 2009).

The sod was transferred and planted in pots in the greenhouse in Feb. 2009. Sod plugs were clonally propagated in greenhouse trays from Feb. 2009 until June 2009. Following greenhouse propagation, the entries were planted at the field research site on 16 June 2009. During establishment, 49 kg N ha^{-1} was applied to the plot area. Phosphorus tested adequate for turfgrass growth and K was applied at 24 kg K_2O ha^{-1}, both according to soil fertility test recommendations. The recommendation was according to buffer index for soil test N index (23), soil test P index (126), and soil test K index

(250). After establishment, 49 kg N ha^{-1} mo^{-1} was applied to the plot area for proper N fertility maintenance (Qian et al., 1997). Plots were mowed with a rotary mower at 5.1 cm height of during establishment and were incrementally mowed lower to a 1.9 cm height of cut with a walk-behind reel mower as the bermudagrass plots matured. Weeds were removed from the plot area by hand and integrated pest management principles (Giles and Walker, 2009) were followed concerning insect and disease scouting and management. No detrimental incidence of insect or disease damage was present in the plot area during the study period. No pesticide were applied.

Reference evapotranspiration data was calculated according to the Penman-Monteith method (Allen et al., 1998) and was retrieved from an Oklahoma Mesonet System (Oklahoma Mesonet) weather station located 0.4 km east of the research site. Plots were irrigated three times per day to 100% ET_o during plot establishment. As the bermudagrass plots matured, plot irrigation was incrementally reduced over time to every other day irrigation events according to the cumulative ET_o two days prior to the day of irrigation. Cumulative ET_o measured two days prior to irrigation.

A field-based raincover (Covermaster, Rexdale, ON, Canada) was used during the treatment period to keep natural precipitation off of the plot area thus replicating drought conditions. The raincover was 694 m^2 and covered the entire research plot area. The raincover was a moveable tarp similar to what is used to cover sports fields during rainy periods. The raincover was stored at the south perimeter of the research plot area with the edges fixed to the ground with tent spikes. The raincover could be deployed by hand and the plot area could be completely protected from precipitation in approximately 15 minutes. The field raincover was only used to avoid precipitation from entering the plot area and the plots were left uncovered during all other periods, resembling natural field conditions. No natural rainfall occurred on uncovered plots during the study.

The experimental field design was a strip-plot with four replications, 23 bermudagrass entries and four irrigation treatments. Four levels of irrigation were used according to ET_o at: 0% ET_o, 33% ET_o, 66% ET_o, and 100% ET_o. Bermudagrass entries were randomly assigned to horizontal strips while irrigation treatments were assigned to vertical strips in a reverse linear gradient design (Hoshmand, 2006). A consecutive 28 days of irrigation treatments was applied, and a 60 day recovery period was applied by re-watering plots with sprinkler irrigation according to the 100% ET_o treatment.

The irrigation treatments were applied by hand at replacement rate according to the respective irrigation treatment. For the total of all plots under each irrigation treatment (29.9 m^2), it was calculated that for every 1 cm of irrigation needed according to ET_o, 298 L of irrigation needed to be evenly applied over the total of all replicates under that irrigation treatment. A water meter was attached to an irrigation hose to monitor the amount of water applied over time. The flow rate was 37.9 L of water per minute and each irrigation treatment was applied thoroughly with hand held hose to get a uniform and even distribution of water within the particular irrigation treatment strip. For example, if the ET_o for two consecutive days prior to application of the irrigation treatment was 1 cm then: for the 100% of ET_o 298 L of water was applied, for the 66% ET_o 196.7 L of water was applied, for the 33% ET_o treatment 98.3 L of irrigation was applied and for the 0% ET_o treatment no irrigation was applied.

Both subjective and objective data was collected to evaluate the bermudagrass entries. Leaf firing is a prominent visual rating for bermudagrass drought response and was measured using 1-9 scale where: 1 = total or complete leaf firing and 9 = no leaf firing. In addition, turf quality was assessed using a 1-9 scale where: 1 = completely brown, dormant, or dead grass, 6 = acceptable visual turf quality, and 9 = excellent turf quality. Turfgrass color was measured using a FieldScout CM1000 NDVI (normalized difference vegetative index) meter (Spectrum Technologies, Plainfield, IL). The NDVI value determined by the meter provides an indication of turfgrass reflectance that measures the relative greenness of the turfgrass plot area. Leaf firing, turf quality, and NDVI were collected once per week throughout the study period. Soil volumetric water content was measured in each plot using a Stevens POGO portable soil sensor (Stevens, Portland, OR). Soil volumetric water content readings were recorded for each individual plot once per week throughout the study period. Percent living cover on visual basis was rated at eight weeks after re-watering all plots according to the 100% ET treatment.

All statistical analyses were completed at the P=0.05 significance level. Analysis of variance (ANOVA) statistical procedures were completed using SAS software (SAS Institute Inc., Cary, NC) to test the effects of rating date, irrigation treatment, bermudagrass entry, and any interactions (Table 2). For turf quality and NDVI there was significant rating date x bermudagrass entry x irrigation treatment interaction (Table 2). Therefore, turf quality and NDVI were analyzed and reported by weekly rating dates. For leaf firing there was no significant rating date x bermudagrass entry x irrigation treatment interaction, and data for leaf firing was averaged across all rating dates (Table 2). For turf quality and NDVI, mean separation test among bermudagrasses within an irrigation treatment on a given sampling date were performed using Duncan's multiple range test at *P*=0.05 significance level while mean separation for leaf firing was completed by pooling data across all weekly rating dates. Simple linear regression was used to determine the relationship of leaf firing with turf quality, NDVI and soil volumetric water content (Hoshmand, 2006).

Results

Turf quality (TQ)

One week following treatment initiation

Before drought was imposed, all treatments had a visual TQ rating ≥ 6, which was considered the minimum acceptable TQ rating (Table 3). After irrigation treatments were imposed for one week at the 0% ET_o level, Celebration had the same TQ as four entries (SIU U-3, OKC 1119, #18, and #20) with average TQ ratings ranging from 8.0 to 7.0 (Table 4). Celebration had a TQ rating of 8 which was higher than 18 bermudagrass entries (Table 4). For the 33% ET_o irrigation treatment, Tifsport had a mean TQ rating of 6.2 and was lower than 14 of 23 bermudagrass entries. In the 66% ET_o irrigation treatment, Tifsport and NC U-3 had mean TQ ratings of 7.3 and 7.2, respectively which were lower than 16 of 23 bermudagrass entries. For the 100% ET_o irrigation treatment, there was no turf quality difference among all bermudagrass entries with average TQ of 7.9. Regardless of irrigation treatment, no bermudagrass entry had a TQ rating below 6 after one week of drought (Table 4).

Two weeks following treatment initiation

Results for TQ after two weeks of drought showed differences among bermudagrass entries (Table 5). For 0% ET_o, the TQ rating was less than 6 for all bermudagrass entries. Celebration had the best TQ rating of 5.5 which was no different from OKC 1134, #2, #12, #16, #24, and #27 but was higher than the other 16 bermudagrass entries. The bermudagrass entries Patriot, Premier, NC U-3, TGS U-3, SIU U-3, #17, #18, #20, and #25 were most affected by the 0% ET_o irrigation treatment with mean TQ ratings≤ 3. All were rated lower than Celebration, OKC 1134, #2 , #12, and #27. In the 33% ET_o irrigation treatment, the impact of drought was not as prominent. All bermudagrass entries had an acceptable mean TQ rating with the exception of #17 which had a mean TQ rating of 5.7. Bermudagrass entry #17 TQ was not different than 18 of 23 bermudagrass entries but was lower than Celebration, Tifway, #26, and #27. In the 66% ET_o and 100% ET_o irrigation treatments, all bermudagrass entries had acceptable TQ ratings, mean ≥ 6.6 and 7.0, respectively.

Three weeks following treatment initiation

After three weeks of irrigation deficit, the TQ ratings were below 6 for all bermudagrass entries at 0% ET_o (Table 5). Celebration, OKC 1134, #2, #12, #16, #24, #27 TQ ratings were not different and were ranked higher than SIU U-3 and #18 (Table 6). For the 33% ET_o irrigation treatment, Celebration, Tifsport, #2, #12, and #27 had a mean TQ rating of ≥ 6 and were ranked better than #18 which had a TQ rating of 4.7 (Table 6). For the 66% ET_o irrigation treatment, Tifsport TQ was not different from Patriot and #17 and was ranked lower than 20 of 23 bermudagrass entries. However, all bermudagrass entries were ranked ≥ 6.6. Results were similar for the 100% ET_o irrigation treatment where Tifsport TQ was not different from Patriot, #17, and #4 but was ranked lower than 19 of 23 bermudagrass entries. Similarly, all bermudagrass entries were ranked ≥ 7.0 in the 100% ET_o treatment.

Four weeks following treatment initiation

During the fourth week of irrigation treatment protocol implementation, under the 0% ET_o irrigation treatment, no entries had an acceptable TQ (Table 7). Celebration, Tifway, OKC 1134, #2, #12, #16, #25, #26, and #27 TQ were not different from each other and mean TQ for each entry ranged from 4.0 to 2.5. TQ for #18 was 1.0 and was not different from Patriot, Premier, Tifsport, Tifway, NC U-3, TGS U-3, SIU U-3, OKC 1119, OKC 70-18, #4, #17, #18, #20, #22, and #25. For the 33% ET_o irrigation treatment, Celebration was the only cultivar to have acceptable mean TQ at 6.2 but was not different from Tifsport, Tifway, #2, #12, #16, #24, #26, and #27. TGS U-3, #17 and #18 had lowest TQ with a mean value of 4.0 but were not different from Patriot, Premier, NC U-3, TGS U-3, OKC 1119, OKC 1134, OKC 70-18, #4, #20, #22, and #25 (Table 7). Within the 66% ET_o irrigation treatment, Celebration had a TQ of 8.0 and which was higher than Patriot, Premier, Tifsport, OKC 1134, #17, #18, and #25. All entries had an acceptable TQ of 6 or above for 66 % irrigation treatment. For the 100% ET_o irrigation treatment, Tifsport had the lowest TQ rating of 7.0 and was not different from Patriot or #17. All bermudagrass entries had acceptable TQ ratings at the 100% ET_o irrigation level.

Recovery TQ

Entries showed differences for recovery upon re-watering (Tables 8-11). TQ during recovery improved in the 0% and 33% ET_o irrigation treatments while TQ in the 66% and 100% ET_o irrigation treatments remained acceptable. TQ in 66% and 100% had never fallen below the minimum acceptable rating of 6.0. On the first week of recovery for the 0% ET_o irrigation treatment, Celebration showed the best TQ and was not different from #2 and #24 (Table 8). Experimental bermudagrass entry #22 had the lowest TQ rating of 1.7 and was not different from Patriot, Premier, Tifway, TGS U-3, SIU U-3, OKC 1119, OKC 1134, OKC 70-18, #4, #17, #20, #25, #26, and #27. However, no bermudagrass entry TQ was rated ≥ 6. For recovery TQ within the 33% ET_o irrigation treatment, Celebration, NC U-3, #2, and #12 had TQ ratings ≥ 6 and were higher than Premier, OKC 70-18, #17, #18, #20, and #22. Premier, OKC 1119, OKC 70-18, #17, #18, #20, and #22 TQ ratings were not different and were ≤ 5.2.

On the third week of recovery for the 0% ET_o irrigation treatment, Celebration was the only cultivar to recover with a TQ rating of ≥ 6 but was not different from #2, #12, #16, #24, and #26 (Table 9). Mean TQ of SIU U-3 was 3.0 and was not different from Patriot, Premier, Tifsport, Tifway, NC U-3, TGS U-3, OKC 70-18, #4, #17, #18, #20, #22, #25, and #27. For the 33% ET_o irrigation treatment recovery TQ ratings, Celebration, Tifsport, Tifway, NC U-3, SIU U-3, OKC 1134, #2, #4, #12, #16, #24, #25, #26, and #27 were not different. Celebration, NC U-3, #2, and #12 TQ ratings were higher than OKC 70-18 at the 33% irrigation level.

During the fourth week of recovery for the 0% ET_o irrigation treatment, Celebration was the only cultivar to recover with a TQ rating of$\geq$ 6 but was no different from NC U-3, OKC 1119, OKC 1134, #2, #12, #16, #24, #25, and #26 after four weeks. There was no difference among bermudagrass entries for the 33% ET_o irrigation treatment recovery TQ ratings. Numerically, Celebration, Patriot, Tifway, NC U-3, SIU U-3, OKC 1134, #2, #4, #12, #16, #24, #26, and #27 had an acceptable TQ rating of $\geq$ 6 at the 33% irrigation level (Table 10).

After two months of recovery for the 0% ET_o irrigation treatment, Celebration, Patriot, TGS U-3, OKC 1119, OKC 1134, #2, #4, #12, #16, #17, #18, #20, #24, #25, #26, and #27 TQ ratings were not different (Table 11). Celebration and #16 had higher TQ ratings than Premier, Tifsport, Tifway, NC U-3, SIU U-3, OKC 70-18, and #22 (Table 10). For the 33% ET_o irrigation treatment recovery TQ ratings, every bermudagrass entry had a mean TQ rating of $\geq$ 6.5, with the exception of Tifsport at 5.7.

Leaf firing (LF)

<u>Data presented across all rating dates following the initiation of irrigation treatments</u>

For the 0% ET irrigation treatment, Celebration had least numeric mean leaf firing rating, performed better than 21 bermudagrass entries, but was not different from bermudagrass entry #2 (Table 12). For the 0% ET irrigation treatment, bermudagrass #18 showed the most leaf firing, showed more leaf firing than 21 bermudagrass entries, but was not different from TGS U-3 (Table 12). For the 33% ET irrigation treatment, Celebration was more leaf firing resistant than 21 bermudagrass entries but was not different from #2 (Table 12). For the 33% ET irrigation treatment, Patriot and #17 showed more leaf firing than 18 bermudagrass entries but were not different from NC U-3, TGS U-3, and #18 (Table 12). For the 66% ET irrigation treatment Celebration and #2 showed the least leaf firing, showed less leaf firing than 15 bermudagrass entries and were not different from OKC 1119, OKC 70-18, #12, #20, #24, and #26 (Table 12). For the 66% ET irrigation treatment, Patriot and Tifsport showed more leaf firing than 21 bermudagrass entries and were not different from each other (Table 12). For the 100% ET irrigation treatment, 14 bermudagrass entries were in the top statistical group while Patriot and #17 exhibited more leaf firing than all other entries (Table 12). However, for both the 66% and 100% ET irrigation treatments, leaf firing did not cause unacceptable turf quality at any rating date during this study (Tables 3 – 11).

NDVI

One week following treatment initiation

For the 0% ET_o irrigation treatment, one week following treatment initiation Celebration had a higher NDVI value than 21 bermudagrass entries but was not different from #24. Premier had a lower NDVI value than 13 bermudagrass entries and was not different from Patriot, Tifsport, NC U-3, TGS U-3, #4, #12, #17, #18, and #22 (Table 13) but no bermudagrass entry TQ was below the acceptable rating of 6.0 (Table 3). For the 33% ET_o irrigation treatment, Celebration, Premier, Tifway, NC U-3, SIU U-3, OKC 1119, OKC 1134 OKC 70-18, #2, #16, #20, #25, and #26 were not different from each other but were higher than Patriot, #12, and #27. All bermudagrass entries showed acceptable TQ at the 33% ET_o irrigation level. While there were some NDVI differences among bermudagrass entries at both the 66% and 100% ET_o levels, all bermudagrasses showed acceptable TQ.

Two weeks following treatment initiation

For the 0% ET_o irrigation treatment, two weeks following treatment initiation Celebration, OKC 1134, #2, #24, and #27 had higher NDVI values than Premier, TGS U-3, SIU U-3, OKC 70-18, #17, #18, and #22 (Table 14). For the 33% ET_o irrigation treatment, #18 had a less NDVI value than 19 bermudagrass entries and was no different than NC U-3, TGS U-3, and OKC 70-18. However, all bermudagrasses showed acceptable TQ at the 33% ET_o irrigation level (Table 4). While there were some NDVI differences among bermudagrass entries at both the 66% and 100% ET_o levels, all bermudagrasses showed acceptable TQ at these irrigation levels.

Three weeks following treatment initiation

For the 0% ET_o irrigation treatment, three weeks following treatment initiation Celebration, #2, #16, #24, #27 had higher NDVI values than TGS U-3 and #22 (Table 15). However, all bermudagrass showed unacceptable TQ at the 0% ET_o irrigation level (Table 6). For the 33% ET_o irrigation treatment OKC 70-18 had a lower NDVI value than 9 of the bermudagrass entries including Celebration, #2, #12, and #27. Celebration, #2, #12, and #27 also showed acceptable TQ at the 33% ET_o irrigation level. While there were some NDVI differences among bermudagrass entries at both the 66% and 100% ET_o levels, all bermudagrasses showed acceptable TQ at these irrigation levels.

Four weeks following treatment initiation

For the 0% ET_o irrigation treatment, four weeks following treatment initiation Celebration, #2, and #27 had higher NDVI values in comparison to 8 bermudagrass entries (Table 16). However, no bermudagrasses showed acceptable TQ at the 0% ET_o irrigation level (Table 7). For the 33% ET_o irrigation level, OKC 70-18 had a lower NDVI value than Celebration, SIU U-3, #2,, #12, #26, and #27. While there were some NDVI differences among bermudagrass entries at both the 66% and 100% ET_o levels, all bermudagrasses showed acceptable TQ at these irrigation levels.

Recovery NDVI

After the first week upon re-watering for the 0% ET_o irrigation treatment, Celebration, NC U-3, OKC 1134, #2, #24, and #26 NDVI values did not differ statistically (Table 17). SIU U-3, #18, and #22 had lower NDVI values than Celebration, #2, and #24 (Table 8). However, no bermudagrasses had recovered to acceptable TQ for the 0% ET_o irrigation level. For the 33% ET_o irrigation treatment, #2 had a higher NDVI value than #17, but all other bermudagrasses were not different from each other. However, only Celebration, NC U-3, #2, and #12 showed a numeric mean TQ ≥ 6.0 at the 33% ET_o irrigation level. While there were some NDVI differences among bermudagrass entries at both the 66% and 100% ET_o levels, all bermudagrasses showed acceptable TQ at these irrigation levels.

After the fourth week upon re-watering for the 0% ET_o irrigation treatment, Patriot, Tifsport, SIU U-3, #18 and #22 had lower NDVI values than #2 (Table 18). Although, the NDVI value for #2 was not different than 17 bermudagrass entries including Celebration. Only Celebration had recovered to the numerically acceptable TQ rating of 6.0, but Celebration TQ was not different than NC U-3, OKC 1119, OKC 1134, #2, #12, #16, #24, #25, and #26 which had mean TQ ratings ranging from 4.7 to 5.7 (Table 10). For the 33% ET_o irrigation treatment, #18 had a lower NDVI value compared to OKC 1134, #2, #16, #24, and #26. However, no bermudagrass entries had unacceptable mean TQ ratings. While there were some NDVI differences among bermudagrass entries at both the 66% and 100% ET_o levels, all bermudagrasses showed acceptable TQ at these irrigation levels.

After the eighth week upon re-watering for the 0% ET_o irrigation treatment, TGS U-3 had a lower mean NDVI value than Celebration, Tifway, OKC 1134, #16, #24, #25, #26, and #27 (Table 19). However, TGS U-3 showed acceptable TQ while Premier, Tifsport, and SIU U-3 did not (Table 11). While there were some NDVI differences among bermudagrass entries at the 33%, 66% and 100% ET_o levels, all bermudagrasses showed acceptable TQ at these irrigation levels.

Recovery – Percent Living Cover

After the eighth week upon re-watering for the 0% ET_o irrigation treatment, Celebration plots had recovered to 100% living cover (Table 20). Celebration percent living cover was not different from Premier, NC U-3, TGS U-3, OKC 1119, OKC 1134, #2, #4, #12, #16, #18, #24, #25, #26, and #27 percent living cover (Table 20). For the 33% ET_o irrigation treatment, Celebration, Premier, SIU U-3, #2, #12, #16, and #26 had recovered to 100% living cover and were not different from Patriot, Tifway, NC U-3, OKC 1119, OKC 1134, OKC 70-18, #4, #17, #18, #20, #22, #24, #25, and #27. TGS U-3 had lower percent living cover than Celebration, Premier, Tifway, SIU U-3, OKC 1119, OKC 70-18, #2, #12, #16, #18, #20, #24, #25, and #26. For the 66% and 100% ET_o irrigation treatments, all bermudagrass entries were at 100% living cover (data not shown).

Soil volumetric water content (SVWC)

Prior to imposing irrigation treatments, there was no difference in SVWC among plot areas (Fig. 1). Soil volumetric water content was approximately 18% when the plot area was at field capacity (Fig. 1). As expected, the 0% ET_o irrigation treatment plots had lower SVWC than all other irrigation treatments at one, two, and three weeks following treatment initiation. At the fourth week of irrigation treatments, there was no difference in the the 0% ET_o and 33% ET_o irrigation treatment areas (Fig. 1). Throughout the course of the irrigation treatment period, the 66% and 100% ET_o irrigation treatments SVWC did not differ (Fig. 1). At the end of the four week irrigation treatment period, all plots were watered according to the 100% ET_o irrigation treatment. After one week of re-watering, all plots had recovered to pretreatment levels and there was no difference in SVWC among irrigation treatment plot areas (Fig. 1).

Discussion

Turfgrass leaf firing resistance refers to the ability of a turfgrass plant to resist or delay the occurrence of drought induced leaf chlorosis or browning. Leaf firing is considered a major indicator for detecting drought tolerance among turfgrass cultivars (Ebdon and Kopp, 2004). In this study, 23 bermudagrass entries (Table 1) were evaluated for leaf firing under four irrigation regimes based on ET_o replacement after 1, 2, 3, and 4 weeks after irrigation treatment. The LF results of this study correspond to prior research (Chalmers et al, 2008) on the drought performance of Celebration (good drought performance standard) and Premier (poor drought performance standard). Similarly, Steinke et al. (2009) reported that Premier had significantly higher leaf firing compared to Celebration during a 60 day drought study in Texas.

Turfgrass quality ratings take into account several turfgrass parameters including color, uniformity, density, texture, and stress response due to pathogens, insects, or environmental factors, including drought response via leaf firing. In this study bermudagrass TQ and LF had a significant ($P < 0.0001$), positive relationship where: TQ = 0.8354 + 0.8187(LF), $r^2 = 0.95$ (n = 2846). No TQ ratings for any bermudagrass were < 6.0 for both the 66% and 100% ET_o irrigation levels (Tables 3-6).

Turfgrass greenness can be objectively evaluated using NDVI collected with active hand-held sensors which have also been used to assess turf quality and turf injury in previous research (Bell and Xiong, 2008). In this study, 23 bermudagrass entries (Table 1) were evaluated for NDVI under the four irrigation regimes. The relationship between leaf firing and NDVI was a significant ($P < 0.0001$), positive relationship where:

LF = -1.0014 + 10.977(NDVI), with r^2 = 0.81 (n = 2833). There was strong relationship between LF and TQ because both data source were observed on a visual basis. The relationship between LF and SVWC and LF and NDVI was weaker because LF was collected on a subjective visual basis while SVWC and NDVI were measured objectively with research equipment. Since drought resistance through drought avoidance is primarily anatomical and morphological, these parameters were supportive to select entries for their phenotypic differences and field drought performance differences.

Soil volumetric water content depletion was observed with prolonged drought periods according to the irrigation treatments used in this study (Fig 1.). Soil volumetric water content depletion was noticeable after the first week of irrigation treatments for the 0% and 33% ET_o levels and continued to deplete until the fourth week of treatments (Fig 1). The relationship between leaf firing and SVWC was a significant ($P < 0.0001$), positive relationship where: LF = 3.5715 + 23.56(SVWC), with r^2 = 0.68 (n = 1418). As expected, lower SVWC resulted in higher LF (Qian and Fry, 1997).

Based on the overall results from this study, the hypothesis that were differences in vegetative bermudagrass entries for their field drought performance was accepted. Similar to prior research and among the bermudagrasses in this study, Celebration was a good drought performer and Premier was a poor drought performer in terms of TQ, LF, and NDVI. At the 0% ET_o irrigation level, the OSU experimental bermudagrasses that performed lower than Celebration but better than all other entries were #2, #12, #16, #24, and #27. At the 33% ET_o irrigation level, Celebration, #2, #12, and #27 performed better than all other bermudagrass entries. Future work should assess the drought tolerance and/or drought avoidance mechanisms of these entries.

Literature Cited

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration – guidelines for computing crop water requirements – FAO irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations. Rome, Italy

Baldwin, C.M., H. Liu, L.B. McCarty, W.L. Bauerle, and J. E. Toler. 2006. Response of six bermudagrass entries to different irrigation intervals. HortTechnology 16(3):466-470.

Beard, J.B. and S.I. Sifers. 1997. Genetic diversity in dehydration avoidance and drought resistance within the *Cynodon* and *Zoysia* species. Int. Turfgrass Soc. Res. J. 8:603-610.

Bell, G.E. and X. Xiong. 2008. The history, role, and potential of optical sensing for practical turf management. p. 641-660. In M. Pessarakli (ed.) Handbook of Turfgrass Management and Physiology. CRC Press, Boca Raton, FL.

Carrow, R.N. 1995. Drought resistant aspect of turfgrasses in the southeast: Evapotranspiration and crop coefficients. Crop Sci. 35:1685-1690.

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

Chalmers, D.R., K. Steinke, R. White, J. Thomas, and G. Fipps. 2008. Evaluation of sixty-day drought survival in San Antonio of established turfgrass species and cultivars. Final report submitted to: The San Antonio Water System and The Turfgrass Producers of Texas. Texas AgriLife Extension Service, College Station, TX.

de Wet, J. M. J. and J. R. Harlan. 1970. Biosynthesis of *Cynodon dactylon* in relation to ecological condition. Taxon 19:565-569.

Dacosta, M. and B. Huang. 2006a. Deficit irrigation on water use characteristics of bentgrass species. Crop Sci. 46:1779-1786.

DaCosta, M. and B. Huang. 2006b. Minimum water requirements for creeping, colonial, and velvet bentgrass under fairway conditions. Crop Sci. 46:81-89.

de Wet, J. M. J. and J. R. Harlan. 1971. South African species of *Cynodon* (Gramineae). J. S. Afr. Bot. 37:53-56.

Devitt, D. A., L. Wright, R.L. Morris, and D.C. Bowman. 1992. Evapotranspiration, crop coefficient, and leaching fractions of irrigated desert turfgrass systems. Agron. J. 84:717-723.

Ebdon, J.S. and K.L. Kopp. 2004. Relationships between water use efficiency, carbon isotope discrimination, and turf performance in genotypes of Kentucky bluegrass during drought. Crop Sci. 44:1754-1762.

Fu, J., J. Fry, and B. Huang. 2004. Minimum water requirements of four turfgrasses in the transition zone. HortScience 39(7):1740-1744.

Gee, G.W., and D. Or. 2002. Particle-size analysis, p. 255–293. In: J.H. Dane and G.C. Topp (eds.) Methods of soil analysis. Part 4. SSSA Book Series No. 5. SSSA, Madison, WI.

Giles, K. L. and N. R. Walker. 2009. Dissimination and impact of IPM programs in US Agriculture, p-481-505. *In* : R. Peshin and A. K. Dhawan (eds). Integrated Pest Management: Dissemination and Impact. Springer, Netherlands.

Han, H. 2009. Development of improved turf-type bermudagrasses. Oklahoma State University, Stillwater, OK, MS Thesis.

Harlan, J.R., and J.M.J. de Wet. 1969. Sources of variation in *Cynodon dactylon* (L.) Pers. Crop Sci. 9:774-778.

Hoshmand, A. R. 2006. Design for Experiment for Agriculture and Natural Sciences. 2nd ed. Chapman & Hall/CRC Press, Boca Raton, FL.

Huang, B., R.R. Duncan, and R.N. Carrow. 1997a. Drought resistant mechanism of seven warm season turfgrasses under surface soil drying: Shoot response. Crop Sci. 37:1858-1863.

Huang, B., R.R. Duncan, and R.N. Carrow. 1997b. Drought resistant mechanism of seven warm season turfgrasses under surface soil drying: Root aspect. Crop Sci. 37:1863-1869.

McCarty, L.B. and G. Miller. 2002. Managing bermudagrass turf: Selection, construction, cultural practices and pest management strategies. Sleeping Bear Press, Chelsea, Mich.

Oklahoma Mesonet. n.d. Oklahoma evapotranspiration model. 15 Nov. 2010. <http://agweather.mesonet.org/models/evapotranspiration/description.html>.

Qian, Y. L. and M. C. Engelke. 1999. Performance of five turfgrasses under linear gradient irrigation. HortScience 34(5):893-896.

Qian, Y. and J.D. Fry. 1997. Water relations and drought tolerance of four turfgrasses. J. Amer. Soc. HortScience 122(1):129-133.

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

Taliaferro, C.M., D.L Martin, J.A. Anderson, M.P. Anderson, and A.C. Guenzi. 2004a. Broadening the horizons of turf bermudagrass. USGA Turfgrass and Environmental Research Online. 3(20):1-9.

Taliaferro, C.M., F.M. Rouquette, Jr., and P. Mislevy. 2004b. Bermudagrass and stargrass. *In* L.E. Moser et al. (ed.) Warm-season (C4) grasses. Agron. Monogr. 45. ASA, CSSA, and SSSA, Madison, WI.

Wu, Y., D.L. Martin, J.A. Anderson, G.E. Bell, M.P. Anderson, N.R. Walker, and J.Q. Moss. 2009. Recent progress in turf bermudagrass breeding research at Oklahoma State University. USGA Turfgrass and Environmental Research Online. 8(16):1-11.

Table 1. Twenty-three bermudagrass cultivars and experimental selections tested for field drought performance in Oklahoma

Bermudagrass Selection	**Notes**
Celebration	Good drought performance standard (Chalmers et al., 2008)
Premier	Poor drought performance standard (Chalmers et al., 2008)
Tifway	Golf course standard
Tifsport	Sports field standard
SIU U-3	Southern Illinois University U-3 standard
TGS U-3	Tulsa Grass and Sod farm U-3 standard
NC U-3	Northcutt sod farm U-3 standard
Patriot	Sports field standard (OSU release)
OKC 70-18	OSU Experimental
OKC 1119	OSU Experimental
OKC 1134	OSU Experimental
#2	OSU Experimental
#4	OSU Experimental
#12	OSU Experimental
#16	OSU Experimental
#17	OSU Experimental
#18	OSU Experimental
#20	OSU Experimental
#22	OSU Experimental
#24	OSU Experimental
#25	OSU Experimental
#26	OSU Experimental
#27	OSU Experimental

Table 2. Significance (p values) for the tests of fixed effects from the ANOVAs for turf quality, leaf firing, and NDVI of 23 bermudagrass entries with four irrigation treatment levels over rating dates[z].

Fixed effects	TQ[y]	LF[x]	NDVI[w]
		p	
Date	<0.0001	<0.0001	<0.0001
Block	<0.0001	0.0004	<0.0001
Date x Block	0.2815	0.9960	0.0588
Bermudagrass entry	<0.1701	<0.0001	<0.0001
Date x Bermudagrass entry	<0.0001	0.8102	0.0079
Irrigation	<0.0001	<0.0001	<0.0001
Date x Irrigation	<0.0001	<0.0001	<0.0001
Bermudagrass entry x Irrigation	<0.0001	<0.0001	<0.0001
Date x Bermudagrass entry x Irrigation	<0.0001	0.1474	0.0032

[z] Turf quality ratings and NDVI values were recorded from each plot on 11 weekly rating dates while leaf firing ratings were recorded on four weekly rating dates, each after initiation of irrigation treatments.

[y] Turf quality ratings were based on a 1-9 scale where 1 = lowest quality, 6 = acceptable quality, and 9 = excellent quality.

[x] Leaf firing ratings were based on a 1-9 scale where 1 = highest leaf firing and 9 = no leaf firing.

[w] NDVI (normalized difference vegetative index) readings were collected using the CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

Table 3. Turf quality ratings[z] of 23 bermudagrass entries prior to initiating irrigation treatments[y].

	Turf Quality			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	7.5 a[x]	8.0 a	8.0 a	8.0 a
Patriot	6.3 b	7.3 a	7.7 ab	8.0 a
Premier	6.5 ab	7.3 a	8.0 a	7.5 a
Tifsport	6.0 b	6.3 b	7.3 b	7.7 a
Tifway	6.3 b	8.0 a	8.0 a	8.0 a
NC U-3	6.5 ab	7.3 a	7.3 b	8.0 a
TGS U-3	6.3 b	7.0 ab	8.0 a	8.0 a
SIU U-3	7.5 a	7.0 ab	7.8 ab	7.5 a
OKC 1119	7.0 ab	8.0 a	8.0 a	8.0 a
OKC 1134	6.5 ab	7.5 a	8.0 a	8.0 a
OKC 70-18	6.5 ab	8.0 a	8.0 a	8.0 a
#2	6.8 ab	7.5 a	8.0 a	8.0 a
#4	6.8 ab	7.3 a	8.0 a	8.0 a
#12	6.8 ab	7.0 ab	7.8 ab	7.5 a
#16	6.5 ab	7.5 a	8.0 a	8.0 a
#17	6.8 ab	7.0 ab	8.0 a	8.0 a
#18	7.0 ab	7.0 ab	7.8 ab	8.0 a
#20	7. 0 ab	7.5 a	8.0 a	8.0 a
#22	6.3 b	7.8 a	8.0 a	8.0 a
#24	6.8 ab	7.8 a	8.0 a	8.0 a
#25	6.8 ab	7.5 a	8.0 a	8.0 a
#26	6.5 ab	8.0 a	8.0 a	8.0 a
#27	6. 0 b	7.3 a	7.8 ab	8.0 a

[z] Turf quality ratings were based on a 1-9 scale where 1 = lowest quality, 6 = acceptable quality, and 9 = excellent quality.

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan’s multiple range test.

Table 4. Turf quality ratings[z] of 23 bermudagrass entries one week following the initiation of irrigation treatments[y].

	Turf Quality			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	8.0 a[x]	8.0 a	8.0 a	8.0 a
Patriot	6.2 c	7.0 ab	7.6 ab	8.0 a
Premier	6.5 bc	7.2 a	8.0 a	7.5 a
Tifsport	6.0 c	6.2 b	7.3 b	7.6 a
Tifway	6.2 c	8.0 a	8.0 a	8.0 a
NC U-3	6.5 bc	7.0 ab	7.2 b	8.0 a
TGS U-3	6.2 c	7.0 ab	8.0 a	8.0 a
SIU U-3	7.5 ab	7.0 ab	7.7 ab	7.5 a
OKC 1119	7.0 abc	8.0 a	8.0 a	8.0 a
OKC 1134	6.5 bc	7.5 a	8.0 a	8.0 a
OKC 70-18	6.5 bc	8.0 a	8.0 a	8.0 a
#2	6.7 bc	7.5 a	8.0 a	8.0 a
#4	6.7 bc	7.2 a	8.0 a	8.0 a
#12	6.7 bc	7.0 ab	7.7 ab	7.5 a
#16	6.5 bc	7.5 ab	8.0 a	8.0 a
#17	6.7 bc	7.0 ab	8.0 a	8.0 a
#18	7.0 abc	7.0 ab	7.7 ab	8.0 a
#20	7.0 abc	7.5 a	8.0 a	8.0 a
#22	6.2 c	7.7 a	8.0 a	8.0 a
#24	6.7 bc	7.7 a	8.0 a	8.0 a
#25	6.7 bc	7.5 a	8.0 a	8.0 a
#26	6.5 bc	8.0 a	8.0 a	8.0 a
#27	6.0 c	7.2 a	7.7 ab	8.0 a

[z] Turf quality ratings were based on a 1-9 scale where 1 = lowest quality, 6 = acceptable quality, and 9 = excellent quality.

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan’s multiple range test.

Table 5. Turf quality ratings^{z} of 23 bermudagrass entries two weeks following the initiation of irrigation treatments^{y}.

	Turf Quality			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	5.5 a^{x}	6.7 a	8.0 a	8.0 a
Patriot	2.7 fghi	6.0 a	7.0 bc	7.2 dc
Premier	2.5 ghi	6.2 a	7.7 a	8.0 a
Tifsport	3.5 defgh	6.2 a	6.6 c	7.0 d
Tifway	4.0 bcdef	6.7 a	7.5 ab	8.0 a
NC U-3	2.7 fghi	6.2 a	7.7 a	7.7 ab
TGS U-3	2.2 hi	6.2 a	7.5 ab	7.7 ab
SIU U-3	3.0 efghi	6.2 a	7.5 ab	8.0 a
OKC 1119	3.5 defgh	6.5 a	8.0 a	8.0 a
OKC 1134	4.5 abcd	6.2 a	7.7 a	7.7 ab
OKC 70-18	3.5 defgh	6.0 a	8.0 a	8.0 a
#2	5.0 abc	6.5 a	8.0 a	8.0 a
#4	3.7 cdefg	6.2 a	7.5 ab	7.5 bc
#12	4.5 abcd	6.5 a	8.0 a	8.0 a
#16	4.2 abcde	6.5 a	7.7 a	7.7 ab
#17	3.2 defghi	5.7 b	7.0 bc	7.2 dc
#18	2.0 i	6.0 a	7.5 ab	7.7 ab
#20	3.2 defghi	6.2 a	8.0 a	8.0 a
#22	3.0 efghi	6.2 a	7.7 a	8.0 a
#24	4.2 abcde	6.5 a	8.0 a	8.0 a
#25	3.0 efghi	6.2 a	7.7 a	8.0 a
#26	4.0 bcdef	6.7 a	8.0 a	8.0 a
#27	5.2 ab	6.7 a	7.5 ab	8.0 a

[z] Turf quality ratings were based on a 1-9 scale where 1 = lowest quality, 6 = acceptable quality, and 9 = excellent quality.

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 6. Turf quality ratings[z] of 23 bermudagrass entries three weeks following the initiation of irrigation treatments[y].

	Turf Quality			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	4.2 a[x]	6.7 a	8.0 a	8.0 a
Patriot	2.2 de	5.0 bc	7.0 bc	7.2 dc
Premier	2.5 cde	5.5 bc	7.7 a	8.0 a
Tifsport	2.5 cde	6.0 ab	6.6 c	7.0 d
Tifway	3.0 bcde	5.7 bc	7.5 ab	8.0 a
NC U-3	2.7 cde	5.2 bc	7.7 a	7.7 ab
TGS U-3	2.0 e	5.0 bc	7.5 ab	7.7 ab
SIU U-3	2.2 de	5.7 bc	7.5 ab	8.0 a
OKC 1119	2.5 cde	5.0 bc	8.0 a	8.0 a
OKC 1134	3.5 abcd	5.7 bc	7.7 a	7.7 ab
OKC 70-18	2.2 de	5.0 bc	8.0 a	8.0 a
#2	4.0 ab	6.0 ab	8.0 a	8.0 a
#4	2.7 cde	5.2 bc	7.5 ab	7.5 bc
#12	3.5 abcd	6.0 ab	8.0 a	8.0 a
#16	3.2 abcde	5.7 bc	7.7 a	7.7 ab
#17	2.5 cde	5.0 bc	7.0 bc	7.2 dc
#18	2.0 e	4.7 c	7.5 ab	7.7 ab
#20	2.7 cde	5.2 bc	8.0 a	8.0 a
#22	2.2 de	5.0 bc	7.7 a	8.0 a
#24	3.7 abc	5.5 bc	8.0 a	8.0 a
#25	2.2 de	5.2 bc	7.7 a	8.0 a
#26	3.0 bcde	5.7 bc	8.0 a	8.0 a
#27	3.7 abc	6.0 ab	7.5 ab	8.0 a

[z] Turf quality ratings were based on a 1-9 scale where 1 = lowest quality, 6 = acceptable quality, and 9 = excellent quality.

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 7. Turf quality ratings[z] of 23 bermudagrass entries four weeks following the initiation of irrigation treatments[y].

	Turf Quality			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	4.0 a[x]	6.2 a	8.0 a	8.0 a
Patriot	1.2 ef	4.3 de	7.0 bc	7.2 bc
Premier	2.0 cdef	4.5 de	6.7 bc	8.0 a
Tifsport	2.0 cdef	5.5 abcd	6.6 c	7.0 c
Tifway	2.5 abcdef	5.2 abcd	7.5 ab	8.0 a
NC U-3	2.0 cdef	4.5 de	7.5 ab	7.7 ab
TGS U-3	1.2 ef	4.0 e	7.2 abc	7.7 ab
SIU U-3	1.7 def	4.5 de	7.5 ab	8.0 a
OKC 1119	1.5 def	4.5 de	7.2 abc	8.0 a
OKC 1134	3.0 abcd	5.0 bcde	7.0 bc	7.5 ab
OKC 70-18	2.0 cdef	4.5 de	7.5 ab	8.0 a
#2	3.7 ab	5.7 abc	8.0 a	8.0 a
#4	2.2 bcdef	5.0 bcde	7.2 abc	7.5 ab
#12	3.0 abcd	6.0 ab	7.2 abc	8.0 a
#16	2.7 abcde	5.7 abc	7.2 abc	7.5 ab
#17	1.7 def	4.0 e	7.0 bc	7.2 bc
#18	1.0 f	4.0 e	6.7 bc	7.5 ab
#20	2.2 bcdef	4.5 de	7.5 ab	8.0 a
#22	1.5 def	4.5 de	7.2 abc	8.0 a
#24	3.5 abc	5.2 abcd	7.2 abc	8.0 a
#25	1.2 ef	4.7 cde	7.0 bc	8.0 a
#26	3.0 abcd	5.7 abc	7.5 ab	8.0 a
#27	3.0 abcd	5.2 abcd	7.5 ab	8.0 a

[z] Turf quality ratings were based on a 1-9 scale where 1 = lowest quality, 6 = acceptable quality, and 9 = excellent quality.
[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.
[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 8. Turf quality ratings[z] of 23 bermudagrass entries one week following the initiation of re-watering all plots according to the 100% irrigation treatment[y].

	Turf Quality			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	5.2 a[x]	6.7 a	8.5 a	8.25 a
Patriot	2.5 cde	5.6 bcd	7.0 d	7.0 c
Premier	2.5 cde	4.7 de	7.2 cd	8.0 ab
Tifsport	3.5 bcd	5.7 bc	7.0 d	7.0 c
Tifway	2.7 bcde	5.7 bc	7.7 bc	8.0 ab
NC U-3	3.7 bc	6.0 ab	7.7 bc	7.7 ab
TGS U-3	3.0 bcde	5.5 bcd	7.5 bcd	8.0 ab
SIU U-3	2.2 cde	5.5 bcd	8.0 ab	8.0 ab
OKC 1119	2.5 cde	5.2 bcde	7.5 bcd	8.0 ab
OKC 1134	3.5 cde	5.5 bcd	7.2 cd	7.5 bc
OKC 70-18	2.5 cde	5.0 cde	7.5 bcd	8.0 ab
#2	4.2 ab	6.0 ab	8.0 ab	8.0 ab
#4	2.7 bcde	5.5 bcd	7.2 cd	7.5 bc
#12	3.7 bc	6.0 ab	7.2 cd	8.0 ab
#16	3.7 bc	5.7 bc	7.5 bcd	7.5 bc
#17	2.2 cde	5.0 cde	7.2 cd	7.5 bc
#18	2.0 de	4.5 e	7.5 bcd	7.7 ab
#20	2.7 bcde	4.7 de	8.0 ab	8.0 ab
#22	1.7 e	4.5 e	7.5 bcd	8.0 ab
#24	4.2 ab	5.7 bc	7.5 bcd	8.0 ab
#25	2.5 cde	5.5 bcd	7.2 cd	8.0 ab
#26	3.5 cde	5.7 bc	7.5 bcd	8.0 ab
#27	3.2 bcde	5.5 bcd	7.5 bcd	8.2 a

[z] Turf quality ratings were based on a 1-9 scale where 1 = lowest quality, 6 = acceptable quality, and 9 = excellent quality.

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 9. Turf quality ratings[z] of 23 bermudagrass entries three weeks following the initiation of re-watering all plots according to the 100% irrigation treatment[y].

	Turf Quality			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	6.0 a[x]	6.7 a	7.0 a	6.7 a
Patriot	3.75 cde	5.3 bc	6.3 bc	6.5 a
Premier	3.5 de	5.5 bc	6.7 ab	6.7 a
Tifsport	4.0 bcde	5.7 abc	6.0 c	6.0 b
Tifway	3.7 cde	6.0 abc	7.0 a	7.0 a
NC U-3	4.2 bcde	6.2 ab	6.5 abc	6.5 a
TGS U-3	4.0 bcde	5.5 bc	6.5 abc	6.5 a
SIU U-3	3.0 e	5.7 abc	7.0 a	6.7 a
OKC 1119	4.5 bcd	5.5 bc	7.0 a	7.0 a
OKC 1134	4.5 bcd	5.7 abc	6.7 ab	6.7 a
OKC 70-18	3.5 de	5.0 c	6.5 abc	6.6 a
#2	5.2 ab	6.2 ab	7.0 a	7.0 a
#4	4.2 bcde	5.7 abc	7.0 a	7.0 a
#12	5.0 abc	6.2 ab	6.5 abc	6.5 a
#16	4.7 abcd	6.0 abc	6.5 abc	6.7 a
#17	4.0 bcde	5.2 bc	6.7 ab	6.7 a
#18	4.0 bcde	5.2 bc	7.0 a	7.0 a
#20	4.0 bcde	5.5 bc	7.0 a	7.0 a
#22	3.5 de	5.2 bc	6.5 abc	6.7 a
#24	4.7 abcd	5.7 abc	6.7 ab	6.7 a
#25	4.2 bcde	5.7 abc	6.7 ab	6.7 a
#26	4.7 abcd	6.0 abc	7.0 a	7.0 a
#27	4.2 bcde	6.0 abc	6.7 ab	6.7 a

[z] Turf quality ratings were based on a 1-9 scale where 1 = lowest quality, 6 = acceptable quality, and 9 = excellent quality.

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 10. Turf quality ratings[z] of 23 bermudagrass entries four weeks following the initiation of re-watering all plots according to the 100% irrigation treatment[y].

	Turf Quality			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	6.0 a[x]	6.5 a	6.7 ab	6.5 ab
Patriot	4.5 bcde	6.0 a	6.3 bc	6.2 ab
Premier	4.0 de	5.7 a	6.2 bc	6.2 ab
Tifsport	4.0 de	5.5 a	6.0 c	6.0 b
Tifway	4.2 cde	6.0 a	6.7 a	6.7 a
NC U-3	4.7 abcde	6.2 a	6.2 bc	6.2 ab
TGS U-3	4.5 bcde	5.5 a	6.2 bc	6.2 ab
SIU U-3	3.7 e	6.0 a	6.2 bc	6.2 ab
OKC 1119	5.0 abcde	5.7 a	7.0 a	6.5 ab
OKC 1134	5.0 abcde	6.2 a	6.5 abc	6.5 ab
OKC 70-18	4.5 bcde	5.5 a	6.5 abc	6.3 ab
#2	5.7 ab	6.5 a	7.0 a	6.7 a
#4	4.5 bcde	6.5 a	6.7 ab	6.7 a
#12	5.2 abcd	6.0 a	6.2 bc	6.2 ab
#16	5.5 abc	6.2 a	6.5 abc	6.5 ab
#17	4.5 bcde	5.7 a	6.5 abc	6.2 ab
#18	4.0 de	5.5 a	6.2 bc	6.2 ab
#20	4.5 bcde	5.7 a	6.5 abc	6.5 ab
#22	4.0 de	5.5 a	6.5 abc	6.5 ab
#24	5.0 abcde	6.0 a	6.7 ab	6.5 ab
#25	4.7 abcde	5.7 a	6.7 ab	6.2 ab
#26	5.0 abcde	6.7 a	7.0 a	6.7 a
#27	4.5 bcde	6.5 a	6.5 abc	6.5 ab

[z] Turf quality ratings were based on a 1-9 scale where 1 = lowest quality, 6 = acceptable quality, and 9 = excellent quality.

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan’s multiple range test.

Table 11. Turf quality ratings^z of 23 bermudagrass entries eight weeks following the initiation of re-watering all plots according to the 100% irrigation treatment^y.

	Turf Quality			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	6.5 a[x]	7.2 a	7.0 a	6.7 a
Patriot	5.5 abcde	6.5 a	6.6 ab	6.5 a
Premier	4.7 de	7.0 a	7.0 a	7.0 a
Tifsport	4.7 de	5.7 b	6.6 ab	6.6 a
Tifway	5.2 bcde	6.7 a	7.0 a	7.0 a
NC U-3	5.0 cde	7.0 a	7.0 a	7.0 a
TGS U-3	5.5 abcde	6.7 a	6.5 b	6.7 a
SIU U-3	4.5 e	7.0 a	7.0 a	6.5 a
OKC 1119	6.0 abc	7.0 a	7.0 a	7.0 a
OKC 1134	6.2 ab	6.7 a	7.0 a	7.0 a
OKC 70-18	5.2 bcde	7.0 a	7.0 a	7.0 a
#2	6.2 ab	7.2 a	7.0 a	7.0 a
#4	5.5 abcde	6.7 a	7.0 a	7.0 a
#12	6.2 ab	6.7 a	7.0 a	6.7 a
#16	6.5 a	7.2 a	7.0 a	6.7 a
#17	5.5 abcde	6.5 a	7.0 a	6.7 a
#18	5.5 abcde	7.0 a	7.0 a	7.0 a
#20	5.7 abcd	7.0 a	7.0 a	7.0 a
#22	5.2 bcde	6.7 a	7.0 a	6.7 a
#24	6.0 abc	7.0 a	7.0 a	7.0 a
#25	6.0 abc	7.0 a	7.0 a	7.0 a
#26	6.0 abc	7.0 a	7.0 a	7.0 a
#27	6.2 ab	6.7 a	6.7 ab	6.7 a

[z] Turf quality ratings were based on a 1-9 scale where 1 = lowest quality, 6 = acceptable quality, and 9 = excellent quality.

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 12. Leaf firing ratings[z] of 23 bermudagrass entries presented across all rating dates[y] following the initiation of irrigation treatments[x].

	Leaf Firing			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	5.0 a[w]	7.0 a	9.0 a	9.0 a
Patriot	2.8 kl	5.6 j	7.3 i	7.7 d
Premier	2.8 kl	6.0 fghi	8.1 efg	8.9 a
Tifsport	3.2 ijk	6.2 cdef	7.3 i	7.4 e
Tifway	3.8 fgh	6.5 bcd	8.2 cdefg	9.0 a
NC U-3	3.1 ijk	5.8 ghij	8.5 bcde	8.6 b
TGS U-3	2.5 lm	5.7 hij	8.0 fgh	8.5 b
SIU U-3	3.1 ijk	6.3 bcdef	8.1 efg	9.0 a
OKC 1119	3.5 ghi	6.1 efg	8.7 abc	9.0 a
OKC 1134	4.2 cde	6.2 def	8.2 cdefg	8.5 b
OKC 70-18	3.4 ijk	6.2 fgh	8.8 ab	9.0 a
#2	4.8 ab	6.7 ab	9.0 a	9.0 a
#4	3.5 ghi	6.1 efg	8.0 efg	8.2 c
#12	4.2 cdef	6.5 bcde	8.6 abcd	9.0 a
#16	3.9 efg	6.5 bcd	8.3 bcdef	8.5 b
#17	3.2 ijk	5.5 j	7.6 h	7.8 d
#18	2.3 m	5.6 ij	7.8 gh	8.3 bc
#20	3.4 ijk	6.0 fghi	8.8 ab	9.0 a
#22	3.0 jk	6.0 fghi	8.4 bcdef	9.0 a
#24	4.3 cd	6.3 cdef	8.7 abc	9.0 a
#25	3.0 jk	6.0 fgh	8.2 cdefg	9.0 a
#26	3.9 defg	6.6 bc	8.8 ab	9.0 a
#27	4.5bc	6.3 bcdef	8.1 defg	9.0 a

[z] Leaf firing ratings were based on a 1-9 scale where 1 = complete leaf firing and 9 = no leaf firing.

[y] Leaf firing was analyzed across all rating dates, which were one, two, three, and four weeks after inititation of irrigation treatments.

[x] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[w] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 13. NDVI[z] of 23 bermudagrass entries one week following the initiation of irrigation treatments[y].

	NDVI			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	0.75 a[x]	0.79 a	0.79 a	0.80 a
Patriot	0.49 ef	0.66 g	0.66 g	0.71 f
Premier	0.47 f	0.76 abc	0.78 abc	0.78 abcde
Tifsport	0.54 cdef	0.69 efg	0.71 ef	0.74 ef
Tifway	0.64 bcd	0.77 ab	0.73 cdef	0.81 a
NC U-3	0.54 cdef	0.74 abcde	0.75 abcde	0.76 bcde
TGS U-3	0.52 def	0.71 cdef	0.75 abcde	0.75 def
SIU U-3	0.61 bcd	0.74 abcd	0.74 bcdef	0.75 cdef
OKC 1119	0.64 bc	0.76 abc	0.78 abc	0.78 abcde
OKC 1134	0.61 bcd	0.75 abcd	0.77 abcd	0.79 abc
OKC 70-18	0.59 bcde	0.76 abcd	0.75 abcde	0.78 abcde
#2	0.64 bcd	0.75 abcd	0.77 abc	0.77 abcde
#4	0.54 cdef	0.72 cdef	0.75 abcde	0.78 abcde
#12	0.55 bcdef	0.68 fg	0.72 def	0.74 ef
#16	0.59 bcde	0.74 abcd	0.75 abcde	0.79 abcd
#17	0.55 cdef	0.72 bcdef	0.77 abcd	0.78 abcde
#18	0.53 cdef	0.71 defg	0.77 abc	0.78 abcde
#20	0.64 bc	0.75 abcd	0.78 ab	0.80 a
#22	0.54 cdef	0.73 bcde	0.75 abcde	0.76 abcde
#24	0.66 ab	0.72 cdef	0.74 bcde	0.77 abcde
#25	0.60 bcde	0.73 abcde	0.76 abcde	0.77 abcde
#26	0.60 bcde	0.74 abcde	0.78 ab	0.80 a
#27	0.63 bcd	0.67 fg	0.69 fg	0.75 cdef

[z] NDVI (normalized difference vegetative index) readings were collected using the CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).
[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.
[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 14. NDVI[z] of 23 bermudagrass entries two weeks following the initiation of irrigation treatments[y].

	NDVI			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	0.60 a[x]	0.82 a	0.85 bcdef	0.86 abc
Patriot	0.37 de	0.80 a	0.80 g	0.85 abc
Premier	0.33 e	0.79 a	0.85 abcd	0.87 ab
Tifsport	0.38 de	0.79 ab	0.82 efg	0.84 bc
Tifway	0.39 cde	0.81 a	0.86 abcd	0.88 a
NC U-3	0.37 de	0.76 abc	0.83 defg	0.83 cd
TGS U-3	0.32 e	0.71 bc	0.83 cdef	0.85 abc
SIU U-3	0.35 e	0.77 ab	0.80 g	0.81 d
OKC 1119	0.38 de	0.82 a	0.88 a	0.86 abc
OKC 1134	0.50 abcd	0.80 a	0.85 abcd	0.86 ab
OKC 70-18	0.31 e	0.76 abc	0.84 bcdef	0.86 ab
#2	0.53 abc	0.82 a	0.86 abc	0.85 abc
#4	0.36 de	0.79 a	0.82 fg	0.85 abc
#12	0.42 cde	0.79 a	0.84 cdef	0.85 abc
#16	0.45 bcde	0.80 a	0.86 abcd	0.85 abc
#17	0.34 e	0.77 ab	0.84 bcdef	0.85 abc
#18	0.31 e	0.69 c	0.84 bcdef	0.86 ab
#20	0.42 cde	0.80 a	0.87 ab	0.87 ab
#22	0.33 e	0.79 ab	0.84 bcdef	0.84 bc
#24	0.50 abcd	0.77 ab	0.83 cdef	0.85 abc
#25	0.38 de	0.77 ab	0.85 abcde	0.86 ab
#26	0.41 cde	0.83 a	0.85 abcde	0.88 a
#27	0.57 ab	0.79 ab	0.84 cdef	0.87 ab

[z] NDVI (normalized difference vegetative index) readings were collected using the CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 15. NDVI[z] of 23 bermudagrass entries three weeks following the initiation of irrigation treatments[y].

	NDVI			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	0.52 a[x]	0.78 a	0.84 ab	0.85 abcd
Patriot	0.35 cde	0.63 abc	0.79 c	0.83 cd
Premier	0.34 cde	0.72 abc	0.85 a	0.87 ab
Tifsport	0.34 cde	0.72 abc	0.81 bc	0.82 d
Tifway	0.31 de	0.70 abc	0.85 ab	0.87 ab
NC U-3	0.31 de	0.67 abc	0.83 ab	0.83 cd
TGS U-3	0.30 e	0.56 bc	0.83 ab	0.86 abcd
SIU U-3	0.31 de	0.78 a	0.81 bc	0.82 d
OKC 1119	0.31 de	0.66 abc	0.86 a	0.87 abc
OKC 1134	0.40 bcde	0.76 a	0.85 ab	0.85 abcd
OKC 70-18	0.31 de	0.54 c	0.86 a	0.87 ab
#2	0.44 abc	0.76 a	0.83 b	0.86 abcd
#4	0.32 de	0.68 abc	0.84 ab	0.84 bcd
#12	0.37 bcde	0.75 a	0.84 ab	0.86 abc
#16	0.42 abcd	0.74 ab	0.86 a	0.86 abcd
#17	0.31 de	0.67 abc	0.83 ab	0.84 bcd
#18	0.30 de	0.59 abc	0.85 a	0.86 abcd
#20	0.34 cde	0.64 abc	0.87 a	0.88 a
#22	0.29 e	0.68 abc	0.85 ab	0.85 abcd
#24	0.44 abc	0.64 abc	0.84 ab	0.85 abcd
#25	0.24 cde	0.78 a	0.85 ab	0.85 abcd
#26	0.37 bcde	0.74 ab	0.85 ab	0.87 ab
#27	0.47 ab	0.76 a	0.83 ab	0.85 abcd

[z] NDVI (normalized difference vegetative index) readings were collected using the CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 16. NDVI[z] of 23 bermudagrass entries four weeks following the initiation of irrigation treatments[y].

	NDVI			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	0.49 a[x]	0.74 a	0.82 ab	0.85 abc
Patriot	0.32 cd	0.60 abcd	0.77 de	0.80 de
Premier	0.31 d	0.63 abcd	0.84 ab	0.86 ab
Tifsport	0.34 cd	0.57 abcd	0.75 e	0.80 e
Tifway	0.30 d	0.55 abcd	0.86 a	0.87 a
NC U-3	0.30 d	0.57 abcd	0.80 bcde	0.83 abcde
TGS U-3	0.29 d	0.49 cd	0.81 abcd	0.85 abcd
SIU U-3	0.29 d	0.72 ab	0.82 abc	0.83 abcde
OKC 1119	0.29 d	0.53 abcd	0.79 bcde	0.84 abcde
OKC 1134	0.38 bcd	0.64 abcd	0.79 bcde	0.83 abcde
OKC 70-18	0.28 d	0.43 d	0.79 bcde	0.82 bcde
#2	0.46 ab	0.70 abc	0.82 ab	0.83 abcde
#4	0.35 cd	0.62 abcd	0.77 cde	0.81 cde
#12	0.36 bcd	0.68 abc	0.81 abcd	0.84 abcde
#16	0.34 cd	0.64 abcd	0.82 ab	0.84 abcde
#17	0.33 cd	0.53 abcd	0.81 abcd	0.84 abcd
#18	0.28 d	0.49 bcd	0.84 ab	0.86 abc
#20	0.35 cd	0.54 abcd	0.83 ab	0.86 abc
#22	0.31 cd	0.52 abcd	0.80 bcd	0.86 abc
#24	0.39 abcd	0.59 abcd	0.79 bcde	0.85 abcd
#25	0.32 cd	0.62 abcd	0.81 abcd	0.83 abcde
#26	0.36 bcd	0.66 abc	0.82 ab	0.83 abcde
#27	0.42 abc	0.70 abc	0.83 ab	0.86 ab

[z] NDVI (normalized difference vegetative index) readings were collected using the CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).
[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.
[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan’s multiple range test.

Table 17. NDVI[z] of 23 bermudagrass entries one week following the initiation of re-watering all plots according to the 100% irrigation treatment[y].

	NDVI			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	0.72 a[x]	0.84 ab	0.85 bcd	0.86 abcd
Patriot	0.43 cd	0.79 ab	0.83 de	0.83 de
Premier	0.43 cd	0.70 ab	0.87 ab	0.87 a
Tifsport	0.49 bcd	0.80 ab	0.82 e	0.83 e
Tifway	0.45 cd	0.80 ab	0.86 abc	0.87 ab
NC U-3	0.53 abcd	0.79 ab	0.84 cde	0.84 cde
TGS U-3	0.43 cd	0.77 ab	0.84 cde	0.86 bcde
SIU U-3	0.37 d	0.81 ab	0.82 e	0.85 abcde
OKC 1119	0.45 cd	0.77 ab	0.86 abc	0.87 ab
OKC 1134	0.54 abcd	0.81 ab	0.86 abc	0.87 ab
OKC 70-18	0.47 cd	0.79 ab	0.86 abc	0.87 ab
#2	0.68 ab	0.84 a	0.85 abc	0.87 ab
#4	0.44 cd	0.82 ab	0.84 cde	0.86 abc
#12	0.53 bcd	0.82 ab	0.85 bcd	0.85 abcde
#16	0.52 bcd	0.81 ab	0.84 bcde	0.84 bcde
#17	0.40 cd	0.68 b	0.85 bcde	0.86 abcde
#18	0.39 d	0.71 ab	0.84 bcde	0.85 abcde
#20	0.46 cd	0.70 ab	0.88 b	0.87 ab
#22	0.38 d	0.70 ab	0.85 bcd	0.86 abcde
#24	0.60 abc	0.80 ab	0.85 bcd	0.85 abcde
#25	0.45 cd	0.72 ab	0.85 bcd	0.84 bcde
#26	0.56 abcd	0.82 ab	0.86 abc	0.85 abcde
#27	0.49 bcd	0.78 ab	0.86 abc	0.87 ab

[z] NDVI (normalized difference vegetative index) readings were collected using the CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 18. NDVI[z] of 23 bermudagrass entries four weeks following the initiation of re-watering all plots according to the 100% irrigation treatment[y].

	NDVI			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	0.77 abc[x]	0.80 abc	0.79 abc	0.75 bc
Patriot	0.71 bcd	0.73 abc	0.76 bc	0.72 cd
Premier	0.78 abc	0.73 abc	0.78 abc	0.79 ab
Tifsport	0.65 d	0.70 bc	0.74 c	0.68 d
Tifway	0.75 abc	0.70 abc	0.79 abc	0.78 abc
NC U-3	0.76 abc	0.77 abc	0.75 bc	0.75 bc
TGS U-3	0.75 abc	0.72 abc	0.76 bc	0.77 abc
SIU U-3	0.65 d	0.76 abc	0.78 abc	0.74 bc
OKC 1119	0.80 ab	0.79 abc	0.80 ab	0.80 abc
OKC 1134	0.80 ab	0.81 ab	0.80 ab	0.77 abc
OKC 70-18	0.75 abc	0.70 bc	0.79 abc	0.76 abc
#2	0.84 a	0.83 a	0.79 abc	0.80 ab
#4	0.76 abc	0.75 abc	0.79 abc	0.82 a
#12	0.75 abc	0.79 abc	0.75 bc	0.77 abc
#16	0.77 abc	0.81 ab	0.79 abc	0.76 abc
#17	0.77 abc	0.75 abc	0.76 bc	0.78 abc
#18	0.68 cd	0.69 c	0.77 abc	0.79 ab
#20	0.75 abc	0.76 abc	0.82 a	0.80 ab
#22	0.73 bcd	0.75 abc	0.78 abc	0.78 ab
#24	0.77 abc	0.82 ab	0.80 ab	0.78 ab
#25	0.79 ab	0.78 abc	0.77 abc	0.77abc
#26	0.80 ab	0.81 ab	0.79 abc	0.79 ab
#27	0.79 ab	0.79 abc	0.77 abc	0.80 ab

[z] NDVI (normalized difference vegetative index) readings were collected using the CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 19. NDVI[z] of 23 bermudagrass entries eight weeks following the initiation of re-watering all plots according to the 100% irrigation treatment[y].

	NDVI			
Bermudagrass Entry	0%	33%	66%	100%
Celebration	0.78 a[x]	0.77 a	0.74 ab	0.71 abcde
Patriot	0.68 abcd	0.65 abcd	0.64 cdef	0.60 g
Premier	0.63 bcd	0.68 abcd	0.73 abc	0.57 g
Tifsport	0.68 abcd	0.58 cd	0.67 abcdef	0.67 abcdefg
Tifway	0.76 ab	0.75 ab	0.75 a	0.77 a
NC U-3	0.59 cd	0.57 d	0.63 def	0.61 fg
TGS U-3	0.57 d	0.57 d	0.62 ef	0.66 bcdefg
SIU U-3	0.67 abcd	0.74 ab	0.70abcde	0.65 cdefg
OKC 1119	0.70 abcd	0.72 ab	0.60 f	0.72 abcde
OKC 1134	0.74 ab	0.77 a	0.75 a	0.72 abcde
OKC 70-18	0.67 abcd	0.63 bcd	0.69 abcdef	0.65 defg
#2	0.68 abcd	0.70 abc	0.70 abcde	0.70 abcdef
#4	0.71 abcd	0.73 ab	0.65 bcdef	0.73 abcde
#12	0.64 abcd	0.65 abcd	0.68 abcdef	0.70 abcdef
#16	0.74 ab	0.77 a	0.71 abcd	0.72 abcde
#17	0.68 abcd	0.64 bcd	0.71 abcde	0.64 fg
#18	0.65 abcd	0.63 bcd	0.72 abcd	0.71 abcde
#20	0.64 abcd	0.74 ab	0.76 a	0.75 abcd
#22	0.64 abcd	0.73 ab	0.73 abc	0.72 abcde
#24	0.76 ab	0.71 ab	0.71 abcd	0.71 abcde
#25	0.72 abc	0.74 ab	0.76 a	0.75 abc
#26	0.72 abc	0.73 ab	0.74 ab	0.75 ab
#27	0.77 a	0.76 a	0.75 a	0.76 a

[z] NDVI (normalized difference vegetative index) readings were collected using the CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 20. Recovery[z] of 23 bermudagrass entries eight weeks following the initiation of re-watering all plots according to the 100% irrigation treatment[y].

	Recovery	
Bermudagrass Entry	0%	33%
Celebration	100 a[x]	100 a
Patriot	87 de	97 abc
Premier	94 abcde	100 a
Tifsport	77 f	93 bc
Tifway	87 de	99 ab
NC U-3	91 abcde	97 abc
TGS U-3	90 abcde	92 c
SIU U-3	77 f	100a
OKC 1119	95 abcde	98 ab
OKC 1134	96 abcd	97 abc
OKC 70-18	86 e	99 a
#2	98 abc	100 a
#4	93 abcde	97 abc
#12	98 abc	100 a
#16	99 ab	100 a
#17	89 cde	95 abc
#18	90 abcde	98 ab
#20	90 bcde	99 a
#22	89 cde	97 abc
#24	95 abcde	98 ab
#25	96 abcde	99 a
#26	97 abcd	100 a
#27	94 abcde	97 abc

[z] Recovery ratings were based on visual estimates of percent living bermudagrass coverage from 0-100%.

[y] Irrigation treatments were based on a percentage of local reference evapotranspiration data.

[x] Means followed by different letters are statistically different at the P = 0.05 significance level according to Duncan’s multiple range test.

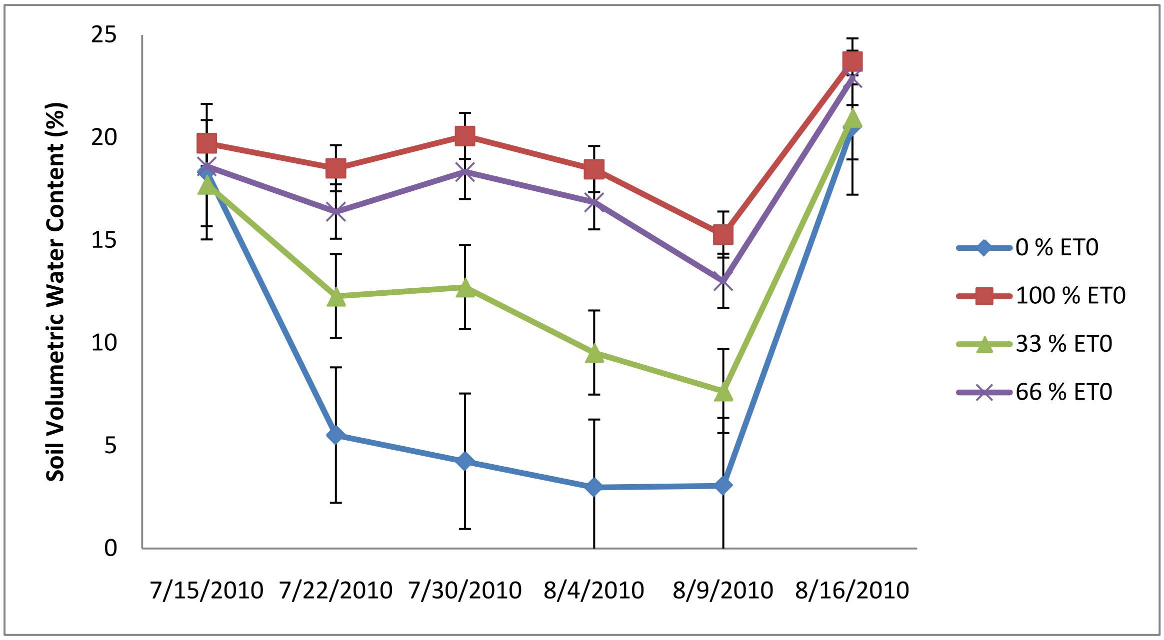

Fig. 1. Mean soil volumetric water content (%) of each irrigation treatment plot area. Irrigation treatments were based on a percentage of local reference evapotranspiration data (ET_o). Data was collected prior to beginning irrigation treatments (7/15/2010); at one week (7/22/2010), two weeks (7/30/2010), three weeks (8/4/2010), and four weeks (8/9/2010) after treatments were imposed; and at one week after re-watering all plots according to the 100% ET_o treatment (8/16/2010).

CHAPTER III

Differences in Root Growth Characteristics of Eight Clonally Propagated Bermudagrass Cultivars and Experimental Genotypes

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Differences in Root Growth Characteristics of Eight Clonally Propagated Bermudagrass Cultivars and Experimental Genotypes

Additional index words: Cynodon dactylon, drought, root growth, root mass, root length

Abstract: Bermudagrass is used in many parts of the world as a forage crop and as turfgrass in sports fields, golf courses and lawns. Selection and identification of drought resistant bermudagrass cultivars under acute or chronic drought stress is important for sustainable turfgrass management and water conservation. Typical mechanisms of drought avoidance include deep, extensive root growth. Extensive root systems allow turfgrasses to avoid drought, enabling them to extract water from deeper in the soil profile during severe moisture stress. The objective of this research was to evaluate and explain differences in root growth characteristics of selected clonal industry standard and OSU experimental bermudagrass entries. It was hypothesized that there were significant differences in clonal industry standard and OSU experimental bermudagrass entries for root growth characteristics. The study was conducted at the Oklahoma State University (OSU) Turfgrass Research Center Greenhouse Facility located in Stillwater, OK. Eight bermudagrass entries were chosen for this study including three industry standards and five OSU experimental selections. The standards were: Celebration, Tifsport, and Patriot. The OSU experimental bermudagrasses were: OKC 1119, OKC 1134, # 2, # 12, and # 17. Uniform sod pieces were transferred from the field to clear polyethylene tubing and were grown in a screened fritted clay material (1 – 2 mm diameter particle size) for root growth analysis. Roots were scanned and analyzed for total root length (TRL), average root diameter (ARD), root surface area (RSA) and root volume. After root characteristics were scanned and analyzed, the root materials were oven dried for 48 h at 80° C and root

dry weights (RDW) were recorded. Shoots were collected and dry weights (SDW) were recorded twice per week. Also, the root/shoot ratio (R/S) was calculated based on the SDW and RDW for each entry. Celebration, OKC 1119, and #2 had the highest R/S among the bermudagrass entries. Celebration, OKC 1119, and #2 also ranked highly for root dry weight in the upper 0 – 30 cm profiles. In addition, Celebration, OKC 1119, and #2 ranked highly in total root length in the upper 0 – 30 cm profiles. Tifsport, Patriot, and #12 had the lowest R/S among the bermudagrass entries. Tifsport, Patriot, and #12 also ranked poorly for root dry weight in the upper 0 – 30 cm profiles. In addition, Tifsport, Patriot, and #12 ranked poorly for total root length in the upper 0 – 30 cm profiles. Based on the results of this study, Celebration, OKC 1119, and #2 have good genetic potential for improved drought performance if proper root growth occurs during the year before a drought event. Tifsport, Patriot, and #12 did not perform as well as Celebration, OKC 1119, and #2 in this study and thus may not have acceptable genetic potential for improved drought performance due to rooting characteristics.

Bermudagrass is used in many parts of the world as a forage crop and as turfgrass in sports fields, golf courses and lawns. Bermudagrass is a warm-season perennial grass species best adapted to tropical and subtropical climates with high temperatures, mild winters and high rainfall (Taliaferro et al., 2004). Bermudagrass is native to Africa and Southeast Asia and is currently found all over the world (Harlan and de Wet, 1969; de Wet and Harlan, 1970; de Wet and Harlan, 1971; Taliaferro et al., 2004). Selection and identification of drought resistant bermudagrass cultivars under acute or chronic drought stress is important for sustainable turfgrass management and water conservation.

Plants survive water stress with mechanisms of drought avoidance and/or drought tolerance. Drought resistance refers to the ability of a plant to avoid dehydration or tolerate dehydration in plant tissue (Levitt, 1980). Typical mechanisms of drought avoidance include deep, extensive root growth. Extensive root systems allow turfgrasses to avoid drought, enabling them to extract water from deeper through the soil profile during severe moisture stress (Hurd, 1975). Bermudagrasses capable of avoiding drought through extensive root systems can extract water from deeper soil layers (Boeker, 1974) which is important for future varietal development. Typical mechanisms of drought tolerance include cell membrane stability and increased or decreased hormone production under drought stress. Turfgrass cultivars with good shoot characteristics for efficient transpiration and extended root system for proper moisture absorption are considered drought resistant (Youngner, 1985).

In comparison to cool-season grasses, warm-season grasses possess better turf quality during periods of drought. Cultivar performance and their selection based on factors responsible for this phenomenon like vertical root distribution, soil water depletion, leaf firing and turf quality is essential. In a drought study of various bermudagrass genotypes, total root mass at the depths of 30 - 60 cm, 60 - 90 cm, 90 - 120 cm and 120 - 150 cm was correlated with turf quality with r = 0.72, 0.86, 0.80, and 0.81, respectively (Hays et al., 1991).

In areas of irregular rainfall, greater root size (diameter) is also a desirable traits for drought resistant bermudagrasses. It is important to screen genotypes for their rooting characteristics within controlled environment and to screen for high root/shoot ratio (Bonos et al., 2004). For example, Karcher et al. (2008) selected tall fescue cultivars with high root/shoot ratios and planted them in field trials for drought performance analysis. These selections performed well under field drought conditions and exhibited improved drought performance compared to their parental lines (Karcher et al., 2008). The objective of this research was to evaluate and explain differences in root growth characteristics of selected clonal industry standard and OSU experimental bermudagrass entries. It was hypothesized that there were significant differences in clonal industry standard and OSU experimental bermudagrass entries for root growth characteristics.

Materials and Methods

The study was conducted at the Oklahoma State University (OSU) Turfgrass Research Center Greenhouse Facility located in Stillwater, OK. This research was conducted from Feb. to May 2010 (study one) and was repeated from July to Sep 2010 (study two). The average greenhouse conditions for study one were 29/18° C day/night air temperature and 66% relative humidity (RH). The average greenhouse conditions for study two were 32/24° C day/night air temperature and 76% RH. Natural light in the greenhouse was supplemented with an overhead lamp set to turn on/off daily at 6:00

AM/20:00 PM and average photosynthetically active radiation (PAR) was 1000 µm m^{-2} sec^{-1}. Eight bermudagrass entries were chosen for this study including three industry standards and five OSU experimental selections. The standards were: Celebration (good drought performance standard; Chalmers et al., 2008), Tifsport (sports field standard), and Patriot (cold tolerant standard, OSU release; Wu et al., 2009). The OSU experimental bermudagrasses were: OKC 1119, OKC 1134, # 2, # 12, and # 17. The OSU experimental standards have excellent sod strength, but little is known about their specific root growth characteristics (Han, 2009).

Growth tubes were made from clear polyethylene tubing (3.5 cm diameter) cut into uniform 120 cm long pieces (Su et al., 2008). Polyvinylchloride (PVC) pipe of 5.08 cm diameter were cut to a uniform 120 cm length to create holding tubes. Holding tubes were capped at bottom and small holes were drilled in the bottom of each cap to facilitate drainage. Fritted clay (Chandler Materials, Tulsa, OK) was used as the bermudagrass root growth medium. The fritted clay had a dry bulk density of 0.67 kg L^{-1}, particle density of 2.50 kg L^{-1}, total porosity of 0.73, and saturated hydraulic conductivity of 9.5×10^{-4} m sec^{-1} (van Bavel et al., 1978). The fritted clay was screened to 1-2 mm where particles greater than 2 mm in diameter were removed with a first screening and particle size of less than 1 mm in diameter were removed during a second screening. Each clear growth tube was evenly filled with the screened fritted clay material and tubes were saturated before plugs were planted (plugs collected from field established as sod). For initial establishment, the growth tubes were set under a mist system for two weeks. The mist system had an automatic irrigation timer control setting and was set to water every 20 min for 15 sec during the day. After a two week establishment period, the tubes were then transferred to a growth tube holding rack. The growth tube holding rack had an automatic irrigation assembly with an SVC-100 smart valve controller (Hunter Industries Inc., San Marcos, CA). A drip-tubing system was setup from the controller to drip-irrigate each individual growth tube. The controller was set to irrigate for ten minutes every four hours during the daytime. Fertilizer was applied during establishment and once a week after establishment at 250 mg N L^{-1} with 20N–8.7P–16.6K fertilizer (J.R. Peters, Inc., Allentown, PA) for a total of 130 kg N ha^{-1} $week^{-1}$ during the study period. The fritted clay material had little N nutrient holding capacity. Therefore, N fertilizer rates were higher than normal field N fertilizer rates to ensure that N was sufficiently applied to each growth tube for proper bermudagrass growth and development.

Grasses were mowed twice a week at 4 cm height and clippings collected. The clippings were collected in paper envelop, immediately after mowing. Collected clippings shoot dry weight (SDW) was recorded twice a week throughout the study period. The visual maximum root extension in each growth tube was measured weekly with a meter stick ruler. The study was stopped once the maximum root extension in one of the tube was observed to reach 120 cm depth. At the end of each study, the clear polyethylene growth tubes were cut into six sections from 0 - 7.5 cm, 7.5 - 15 cm, 15 - 30 cm, 30 - 60 cm, 60 - 90 cm and 90 - 120 cm. The totals for each study parameter were also calculated by adding together the totals for each individual section (0 - 120 cm). Any aboveground shoots were collected at the end of the study and final shoot dry weight was recorded. The clay from each section was washed out by hand and roots were collected in plastic bags and refrigerated at 4°C until further analysis. Roots were separated, scanned and analyzed with Win-Rhizo software (Regent Instruments, Nepean, ON, Canada). Methyl blue (5 g L^{-1} water) was used to stain roots for proper imaging of fine roots. Once the roots were scanned the software was used to calculate total root length (TRL), average root diameter (ARD), root surface area (RSA) and root volume (RV). After root characteristics were scanned and analyzed, the root materials were oven dried for 48 h at 80° C and root dry weights (RDW) were recorded. Also, the root/shoot ratio (R/S) was calculated based on the SDW and RDW for each entry. Lastly, visual turf quality was rated weekly on a 1-9 scale where: 1 = completely brown, dormant, or dead grass, 6 = acceptable visual turf quality, and 9 = excellent turf quality.

The design of the experiment was a randomized complete block (RCBD) with four replications and eight bermudagrass entries. Analysis of variance (ANOVA) was performed using PROC GLM (SAS Institute Inc., Cary, NC). There was no significant date x cultivar treatment interaction for TQ or SDW and data was analyzed as one combined experiment. When the criteria for ANOVA were met at the $P = 0.05$ level, mean separation tests were performed using Duncan's multiple range test at the $P = 0.05$ significance level.

Results

Total root length (TRL)

There was no significant difference in entries for mean TRL from 0-120 cm (Table 21). For the 0 – 7.5 cm section, mean TRL was highest for # 2 and #17 and was lowest for Celebration, Tifsport, Patriot and #12 (Table 23). For the 7.5 – 15 cm section, mean TRL was highest for Celebration, OKC 1119, and #17 and was lowest for Tifsport and #12 (Table 25). For the 15 – 30 cm section, mean TRL was highest for Celebration and Patriot and lowest for Tifsport, OKC 1134, #2, #12, and #17 (Table 23). For the 30 – 60 cm section, Celebration and Patriot had the highest mean TRL while OKC 1119, OKC 1134, #2, and #17 had the lowest mean TRL (Table 24). For the 60-90 cm section, Patriot and #12 had the highest mean TRL while Celebration and #17 had the lowest mean TRL (Table 24). There was difference in mean TRL at the 90 – 120 section where Tifsport, #12, OKC 1119, and Patriot had greater mean TRL than Celebration, OKC 1134, #2, and #17 (Table 24).

Root surface area (RSA)

There were no differences in mean RSA from 0 – 120 cm (Table 21). For the 0 – 7.5 cm section, mean RSA was highest for # 2 and #17 and was lowest for Tifsport and Patriot (Table 23). For the 7.5 – 15 cm section, mean RSA was highest for Celebration and OKC 1119 and was lowest for Tifsport and #12 (Table 23). For the 15 – 30 cm section, mean RSA was highest for Celebration and Patriot and lowest for Tifsport (Table 23). For the 30 – 60 cm section, Celebration and Patriot had the highest mean RSA while OKC 1119, #2, and #17 had the lowest mean RSA (Table 24). There were no differences in mean RSA for the 60 – 90 cm. There was difference in mean RSA at the 90 – 120 section where Tifsport, #12, OKC 1119, and Patriot had greater mean RSA than Celebration, OKC 1134, #2, and #17 (Table 24).

Average root diameter (ARD):

There were differences in ARD from 0- 120 cm where Celebration, OKC 1119, OKC 1134, and #2 had the highest ARD while Tifsport had the lowest ARD (Table 21). For the 0 – 7.5 cm section, mean ARD was highest for OKC 1119, OKC 1134, #2, and #17 and was lowest for Tifsport (Table 23). For the 7.5 – 15 cm section, mean ARD was highest for Celebration and OKC 1119 and was lowest for Tifsport and Patriot (Table 23). For the 15 – 30 cm section, mean ARD was highest for Celebration, OKC 1119, and OKC 1134 and lowest for Tifsport (Table 23). There were no differences in mean ARD for the 30 – 60 cm, 60 – 90 cm. There was difference in mean ARD at the 90 – 120 section where Tifsport, #12, OKC 1119, and Patriot had greater mean ARD than Celebration, OKC 1134, #2, and #17 (Table 24).

Root volume (RV)

There were differences in RV from 0- 120 cm where Celebration and #2 had the highest RV while Tifsport had the lowest ARD (Table 21). For the 0 – 7.5 cm section, mean RV was highest for #2 and was lowest for Tifsport and Patriot (Table 23). For the 7.5 – 15 cm section, mean RV was highest for Celebration, OKC 1119, and #2 and was lowest for Tifsport (Table 23). For the 15 – 30 cm section, mean RV was highest for Celebration and lowest for Tifsport (Table 23). For the 30 – 60 cm section, Celebration and Patriot had the highest mean RV while OKC 1119, #2, and #17 had the lowest mean RV (Table 24). There were no differences in mean RV for the 60 – 90 cm. There was difference in mean RV at the 90 – 120 section where Tifsport, #12, OKC 1119, and Patriot had greater mean RV than Celebration, OKC 1134, #2, and #17 (Table 24).

Shoot dry weight (SDW)

There were differences in SDW among cultivars where Celebration, #12, and #17 had the highest mean SDW while Tifsport had the lowest mean SDW (Table 22).

Root dry weigh (RDW)

There were differences in RDW for the 0 – 120 cm totals where Celebration and #2 had the highest RDW and were not different from each other. Tifsport had the lowest mean RDW, which was lower than Celebration, OKC 1119, OKC 1134, #2, #12, and #17 but was not different from Patriot. For the 0 – 7.5 cm section, mean RDW was highest for Celebration, OKC 1134, #2, #12, and #17 and was lowest for Tifsport and Patriot (Table 23). For the 7.5 – 15 cm section, mean RDW was highest for Celebration, OKC 1119, OKC 1134, #2, and #17 and was lowest for Tifsport (Table 23). For the 15 – 30 cm section, mean RDW was highest for Celebration and lowest for Tifsport, Patriot, OKC 1134, #2, #12, and #17 (Table 23). There were no differences in mean RDW for the 30 – 60 cm, 60 – 90 cm. There was difference in mean RDW at the 90 – 120 section where Tifsport, #12, OKC 1119, and Patriot had greater mean RDW than Celebration, OKC 1134, #2, and #17 (Table 24).

Root shoot ratio (R/S)

There were differences in R/S for the total 0 – 120 cm where Celebration, OKC 1119 and #2 had the highest R/S while Tifsport, Patriot, and #12 had the lowest R/S.

Visual turf quality (TQ)

There were no differences in TQ among the bermudagrass entries at any rating date and all ratings were≥ 6, the minimum acceptable TQ rating (data not shown). This is due to the uniform maintenance conditions given to each bermudagrass growth tube during this study. All bermudagrass growth tubes were given adequate irrigation, fertilizer, light, and ideal environmental conditions to prevent any turf stress from occurring over the course of these studies.

Discussion

For all entries 85 % to 90 % of TRL was located in upper 30 cm of soil. Similar results were observed for bermudagrasses in a greenhouse study conducted by Qian et al. (1997). Greater root mass within the upper 30 cm profile is desirable to extract water during periods of adequate rainfall. Genetic variability of root characteristics is of prime importance for selecting species that have potential to survive better under drought stress (Su et al., 2008). Extensive deep rooting is essential for selecting cultivars that perform better in drought stressed environments (Duncan, 1994). Higher R/S is also important and accounted for better water use efficiency when measured to evaluate cultivar differences for potential to survive under drought stress (Bonos, 2004). Based on the results of this study, Celebration, OKC 1119, and #2 had the highest R/S among the bermudagrass entries. Celebration, OKC 1119, and #2 also ranked highly for root dry weight in the upper 0 – 30 cm profiles. In addition, Celebration, OKC 1119, and #2 ranked highly in total root length in the upper 0 – 30 cm profiles and demonstrated excellent performance under drought in the field (Chapter II). Tifsport, Patriot, and #12 had the lowest R/S among the bermudagrass entries. Tifsport, Patriot, and #12 also ranked lowly for root dry weight in the upper 0 – 30 cm profiles. In addition, Tifsport, Patriot, and #12 ranked poorly for total root length in the upper 0 – 30 cm profiles and demonstrated relatively poor performance in drought induced field test (Chapter II).

Based on the results of this study, Celebration, OKC 1119, and #2 have good genetic potential for improved drought performance through extensive rooting and high root/shoot ratios. Tifsport, Patriot, and #12 did not perform as well as Celebration, OKC 1119, and #2 in this study and did not demonstrated good genetic potential for improved drought performance due to rooting characteristics. While rooting characteristics are important to avoid drought conditions, turfgrass drought tolerance mechanisms should also be studied for use in selecting and breeding drought resistant bermudagrasses. Future work should focus on any potential genetic variation that confers physiological attributes that may contribute to differences in bermudagrass drought resistance.

Literature Cited

Boeker, P. 1974. Root development of selected turfgrass species and entries. P 55-61. *In* E.C. Roberts (ed.) Proc. 2nd Intl. Turfgrass Res. Conf. ASA and CSSA, Madison, WI.

Bonos, S.A., D. Rush, K. Hingnight, and W.A. Meyer. 2004. Selection for deep root production in tall fescue and perennial ryegrass. Crop Sci. 44: 1770-1775.

Chalmers, D.R., K. Steinke, R. White, J. Thomas, and G. Fipps. 2008. Evaluation of sixty-day drought survival in San Antonio of established turfgrass species and cultivars. Final report submitted to: The San Antonio Water System and The Turfgrass Producers of Texas. Texas AgriLife Extension Service, College Station, TX.

de Wet, J.M.J. and J.R. Harlan. 1970. Biosynthesis of *Cynodon dactylon* in relation to ecological condition. Taxon 19:565-569.

de Wet, J.M.J. and J.R. Harlan. 1971. South African species of *Cynodon* (Gramineae). J. S. Afr. Bot. 37:53-56.

Duncan, R.R. 1994. Seashore paspalum may be grass for the year 2000. Southern Turf Mgmt. 5: 31-32.

Fry, J.D., and B. Huang. 2004. Applied turfgrass science and physiology. John Wiley & Sons, Hoboken, NJ.

Han, H. 2009. Development of improved turf-type bermudagrasses. Oklahoma State University, Stillwater, OK, MS Thesis.

Harlan, J.R., and J.M.J. de Wet. 1969. Sources of variation in *Cynodon dactylon* (L.) Pers. Crop Sci. 9:774-778.

Hays, K. L., J. F. Barber, M.P. Kenna, and T.G. McCollum. 1991. Drought avoidance mechanisms of selected bermudagrass genotype. HortScience 26 (2):180-182.

Hurd, E. A. 1975. Phenotype and drought tolerance in wheat. P 39-55. *In* J. F. stone (ed.). Plant modification for more efficient water use. Elsevier Sci. Publ. Co., Armsterdam.

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

Levitt, J. 1980. Response of plants to environmental stress. 2nd ed., Vol 2. Academic Press, New York.

Qian, Y., and J.D. Fry. 1997. Water relations and drought tolerance of four turfgrasses. J. Amer. Soc. Hort. Sci. 122(1): 129-133.

Su, K., D.J. Bremer, S.J. Keeley, and J.D. Fry. 2008. Rooting characteristics and canopy response to drought of turfgrasses including hybrid bermudagrass. Agron. J. 100 (4): 949-956.

Taliaferro, C.M., F.M. Rouquette, Jr., and P. Mislevy. 2004. Bermudagrass and stargrass. *In* L.E. Moser et al. (ed.) Warm-season (C4) grasses. Agron. Monogr. 45. ASA, CSSA, and SSSA, Madison, WI.

van Bavel, C.H.M., R. Lascano, and D. R. Wilson. 1978. Water relations of fritted clay. J. Soil. Sci. Soc. Am. 42 (4): 657-659.

Youngner, V.B. 1985. Physiology of water use and water stress, p. 37-43. *In* V.A. Gibeault and S.T. Cocker ham (ed.) Turfgrass water conservation. Univ. of Calif., Riverside, Coop. Ext. Publ. 21405.

Table 21. Total root length, surface area, average diameter and volume of eight bermudagrass entries from 0-120 cm depth[z], as calculated using Win-Rhizo scanning software.

Soil Depth (cm)	Bermudagrass Entries	Length (cm)	Surface Area (cm^2)	Average Diameter (mm)	Volume (cm^3)
0-120	Celebration	18403 a[y]	946.59 a	0.62 a	3.93 a
	Tifsport	13638 a	656.86 a	0.46 b	2.49 b
	Patriot	17143 a	813.01 a	0.53 ab	3.09 ab
	OKC 1119	17442 a	850.47 a	0.66 a	3.33 ab
	OKC 1134	14921 a	769.37 a	0.59 a	3.21 ab
	#2	16672 a	875.63 a	0.60 a	3.71 a
	#12	14926 a	759.34 a	0.57 ab	3.11 ab
	# 17	17268 a	826.69 a	0.55 ab	3.18 ab

[z] Growth tubes were made from clear polyethylene tubing (3.5 cm diameter x 120 cm length).

[y] Means followed by same letters within each column are not significantly different at the P = 0.05 significance level according to Duncan's multiple range test.

Table 22. Total shoot dry weight, root dry weight, and root-to-shoot ratio of eight bermudagrass entries from 0-120 cm depth[z].

Soil Depth (cm)	Bermudagrass Entries	Shoot Dry Weight[y] (g)	Root Dry Weight (g)	Root/Shoot Ratio
0-120	Celebration	5.75 ab[x]	0.76 a	0.13 a
	Tifsport	4.59 c	0.44 c	0.09 b
	Patriot	4.85 bc	0.49 bc	0.10 b
	OKC 1119	5.06 bc	0.67 ab	0.13 a
	OKC 1134	5.36 abc	0.64 ab	0.11 ab
	#2	5.50 abc	0.71 a	0.12 a
	#12	6.28 a	0.66 ab	0.09 b
	# 17	5.66 ab	0.64 ab	0.11 ab

[z] Growth tubes were made from clear polyethylene tubing (3.5 cm diameter x 120 cm length).

[y] Dry weights were determined after drying at 80° C for 48 hours.

[x] Means followed by same letters within each column are not significantly different at the P = 0.05 significance level according to Duncan’s multiple range test.

Table 23. Root length, surface area, average diameter, volume, and dry weight of eight bermudagrass entries from 0-7.5, 7.5-15, and 15-30 cm depths[z], as calculated using Win-Rhizo scanning software.

Soil Depth (cm)	Bermudagrass Entries	Root Length (cm)	Surface Area (cm^2)	Average Diameter (mm)	Volume (cm^3)	Root Dry Weight[y] (g)
0 - 7.5	Celebration	4121.1 cd[x]	245.5 bc	0.82 ab	1.17 b	0.29 ab
	Tifsport	3348.6 d	173.8 d	0.59 c	0.72 c	0.16 c
	Patriot	3595.1 d	186.6 cd	0.64 bc	0.77 c	0.17 c
	OKC 1119	4879.3 bc	258.8 b	0.93 a	1.09 b	0.27 b
	OKC 1134	4910.2 bc	272.5 b	0.92 a	1.22 b	0.29 ab
	#2	6288.9 a	361.2 a	0.98 a	1.66 a	0.37 a
	#12	4466.6 cd	256.1 bc	0.81 ab	1.17 b	0.29 ab
	# 17	5973.6 ab	313.5 ab	0.88 a	1.31 b	0.31 ab
7.5-15	Celebration	5516.9 ab	275.5 a	0.64 ab	1.10 a	0.21 a
	Tifsport	3977.9 c	187.0 c	0.47 c	0.70 c	0.10 c
	Patriot	4400.2 bc	204.5 bc	0.46 c	0.75 bc	0.12 bc
	OKC 1119	5918.0 a	277.8 a	0.72 a	1.04 ab	0.20 a
	OKC 1134	4671.3 abc	226.6 abc	0.59 abc	0.88 abc	0.18 ab
	#2	5027.1 abc	252.1 abc	0.57 bc	1.01 ab	0.18 ab
	#12	3785.8 c	189.9 c	0.56 bc	0.76 bc	0.16 abc
	# 17	5771.2 ab	264.5 ab	0.56 bc	0.96 abc	0.17 ab
15-30	Celebration	6052.5 a	292.1 a	0.57 a	1.12 a	0.18 a
	Tifsport	3740.8 b	169.7 c	0.36 c	0.61 c	0.10 b
	Patriot	5944.6 a	269.8 ab	0.52 ab	0.97 ab	1.13 b
	OKC 1119	5104.6 ab	235.8 abc	0.55 a	0.87 abc	0.14 ab
	OKC 1134	3738.2 b	186.7 bc	0.51 ab	0.75 bc	0.11 b
	#2	3894.4 b	187.3 bc	0.45 abc	0.72 bc	0.11 b
	#12	4144.5 b	193.4 bc	0.39 bc	0.71 bc	0.13 b
	# 17	4206.2 b	187.3 bc	0.46 abc	0.66 bc	0.11 b

[z] Growth tubes were made from clear polyethylene tubing (3.5 cm diameter x 120 cm length) and were sections were cut for analysis from 0-7.5, 7.5-15, 15-30, 30-60, 60-90, and 90-120 cm depths.

[y] Root dry weight determined after drying at 80° C for 48 hours.

[x] Means followed by same letters within each column are not significantly different at the P = 0.05 significance level according to Duncan’s multiple range test.

Table 24. Root length, surface area, average diameter, volume, and dry weight of eight bermudagrass entries from 30-60, 60-90, and 90-120 cm depths[z], as calculated using Win-Rhizo scanning software.

Soil Depth (cm)	Bermudagrass Entries	Root Length (cm)	Surface Area (cm^2)	Average Diameter (mm)	Volume (cm^3)	Root[y] Dry Weight (g)
30-60	Celebration	2677.3 ab[x]	130.7 ab	0.35 a	0.51 a	0.07 a
	Tifsport	2354.0 abc	115.2 abc	0.31 a	0.40 ab	0.06 a
	Patriot	2935.5 a	140.5 a	0.34 a	0.53 a	0.06 a
	OKC 1119	1439.3 c	71.8 c	0.25 a	0.28 b	0.04 a
	OKC 1134	1543.3 bc	80.2 bc	0.32 a	0.33 ab	0.05 a
	#2	1384.9 c	69.9 c	0.24 a	0.28 b	0.04 a
	#12	2281.7 abc	106. 8 abc	0.32 a	0.39 ab	0.06 a
	# 17	1302.7 c	60.4 c	0.24 a	0.22 b	0.03 a
60-90	Celebration	35.1 cd	2.8 a	0.10 a	0.02 a	0.0022 a
	Tifsport	197.9 abc	10.2 a	0.13 a	0.04 a	0.0049 a
	Patriot	206.1 ab	10.8 a	0.12 a	0.05 a	0.0056 a
	OKC 1119	85.9 abcd	5.2 a	0.11 a	0.03 a	0.0033 a
	OKC 1134	57.6 bcd	3.4 a	0.13 a	0.02 a	0.0027 a
	#2	77.0 abcd	4.9 a	0.14 a	0.03 a	0.0029 a
	#12	228.9 a	11.7 a	0.14 a	0.05 a	0.0069 a
	# 17	14.5 d	1.0 a	0.05 a	0.01 a	0.0007 a
90-120	Celebration	0.0 b	0.0 b	0.00 b	0.000 b	0.0000 b
	Tifsport	19.0 a	1.0 a	0.02 a	0.004 a	0.0010 a
	Patriot	11.2 a	0.8 a	0.06 a	0.004 a	0.0005 a
	OKC 1119	15.0 a	1.0 a	0.06 a	0.006 a	0.0012 a
	OKC 1134	0.0 b	0.0 b	0.00 b	0.00 b	0.0000 b
	#2	0.0 b	0.0 b	0.00 b	0.00 b	0.0000 b
	#12	19.0 a	1.6 a	0.06 a	0.010 a	0.0007 a
	# 17	0.0 b	0.0 b	0.00 b	0.00 b	0.0000 b

[z] Growth tubes were made from clear polyethylene tubing (3.5 cm diameter x 120 cm length) and were sections were cut for analysis from 0-7.5, 7.5-15, 15-30, 30-60, 60-90, and 90-120 cm depths.

[y] Root dry weight determined after drying at 80° C for 48 hours.

[x] Means followed by same letters within each column are not significantly different at the P = 0.05 significance level according to Duncan's multiple range test.

VITA

Bishow Prakash Poudel

Candidate for the Degree of

Master of Science

Thesis: TESTING OF CLONAL BERMUDAGRASS CULTIVARS AND EXPERIMENTAL GENOTYPES FOR DIFFERENCES IN DROUGHT PERFORMANCE

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Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: TESTING OF CLONAL BERMUDAGRASS CULTIVARS AND EXPERIMENTAL GENOTYPES FOR DIFFERENCES IN DROUGHT PERFORMANCE

Pages in Study: 92 Candidate for the Degree of Master of Science

Major Field: Horticulture

Scope and Method of Study:

Bermudagrass is used in many parts of the world as a forage crop and as turfgrass in sports fields, golf courses and lawns. Selection and identification of drought resistant bermudagrass cultivars under acute or chronic drought stress is important for sustainable turfgrass management and water conservation. The objective of this research were to: 1) identify differences in overall field drought performance of selected industry standard and OSU experimental bermudagrass entries; and 2) evaluate and explain differences in root growth characteristics of selected clonal industry standard and OSU experimental bermudagrass entries. This research was conducted at the Oklahoma State University Turfgrass Research Center in Stillwater, OK. Twenty-three clonal bermudagrasses were used in the field study for objective 1 while eight clonal bermudagrasses were used in the greenhouse study for objective 2.

Findings and Conclusions:

Based on the overall results from the field study, the hypothesis that were differences in bermudagrass entries for their field drought performance was accepted. At the 0% ET irrigation level, the OSU experimental bermudagrasses that performed lower than Celebration but better than all other entries were #2, #12, #16, #24, and #27. At the 33% ET irrigation level, Celebration, #2, #12, and #27 performed better than all other bermudagrass entries. Based on the overall results from the greenhouse study, the hypothesis that there were differences in bermudagrass entries for their root growth characteristics was accepted. Celebration, OKC 1119, and #2 have great genetic potential for improved drought performance if proper root growth occurs during the year before a drought event. Tifsport, Patriot, and #12 did not perform as well as Celebration, OKC 1119, and #2 in this study and thus may not have great genetic potential for improved drought performance due to rooting characteristics.

ADVISER'S APPROVAL: Dr. Justin Q. Moss