IDENTIFICATION AND EVALUATION OF DROUGHT RESISTANT CULTIVARS AND EXPERIMENTAL GENOTYPES OF FOUR WARM SEASON GRASSES

By

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Bachelor of Science in Agriculture

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Kathmandu, Nepal

2011

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 2015

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ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my major advisor, Dr. Justin Q. Moss, for his enduring guidance and motivation throughout my stay at Oklahoma State University (OSU). I highly appreciate the way he explained minute details in my study and encouraged me to think out of the box. I would like to thank my committee members Dr. Dennis L. Martin and Dr. Yanqi Wu for their continuous support, suggestions, and guidance. This research would not have been accomplished had I not been under the guidance of my major advisor and committee members.

I would like to thank Dr. Kemin Su for guiding me in my research. I highly appreciate his help, teaching me each simple but crucial step to carry out research. It was one of the best opportunities to work with one of the great minds at OSU. I would like to mention and thank Dr. Mike Smith and Dr. Mark Payton for their help in statistical analysis.

At the end, I would like to thank Bijay Poudel and Madhav Bhatta for providing an emotional support through my ups and downs. It demands huge encouragement, support, motivation, and guidance to be able to reach this stage. I thank all of you and God as well for allowing me to meet with different people with great minds.

Name: RACHANA POUDEL

Date of Degree: JULY, 2015

Title of Study: IDENTIFICATION AND EVALUATION OF DROUGHT RESISTANT CULTIVARS AND EXPERIMENTAL GENOTYPES OF FOUR WARM SEASON GRASSES

Major Field: HORTICULTURE

Abstract: The objective of this study was to identify drought resistant experimental genotypes or cultivars of four commonly used warm season grasses. Bermudagrass (*Cynodon* spps.), zoysiagrass (*Zoysia* Willd.), St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze], and seashore paspalum (*Paspalum vaginatum* Swartz) were used in this study. In this project, drought resistance of the 13 bermudagrass, 13 zoysiagrass, 12 St. Augustinegrass, and 7 seashore paspalum lines were separately studied by evaluating turf quality, leaf firing, normalized difference vegetation index (NDVI), and percent green cover (digital image analysis). All of these parameters were highly correlated. Although lines among the species were not compared, all grasses of the four species responded within one week of stopping watering. Ratings during the dry down cycle were collected until all grasses reached 30% green cover. Though all the grasses were completely leaf fired by 28 days, drought stress was extended up to 90 days. After 90 days of drought all the grasses were re-watered but no grass species survived. The performance of experimental genotypes 'OKC 1302' (bermudagrass) and 'UGP 10' (seashore paspalum) were better than rest of the entries of each species. None of the experimental genotypes of zoysiagrass and St. Augustinegrass performed better than the commercial cultivar 'Zeon' and 'Raleigh' respectively.

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CHAPTER I

LITERATURE REVIEW

Warm Season Grasses

Warm season grasses can grow at temperatures ranging from 27 to 35^{o} C. These grasses are of tropical origin and are adapted to warm humid, warm sub-humid, and semi-arid environments (Beard, 1973). Nearly fourteen warm season grass species are used in the turf industry (Beard, 1973). Common bermudagrass (*Cynodon dactylon* var. *dactylon* L pers.,), seashore paspalum (*Paspalum vaginatum* Swartz), St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze], and zoysiagrass (*Zoysia* Willd.) are widely used warm season grasses in the southern zone of the United States (Duble, 2001). High tolerance to low mowing, drought, heat, and salinity makes them the ideal choice for areas prone to these abiotic stresses.

Warm season grasses are commonly known as C_4 grasses, whereas cool season grasses are known as C_3 grasses. The principle difference between cool season and warm season grass lies in their photosynthesis pathway (Moser et al., 2004). The first stable carbon compound produced in the Calvin cycle/C_3 cycle is phosphoglyceric acid, a three carbon compound (Moser et al., 2004). In C_4 plants, the first stable carbon compound is oxaloacetic acid (OAA), a four carbon compound (Ghannoum, 2009). The C_3 cycle occurs in all plants, whereas the C_4 cycle occurs in C_4 plants only. Ribulose- 1,5-biphosphate carboxylase or oxygenase (rubisco) is the initial enzyme in the C_3 cycle (Moore et al., 2004). Under a condition of low atmospheric carbon dioxide (CO_2) and high oxygen (O_2), rubisco oxygenate ribulose- 1,5-biphosphate which results in a decrease in the efficiency of photosynthesis due to the occurrence of photorespiration (Bell, 2011). The advantage of the C_4 cycle over the C_3 cycle is that the C_4 plants act as the CO_2 concentrating mechanism (Bell, 2011). The first step of the C_4 cycle begins in mesophyll cells (Ghannoum, 2009). In mesophyll cells, CO_2 is hydrated to bicarbonate which reacts with phosphoenolpyruvate with the help of phosphoenolpyruvate carboxylase (PEPC) enzyme (Bell, 2011). The resulting compound OAA is decarboxylated in the bundle sheath releasing CO_2 fixation for rubisco enzyme and the rest of C_3 cycle occurs (Bell, 2011). This phenomenon of C_4 plants helps in the suppression of photorespiration and the saturation of C_4 photosynthesis at a lower ambient CO_2 than for C_3 plants (Moser et al., 2004). When C_4 plants experience drought, the CO_2 concentrating mechanism of C_4 plants mitigate the effect of water stress on plant performance by improving the plant water status as a result of decreased stomatal conductance and reduced leaf transpiration (Ghannoum, 2009).

Bermudagrass

Bermudagrass is a perennial warm season turfgrass which belongs to the family *Poaceae*, subfamily *Chloridoideae*, and tribe *Cynodonteae* (Hanna et al., 2013). The common bermudagrass and interspecific hybrids of common and African bermudagrass (*C. transvaalensis* Burtt Davy) are the most important grasses in the turf industry (Taliaferro et al., 2004). African bermudagrass has the finest texture and highest shoot density of the *Cynodon* species (Beard, 1973). It has yellow green erect leaves which turn to a reddish - purple color upon exposure to low temperatures. The common bermudagrass has a different name in different parts of the world. It is also known as ‘kweek’ and ‘quick’ grass in South Africa, ‘devil’s’ grass in India, ‘couch’ grass in Australia and Africa, ‘gramillia’ in Argentina , and ‘tooth grass’ in China (Duble, 2001). Three major races of common bermudagrass are tropical, temperate, and seleucidus race (Harlan and de Wet, 1969). The tropical race has adapted to leached, acid soils and to drought and water logged conditions. The temperate race is winter hardy but susceptible to disease and less tolerant to a low fertile, acid, and waterlogging soil. Plants of the seleucidus race are very winter hardy, tall and highly productive in fertile soil (Taliaferro et al., 2004). Of the three races, plants belonging to the seleucidus race are coarser than the temperate and tropical races (Taliaferro et al., 2004).

Bermudagrass is a predominantly used warm season turfgrass species in the southern regions of the United States (Duble, 2001). It is adapted throughout the warm humid and warm semi-arid regions of the world (Beard, 1973). Most of the turf type bermudagrasses originated in eastern Africa (Beard, 1973). Bermudagrass produces a very dense and a high quality turf cover. It is adapted in a broad range of soil pH, fertility, and textures.

The drought and wear tolerance of bermudagrass is excellent. However, poor performance at low temperatures and low light intensity (shade) has limited bermudagrass use in cool and shaded environments (Hanna et al., 2013). It is used on lawns, parks, fairways, greens, tees, roughs, roadsides, and athletic fields. It is also used for forage. Pointed leaf tips, variable internodes in the same plants, and folded vernation are the characteristic features of bermudagrass (Beard, 1973). The hybridization of the common bermudagrass and African bermudagrass results in sterile interspecific triploid hybrids which do not produce seeds (Hanna et al., 2013). That's why all hybrid bermudagrasses are propagated vegetatively by sprigs, sods, or plugs. Common bermudagrass is a cross pollinated tetraploid and produces viable seeds (Duble, 2001).

Zoysiagrass

Zoysiagrass is a perennial warm season grass which belongs to the family *Poaceae*, subfamily *Chloridoideae*, and tribe *Zoysieae* (Hanna et al., 2013). On the basis of morphological and molecular variation (DNA RFLP fingerprints), 11 species are found in genus *Zoysia* (Anderson, 2000). The important cultivated species that are used in the turf industry are: *Z. japonica* (Steud.), commonly known as Japanese lawngrass or Korean lawngrass; *Z. matrella* (L.) Merr, commonly known as manilagrass; and *Z. tenuifolia* Willd. ex Trin, commonly known as mascarenegrass or Korean velvetgrass (Beard, 1973; Hatch & White, 2004). *Zoysia japonica* is coarse textured (leaf width of 3 mm or more), lower in shoot density, and superior in low temperature hardiness than *Z. matrella* and *Z. tenuifolia* (Beard, 1973). Zoysiagrass forms a uniform, dense sod which makes it very competitive with weeds (Beard, 1973). Due to high dense sod and a very stiff leaf and stem, this grass is difficult to mow. Leaf blades are smooth and sharply pointed. High silica content in the leaf makes the leaf blades of this grass very stiff (Duble, 2001). Auricles are absent in this grass. It is cross pollinated and has a protogynous flower (Hatch & White, 2004). Zoysiagrass was first introduced to the United States from Japan. The center of origin is near south-eastern Asia and Indonesia (Anderson, 2000). Zoysiagrass is widely adapted along the Atlantic coast from Florida to Connecticut, the Gulf coast to Texas, and in California (Duble, 2001). It is popularly used throughout the transition zone of the United States. It has adapted to a wide range of soil types from sand to clays (Duble, 2001) having a pH of 6 to 7. This grass grows best on well drained and fertile soil. This grass is tolerant to abiotic stress like drought, salt, shade, and traffic/wear. The use of this grass on athletic fields is limited because of its slow recuperative ability.

Zoysiagrass is propagated by sprigs, sod plugs, and seeds (Beard, 1973; Duble, 2001). Zoysiagrass spreads by an integration of thick stolons and rhizomes which form very tight, vigorous, tough, and prostrate growing turf. Zoysiagrass is used for lawns, golf greens, fairways and tees, and sports fields. The slow growing zoysiagrass is used as buffer strips between bentgrass greens and bermudagrass fairways to restrict encroachment of bermudagrass (Beard, 1973). In Japan and other native habitats it is used for forage (Ogura et al., 2001).

Seashore Paspalum

Seashore paspalum is a perennial grass which belongs to the *Poaceae* family, *Panicoideae* subfamily, and tribe *Paniceae* (Hanna et al., 2013). This grass is also known as slit grass or sand knotgrass and salt water couch (Duncan and Carrow, 2000). This grass grows on sandy beaches, banks of coastal rivers, and banks of estuaries which are rich in salt water (Duncan and Carrow, 2000). This grass was transported to different parts of the world as a bedding material in slave boats and as a hardy grass against salt affected areas (Duncan and Carrow, 2000). In the United States, seashore paspalum grows along the Atlantic coast from North Carolina to Florida and the Gulf coast from Florida to southern Texas (Duncan and Carrow, 2000; Evers and Burson, 2004). Seashore paspalum is a sexually reproduced, cross pollinating diploid grass which is well adapted to coastal regions in tropical and sub-tropical environments (Hanna et.al. 2013). It is heterozygous and rarely pollinates with other paspalum grasses. The vegetative propagation in paspalum grass is via sprig and sod. The coarse textured paspalum is used on roadsides, whereas fine textured paspalum is used on golf courses, athletic fields, and home lawns or any other recreational areas (Duncan and Carrow, 2000). It has folded vernation and auricles are absent in the plant. The ligule is membranous and hairy, whereas inflorescence has two racemes. Seashore paspalum has a stoloniferous and a rhizomatous growth habit. This grass is considered a boon especially in a coastal area. Due to the prevalence of high salinity and salinity induced stresses in the coastal area, it is a challenge to maintain high turf quality. Seashore paspalum is considered to be an environmentally friendly turfgrass (Duncan and Carrow, 2000). Seashore paspalum is tolerant to salinity and drought (Huang et al., 1997). Indeed, Duncan and Carrow (2000) stated that this grass turf quality is similar to or better than alternative turfgrass species when grown in a high stress environment. The usage of seashore paspalum varies from aesthetic to forage purposes.

St. Augustinegrass

St. Augustinegrass is a perennial grass which belongs to the family *Poaceae*, subfamily *Panicoideae*, and tribe *Paniceae*. This grass is native to the West Indies (Beard, 1973), Gulf of Mexico region, and Western Africa (Duble, 2001). Sometimes St. Augustinegrass is also known as ‘carpetgrass’ in the southeastern United States and in California, ‘crabgrass’ in Bermuda and the West Indies, ‘gramillon’ in Argentina, ‘wiregrass’ in Saint Helena, and ‘buffalograss’ in Australia and the South Pacific (Duble, 2001). The leaf sheaths are flat. The leaf blades are folded and rounded at the tip (Beard, 1973).

St. Augustinegrass has adapted to moist, coastal areas with mild winter temperatures (Duble, 2001). It is best grown on moist, well drained, fertile, sandy loam soil with pH varying from 6.5 to 7.5 (Beard, 1973). Temperature and moisture are the two limiting factors for the wide distribution of St. Augustinegrass. It has a lower temperature hardiness compared to other commonly used warm season turfgrasses (Beard, 1973). Though it is less drought resistant than bermudagrass, zoysiagrass and bahiagrass (*Paspalum notatum* Flugge), it is more shade tolerant than other warm season turfgrasses (Hanna et al., 2013). Fall color retention and spring green up ratings are inferior to bermudagrass and zoysiagrass (Beard, 1973). St. Augustinegrass can tolerate and maintain satisfactory growth at salt levels as high as 1.6 S m^{-1} (Duble, 2001).

St. Augustinegrass is propagated vegetatively by stolons, plugs or sod. Due to poor seed set and unbalanced chromosome numbers extensive studies has not been done in seed-propagation (Hanna et al., 2013; Duble, 2001). It is a coarse textured grass that does not produce rhizomes. It is mainly used for lawns and forage. It is not used in athletic fields and golf courses because it does not tolerate traffic stress. This grass is a widely used lawn grass in Florida and has been planted since the 1890s for lawns (Duble, 2001).

Drought

Drought is an abiotic stress experienced by plants due to a limited supply of water. Plants have an interesting mechanism for continuing their life cycle during drought stress. In a condition where water absorption by a plant is lower than water expenses, an imbalance is created in the plants (Levitt, 1972). If at that time plants do not get sufficient moisture to restore the balance, a stress is felt. Prolonged shortage of moisture at that stress level is characterized as drought. During drought stress, a plant begins to show its stress level beginning with retarded growth, wilting of the leaves, and biochemical changes (Blum, 1988). It either succumbs to drought stress leading to the permanent death of the tissues or enters to an inactive phase, i.e. becomes dormant (Farooq et al., 2012).

Drought Resistance

Drought resistance is a defense mechanism executed by plants in response to a water deficit stress. Plants undergo several physiological and biochemical changes at the subcellular and cellular level to execute these defense mechanisms (Farooq et al., 2012). A drought resistant plant survives water deficit stress by escape, avoidance, and tolerance or a combination of one or all mechanisms (Turner, 1986).

Drought Escape

Drought escape is the ability of plants to escape the drought period by adjusting their life cycle. In the area of a terminal drought, this resistance mechanism is of major concern.

Meyre et al. (2001) found that short duration cultivars frequently escape a terminal drought compared to late maturing cultivars. Annual grasses complete their life cycle before the onset of drought, whereas perennial grasses become dormant during drought periods (Huang, 2008). Under limited water supply, desert annuals exhibit a shorter vegetative growth phase, fewer flowers and seeds. When water supply is ample, plants show vigorous vegetative growth, more flowers and seeds.

Drought Avoidance

The ability of plants to withstand drought by maintaining high tissue water potential is known as drought avoidance. The key point here is that plants do not avoid the drought; they avoid tissue dehydration. Plants try to maintain high tissue water potential by maintaining the water uptake or by reducing the loss of water (Blum, 2005). Water uptake is maintained by extending the root growth deeper into the soil or by increasing the root density to absorb more water from a greater volume of the soil or by increasing hydraulic conductance of the plants (Plaeg and Aspinall, 1981). High conductance of plants or low hydraulic resistance is required for the efficient distribution of water to whole plant body. Plants reduce the loss of water by reducing the evaporative surface, absorbed radiation, and epidermal conductance (Huang, 2008).

Drought Tolerance

The ability of plants to resist drought stress at a low tissue water potential is known as drought tolerance (Levitt, 1970). Mechanisms for drought tolerance include osmotic adjustment, membrane stability, and accumulation of proteins and other metabolites (Huang, 2008). Plants accumulate different organic and inorganic solutes when exposed to water stress; this characteristic of a plant is referred to as an osmotic adjustment (Huang, 2008). Osmotic adjustment facilitates a plant in maintaining leaf turgor to improve stomatal conductance and in promoting the root's ability to uptake more water. An association of osmotic adjustment and increased drought tolerance has been reported in zoysiagrass (Qian and Fry, 1997) and Kentucky bluegrass (*Poa pratensis* L.) (Jiang and Huang, 2001). Once drought stress is removed the compatible solutes are remobilized for plant regrowth. The increased solutes are called compatible solutes because they do not have any negative effects on enzymes and other macromolecules at a higher concentration (Plaeg and Aspinall, 1981). Plant tissue with high elasticity has a greater ability to maintain turgor pressure (Blum, 1988).

Turfgrass, Water and Drought

Turfgrass occupies 50 million acres (20.2 million ha) of land in the United States with an estimated annual economic value of $40 billion (Breuninger et al., 2013). Turfgrass is used in lawns, athletic fields, golf courses, parks and other recreational areas. The aesthetic scenes created by turfgrass allure the eyes of many people. The turf industry plays a significant role in creating economic opportunities in lawn care companies, athletic and park facilities, golf courses, sod and seed producers, and other industries which supply chemicals, fertilizers and necessary equipment used on turf (Breuninger et al., 2013). In the United States, 1,504,210 acres of maintained turfgrass were estimated on golf facilities (Throssell et al., 2009). It was estimated that 80% of maintained turfgrass (1,198,381 acres) was irrigated (Throssell et al., 2009). Though the turfgrass industry is prospering, challenges like water use, fertilizer use, and pesticide use for healthy turf are burgeoning making it a sensitive and tough issue. Supplying water for landscape areas and golf courses located in urban areas are of major concern.

Water is a natural resource that is limited and has no alternatives for its use. The demand for water has increased by more than 300% during the past five decades (Huffman, 2004). With an upsurge in demand but only a fixed supply of water, water conservation/sustainable use of water has become a burning topic. Because of climate change, population increase, and migration to urban areas, water shortages are very likely to increase in the future. Of the available water, 0.03 percent is considered to be useable fresh water. In the United States, daily water withdrawal was 408 billion gallons of water; fresh water withdrawals were 85% of the total (Breuninger et al., 2013). The foremost and logical step in water conservation is improving water use in agriculture because about 70% of usable fresh water is used in agricultural irrigation. In a hot, dry urban region, the use of a low water consuming plant, also called xeriscape, is an appropriate choice to conserve water in landscape areas.

Drought can occur from desert to humid regions. Prolonged drought stress is detrimental for plant growth (Beard, 1973). This requires a selection of a better plant which can maintain plant growth under a drought stress condition. Though selecting turfgrass varieties based on low evapotranspiration (ET) is a key water conservation strategy, this strategy alone does not correlate well with plant performance during drought stress (Sun et al., 2013). Tall fescue (*Festuca arundinacea* Schreb.), a drought resistant cool season turfgrass, has a higher ET rate than other drought sensitive turfgrass species (Sun et al., 2013). Several strategies against drought stress vary from species to species and even within species of plants. Plants that are able to survive drought stress by means of drought avoidance, drought tolerance at low leaf water potential, or both are considered to have good drought resistance.

Past Drought Research in Turfgrasses

Numerous studies on drought have been carried out to date with no sign of slowing down. Through several studies on drought, many drought resistance cultivars/species are being used in the turf industry. However, a sufficient amount of water is required to harbor high turf quality. The best way to overcome drought stress is to select the drought resistant species (Carrow, 1996).

Qian and Fry (1997) carried out a greenhouse study about the water relations and drought tolerance of four turfgrasses. On the basis of response to drought, drought survival, and magnitude of osmotic adjustment, warm season grasses were found to be superior to tall fescue, a cool season grass. Carrow (1996) evaluated seven commonly used turfgrasses in the turf industry for their drought resistance. These grasses were ranked on the basis of their leaf firing and wilt data. ‘Tifway’ bermudagrass and common bermudagrass were more drought resistant compared to other grasses. Bermudagrasses were followed by ‘Raleigh’ St. Augustinegrass and common centipedegrass [*Eremochloa ophiuroides* (Murno.) hack.], ‘Rebel II’ tall fescue, ‘K-31’ tall fescue, and ‘Meyer’ zoysiagrass for their drought resistance. Steinke et al. (2011) evaluated commonly grown and marketed eight cultivars of bermudagrass (‘Celebration’, ‘Common’, ‘GN1’, ‘Grimes Exp’, “Premier’, ‘TexTurf’, ‘Tifsport’, and Tifway) and one cultivar of buffalograss (‘609’) [*Buchloe dactyloides* (Nutt.) Engelm.] in the San Antonio, TX area in order to identify drought response of these turfgrasses. A 60 day drought stress was followed by a 60 day recovery period in 2006 and 2007. This study was conducted on the native agricultural soil (unrestricted root growth) and on the 10 cm soil depth (restricted root growth). It was found that no bermudagrass or buffalograss cultivars were able to survive a 60 day drought stress on a shallow (10 cm) soil profile; cultivars were completely browned off during the first 20 days of the drought stress in both years. All grasses survived a 60 day drought stress on the native soil profile. Premier bermudagrass showed the poorest turf quality by the end of a 60 day drought stress. 'Celebration' bermudagrass showed the best drought tolerance in both years. Overall, Celebration and TexTurf bermudagrass were found to be more drought resistant than other grasses in the study. Those grasses which lose green color slowly during the stress were the quickest to recover from drought stress once they were re-watered. Celebration and TexTurf bermudagrass reached to 50% green cover in 1.8 and 4.4 days respectively. Premier bermudagrass was the slowest to recover in both study years. The St. Augustinegrass cultivars were studied for their drought response and recovery by Steinke et al. (2010). The St. Augustine cultivars were 'Amerishade', 'Common', 'Delmar', 'Floratam', 'Palmetto', Raleigh, and 'Sapphire'. The study procedure was similar with the one carried out by Steinke et al. (2011), which has been described above. Sapphire and Floratam were the most drought tolerant cultivars. Palmetto and Raleigh were the least drought tolerant cultivars. None of the St. Augustinegrasses survived 60 days drought on shallow soil profile (10 cm).

Baldwin et al. (2006) conducted a greenhouse experiment to study drought tolerance of six bermudagrass cultivars. The bermudagrass cultivars used in the study were: 'SWI-1012', 'Arizona Common', 'Tift No. 3', Tifsport, 'Aussie Green', and Celebration. Three water stress treatments include five, 10, and 15 days irrigation intervals. Turf quality, evapo-traspiration rate (ET) and total root biomass were collected to analyze drought tolerance of the grasses. Turf quality (TQ) was rated visually from a scale 1 to 9: 1 = brown and dead turf, 7 = minimal acceptable turf, and 9 = healthy and green turf. Soil volumetric water content was measured in the top 15cm using a soil moisture sensor. After each drought treatment the lysimeters were brought back to field capacity. At five days irrigation interval, Celebration and Aussie Green were in the top statistical group throughout the study period (one month). Both of the grasses maintained acceptable TQ at week two. At the treatment 10 days irrigation interval and 15 days irrigation interval none of the grass showed acceptable turf quality. The root mass of the Celebration was higher than the other grasses. The root length was more in all of the cultivars at 15 days drought stress. The ET rate of Celebration was higher than other cultivars. According to this study, Celebration was more drought resistant than SWI-1012, Arizona common, Tift.No 3, Tifsport, and Aussie Green.

Kim and Beard (1988) compared drought resistance mechanisms of the 11 warm season turfgrasses. Commercially available cultivars of bermudagrass, seashore paspalum, St. Augustinegrass, zoysiagrass, centipedegrass, buffalograss, and bahiagrass were compared for their performance under drought stress. Bermudagrass (Arizona Common, ‘Tifgreen’, and ‘Textturf 10’), zoysiagrass (‘Emerald’ and Meyer) and centipedegrass (‘Georgia common’) possessed good drought resistance, whereas St. Augustinegrass (‘Texas Common’) and bermudagrass (Tifway) possessed poor drought resistance. The relative drought resistance of the zoysiagrass, bermudagrass, and centipedegrass was higher than bahiagrass, buffalograss, seashore paspalum, and St. Augustinegrass. St. Augustinegrass was found to have the lowest relative drought resistance. The shoot response during drought stress was studied to rank drought resistance of 7 warm season grasses in the 0-40 cm surface soil drying regime (Huang et al., 1997). Data on canopy temperature, leaf chlorophyll content, relative water content, and shoot dry matter production were used to rank the grasses. The grasses used on this study were: ‘TifBlair’ centipedegrass, ‘Adalayd’ paspalum, ‘Common’ bermudagrass, ‘Emerald’ zoysiagrass, ‘PI 509018’ paspalum, ‘AP14’ paspalum, and ‘PI 299042’ paspalum. There was no significant difference between the control (well-watered) and drought stressed TifBlair, PI 509018, AP14, and PI 299042 grasses in the soil surface drying regime 0-20 cm. PI 509018 showed the best drought resistance. In the 40 cm soil drying regime, TifBlair and PI 509018 were least influenced by drought stress. The superior drought resistance of the TifBlair and PI 509018 was associated with rapid root growth and water uptake from deep layers (Huang et al., 1997b). The best drought resistant paspalum genotype was later released as Sea Isle 1 (Duncan and Carrow, 2000).

Goals and Objectives

This study was a part of the Specialty Crops Research Initiative (SCRI) project: Plant Genetics and Genomics to Improve Drought and Salinity Tolerance for Sustainable Turfgrass Production in the Southern United States. This study included four warm season turfgrass species widely used in the turf industry: bermudagrass, zoysiagrass, seashore paspalum, and St. Augustine grass. Thirteen lines of bermudagrass and zoysiagrass each, 12 lines of St. Augustinegrass, and 7 lines of seashore paspalum were studied. The goal was to evaluate:

- The drought resistance of bermudagrass: commercially available standard cultivars, Oklahoma State University (OSU) experimental lines, and University of Georgia (UG) experimental lines.
- The drought resistance of seashore paspalum: commercially available standard cultivars and UG experimental lines.
- The drought resistance of zoysiagrass: commercially available standard cultivars, Texas A&M University (TAMU) experimental lines, and University of Florida (UF) experimental lines.
- The drought resistance of St. Augustinegrass: commercially available standard cultivars, North Carolina State University (NCSU) experimental lines, and TAMU experimental lines.

The objectives were to:

- Evaluate and rank entries of four turfgrass species on the basis of their visual quality, leaf firing, normalized difference vegetative index (NDVI) response, and percent green cover (digital image analysis) in response to acute drought stress.
- To evaluate relationships among all the parameters: turf quality, leaf firing, NDVI, and percent green cover using correlation analysis.

Research Hypothesis

There are significant differences in the performance of the entries within each species tested with respect to turf quality, leaf firing, NDVI, and percent green cover in response to acute drought stress.

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Table 1. Bermudagrass cultivars and experimental selections tested for drought resistance.

Entries	Notes
Celebration	Good drought tolerance[1]
Tifway	Good drought tolerance[2]
OKC 1302	OSU experimental
OSUB 1131	OSU experimental
OSUB 1163	OSU experimental
OSUB 1156	OSU experimental
OSUB 111	OSU experimental
OSUB 1117	OSU experimental
UGB 8	UG experimental
UGB 14	UG experimental
UGB 42	UG experimental
UGB 70	UG experimental
UGB 79	UG experimental

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[1] Steinke, K., D. Chalmers, J. Thomas, and R. White. 2011. Bermudagrass and buffalograss drought response and recovery at two soil depths. Crop Sci. 51:1215-1223.

[2] Qian, Y. and J.D. Fry. 1997. Water relations and drought tolerance of four turfgrasses. HortScience 122:129-133.

Table 2. Seashore paspalum cultivars and experimental selections tested for drought resistance.

Entries	Notes
Sea Isle 1	Good drought tolerance[1]
SeaStar	Good drought tolerance
UGP 1	UG experimental
UGP 3	UG experimental
UGP 10	UG experimental
UGP 38	UG experimental
UGP 79	UG experimental

[1] Huang, B., R.R. Duncan, and R.N. Carrow. 1997. Drought-resistance mechanisms of seven warm season turfgrasses under surface soil drying: I. Shoot response. Crop Sci. 37:1858-1863.

Table 3. Zoysiagrass cultivars and experimental selections tested for drought resistance.

Entries	Notes
Palisades	Good drought resistance[1,2]
Zeon	Good drought resistance[1]
Empire	Good drought resistance[1]
DALZ 1310	Texas A&M experimental
DALZ 1311	Texas A&M experimental
DALZ 1312	Texas A&M experimental
DALZ 1313	Texas A&M experimental
DALZ 1319	Texas A&M experimental
FAES 1303	UF experimental
FAES 1304	UF experimental
FAES 1305	UF experimental
FAES 1306	UF experimental
FAES 1307	UF experimental

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Table 4. St. Augustinegrass cultivars and experimental selections tested for drought resistance.

Entries	Notes
Floratam	Good drought tolerance[1]
Palmetto	Good drought tolerance[2]
Raleigh	Good drought tolerance
NCSA 17	NCSU experimental
NCSA 43	NCSU experimental
NCSA 65	NCSU experimental
NCSA 80	NCSU experimental
DALSA 1315	Texas A&M experimental
DALSA 1316	Texas A&M experimental
DALSA 1317	Texas A&M experimental
DALZA 1318	Texas A&M experimental
DALSA 1319	Texas A&M experimental

[1] Steinke, K., D. Chalmers, J. Thomas, R. White, and G. Fipps. 2010. Drought response and recovery characteristics of St. Augustinegrass cultivars. Crop Sci. 50:2076-2083.

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CHAPTER II

IDENTIFICATION AND EVALUATION OF DROUGHT RESISTANT CULTIVARS AND EXPERIMENTAL GENOTYPES OF FOUR WARM SEASON GRASSES

Water is a natural resource that is limited and has no alternatives for its replacement. An actively growing turfgrass contain 75 to 85% water by weight (Beard, 1973). Plants begin to wilt with a 10% decrease in water content (Beard, 1973). Because of climate change, population increase, and migration to urban areas, water shortages are very likely to increase in the future (Wherley et al., 2015). The availability of water for turfgrass irrigation is becoming more restricted, especially during hot and dry summer months, because 60 to 70% withdrawal of residential water use accounts for landscape irrigation in the summer (Greston et al., 2002; Merewitz et al., 2010), efficient irrigation coupled with a selection of drought resistant cultivars is the best way to overcome high water demand of turfgrass species. Over the years, significant efforts have been put to develop and evaluate turfgrass species with a better drought resistance. With an upsurge in demand but only a fixed supply of water, water conservation is a major issue, therefore, interest in identifying grasses with low water requirement is increasing with no sign of slowing down (Qian and Fry, 1997).

Drought resistance is acquired by plants undergoing several changes in morphological, physiological, and metabolic characteristics (Levitt, 1980). The response to drought stress varies between plant species and cultivars of same species. Turfgrasses use three mechanisms against drought stress: drought avoidance, drought tolerance, and drought escape (Huang, 2008).

Warm season grasses, characterized by C_4 photosynthesis, are widely adapted in a warm humid, warm sub-humid and warm semi-arid environment (Beard, 1973). Four commonly used warm season grasses in the southern United States are bermudagrass (*Cynodon* spp.), zoysiagrass (*Zoysia* Willd.), seashore paspalum grass (*Paspalum vaginatum* Swartz), and St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] (Duble, 2001).

The goal of this study was to evaluate drought resistant genotypes/cultivars of four warm season grasses. The objective was: to evaluate and rank genotypes/cultivars of four warm season grass species on the basis of visual quality (TQ), leaf firing (LF), normalized difference vegetative index (NDVI) response, and percent green cover (COVER) in response to acute drought stress. Our research hypothesis was: there were significant differences in the performance of the entries within each species tested with respect to TQ, LF, NDVI, and COVER in response to acute drought stress.

MATERIALS AND METHODS

A greenhouse study was conducted at Oklahoma State University (OSU) at the Ridge Road greenhouse facility located in Stillwater, OK. Plant materials were taken on 1 Oct. 2014 using a 4.25 inch cup cutter (10.8 cm diameter) from a one year old field located at the OSU Turfgrass Research Center in Stillwater, OK (36^{o} 07’ 06.76” N and 97^{o} 06’ 11.60” W). This study was a part of the United States Department of Agriculture (USDA) Specialty Crops Research Initiative (SCRI) project: Plant Genetics and Genomics to Improve Drought and Salinity Tolerance for Sustainable Turfgrass Production in the Southern United States (Project: 2010-51181-21064). This study included four warm season turfgrass species widely used in the turf industry: bermudagrass, zoysiagrass, seashore paspalum, and St. Augustinegrass. These grasses were established in a field on 22 July 2013. St. Augustinegrasses were severely affected by winterkill in 2013. So, St. Augustinegrasses were re-transplanted on 1 July 2014. At the time of sample collection for the greenhouse study, St. Augustinegrasses were only four months old.

Establishment

Polyvinyl Chloride (PVC) green sewer pipes (10.2 cm diameter) were used to construct the growing tubes for this study. The PVC pipes were cut to a 45 cm length (depth = 45.0 cm) and each was fitted with a PVC cap having a 1.0 cm diameter hole at the bottom to facilitate drainage. Drainage holes were covered with corks once fully drained. PVC tubes were filled with a mixture of sand and top soil [1 sand : 1 top soil (by volume)] (Su et al., 2009) and allowed to saturate. Full saturation was reached by continuous water application and allowing it to drain and re-watered again. The top soil and sand were sieved separately with a 0.2 cm net mesh to remove clumps and unwanted materials. The sod plugs of all the grasses were washed free of soil and any other unwanted materials. In the end, healthy and uniform sod plugs were transplanted to PVC tubes. Extra care was taken to avoid contamination among the grasses by working with only one entry at a time during transplanting the grasses in the PVC tubes. Zoysiagrasses were transplanted on 15 Oct. 2014. Seashore paspalum, bermudagrass, and St. Augustinegrass were transplanted on 6 Nov., 15 Nov., and 17 Nov. 2014 respectively.

Bermudagrass

A total of 13 genotypes were selected for the drought study. Two cultivars, ‘Celebration’ (Stienke et al., 2011) and ‘Tifway’ (Qian and Fry, 1997), were used as standard cultivars. Selected bermudagrass entries from OSU included the experimental lines ‘OSUB 111’, ‘OSUB 1117’, ‘OSUB 1131’, ‘OSUB 1156’, ‘OSUB 1163’, and ‘OKC 1302’. Selected bermudagrass entries from the University of Georgia (UG) included the experimental lines; ‘UGB 8’, ‘UGB 14’, ‘UGB 42’, ‘UGB 70’, and ‘UGB 79’. These experimental lines (except OKC 1302) were selected from 160 experimental lines of shared spaced plant nurseries (SSPN) in 2011. The 160 experimental lines were from the OSU turfgrass breeding & development program (80 entries) and the UG turfgrass breeding program (80 entries). Out of these entries 10 lines were advanced for more intensive test and evaluation for their drought resistance in 2013.

Seashore Paspalum

The experimental lines of seashore paspalum were taken from the UG turfgrass breeding program. Two standard cultivars were ‘Sea Isle 1’ (Huang et al., 1997) and ‘SeaStar’ (best turf quality, color, and texture on the basis of NTEP 2007-2009 evaluation). The five experimental genotypes included ‘UGP 1’, ‘UGP 3’, ‘UGP 10’, ‘UGP 38’, and ‘UGP 73’. These experimental genotypes were selected from 80 experimental lines of SSPN in 2011. The five best genotypes were advanced to study drought resistance in the replicated field trial (RFT) in 2013.

Zoysiagrass

The experimental lines of zoysiagrass were taken from the University of Florida (UF) turfgrass breeding program and the Texas A&M University (TAMU) breeding program. The standard cultivars were ‘Zeon’, ‘Empire’, and ‘Palisades’ (Patton, 2009; Wherley et al., 2015). The experimental lines from the UF were ‘FAES 1303’, ‘FAES 1304’, ‘FAES 1305’, ‘FAES 1306’, and ‘FAES 1307’. The experimental lines from the TAMU included ‘DALZ 1310’, ‘DALZ 1311’, ‘DALZ 1312’, ‘DALZ 1313’, and ‘DALZ 1314’. In total, there were 10 experimental genotypes and three commercial cultivars of the zoysiagrass. These experimental genotypes were selected for inclusion in the RFT; were selected from 160 lines in the 2011 SSPN in the year 2013.

St. Augustinegrass

The standard cultivars were ‘Palmetto’, ‘Raleigh’, and ‘Floratam’ (Stienke et al., 2010; Hatch and White, 2004). The experimental lines from the North Carolina State University (NCSU) turfgrass breeding program were ‘NCSA 17’, ‘NCSA 43’, ‘NCSA 65’, and ‘NCSA 80’, whereas the experimental lines from the TAMU turfgrass breeding program were ‘DALSA 1315’, ‘DALSA 1316’, ‘DALSA 1317’, ‘DALSA 1318’, and ‘DALSA 1319’. These experimental genotypes were advanced experimental lines from the 2011 SSPN. Five experimental lines from each university were used in the 2013 RFT.

Greenhouse Conditions and Cultural Management

The greenhouse air temperature was set at 32/25°C (day/night) and 76% average relative humidity (RH). The photosynthetically active radiation (PAR) readings were taken at 30 minute intervals by PAR sensors (WatchDog Micro Stations 1450, Spectrum Technologies, Plainfield, IL). The average PAR was 1200 μ mol m^{-2} s^{-1} throughout the study period. High pressure sodium (HPS) light was used for providing supplemental light. The photoperiod was 14 hours in the greenhouse.

During the first week after transplantation all the PVC tubes were placed under the automated mist system. The mist system was turned on five times per day for 3 minutes each time to keep the soil moist. After removing the grasses from the mist system, they were watered every three days to full saturation. The 20-8.8-16.6 NPK and water soluble general purpose fertilizer (J.R Peters Inc., Allentown, PA) was applied three times a week at 0.25 g N L^{-1}. Fertilizers were not applied after the treatment was started. The grasses were trimmed manually with scissors at a 5 cm height (bermudagrass and seashore paspalum) and at a 6 cm height (zoysiagrass and St. Augustinegrass) from the soil surface in 3 day intervals. A PVC ring was made to ensure uniformity in mowing. Mowing was continued for one more week after imposing drought stress. After this, mowing was halted to prevent any other stress to the grass other than from drought.

Though the grasses showed no sign of pest infestation when transferred to the greenhouse, pesticides were applied as a preventive measure. Pesticides were applied to prevent mealy bugs (*Pseudococcus spp*.) and eriophyid mites (*Eriophes cynodoniensis*). The grasses were sprayed with bifenthrin (Talstar Insecticide, FMC Agricultural

Solutions, Pennsylvania, PA) at the rate of 70.2ml/L along with the surfactant at the rate of 7.8ml/L. Pesticides application was repeated every week.

Drought Treatment

The planted materials were allowed to establish fully in PVC tubes for 70 days (bermudagrass, seashore paspalum, and St. Augustinegrass) to ensure proper root growth prior to introduction of drought stress. Considering the slow growing habit of zoysiagrasses, they were established for 100 days before the initiation of drought stress. Drought stress was introduced on: 15 Jan. in seashore paspalum, 23 Jan. in bermudagrass, 28 Jan. in zoysia grass and St. Augustinegrass. Before the irrigation was halted, all the PVC tubes were saturated to the field capacity of loam soil, i.e., 35-45% volumetric water content.

Data Collection

All measurements were taken every seven days after the initiation of a drought treatment. Data were collected at day 0, day 7, day 14, and day 21. On day 28, all the grasses were completely dormant and 100% leaf fired (data not shown). The data collection for drought stress was stopped once all the grasses had percent green cover less than or equal to 30%. However, drought stress was continued for 90 days and pots were re-watered to evaluate recovery of the grasses at that time. Drought stress was commenced on 23 Jan. 2015 in bermudagrass, 15 Jan. 2015 (seashore paspalum), and 28 Jan. 2015 (zoysiagrass and St. Augustinegrass). All data were tested at the p=0.05 level of significance. Parameters considered in this study are briefly described below.

Turf Quality: The visual assessment of aesthetic and functional aspects of the grass is known as turf quality (TQ). TQ rating is based on color, density, uniformity, texture, and disease or environmental stress (Turgeon, 2008). It is rated from 1 to 9 where 1 = poor quality turf, 9 = outstanding/ideal turf, and 6 = acceptable turf quality. Though turf quality is an important parameter considered in the turf industry but it is subjected to the bias of the evaluator.

Leaf Firing: The chlorosis of a leaf, starting from the leaf tips and margins and gradually progressing down the leaf, is known as leaf firing (LF) (Carrow, 1996). This is rated visually from 1 to 9 scale; 1 = completely yellow/dead and 9 = completely green.

Normalized Difference Vegetative Index: The normalized difference vegetative index (NDVI) was measured by the FieldScout CM 1000 NDVI meter (Spectrum Technologies Inc., 3600 Thayer Court Aurora, IL). This is calculated from the measured ambient and reflected light data (CM 1000 NDVI meter, Product Manual).

The NDVI value gives the relative measure of the greenness of the leaf. Before using this meter, several sets of sample data were recorded during different times of the day in a greenhouse to minimize error due to the temporal and spatial variations. Sample data taken during 12 to 2 PM central time showed a steady reading across days. When collecting the real sets of data (to be used in the data analysis), for precision, data were collected at the same spot in the greenhouse and the same time of the day. The lens was held 60 cm above the grass canopy.

Digital Image Analysis: Digital photographs were taken to analyze percent green cover (COVER). The digital images were analyzed individually by SigmaScan Pro software

(Systat Software, Inc., San Jose, CA 95100). This software counts the total number of green pixels of the selected image (Richardson et al., 2001). While analyzing the percent green cover of the images, hue and saturation threshold settings ranged from 30 to 140 and 0 to 100 respectively. To maintain uniformity of the light source and minimize errors due to the day of time and angle of the sunlight, a light box was utilized. Two fluorescent bulbs (LF Illumination, Chatsworth, CA) were fixed inside the box, which served as the artificial light source to facilitate in taking pictures. The images were taken by Canon PowerShot G16 12.1 MP CMOS (Melville, NY.)

Volumetric Soil Water Content: The volumetric soil water content (VSWC) is the fraction of the total volume of the soil that is occupied by the water contained in the soil. It is also known as volume wetness or volume fraction of soil water. If ‘V_i’ is the volume of water in the soil and ‘V_t’ is the total volume of the sample then the volumetric water content is given as V_i/V_t. For this research we used the HydroSenseTM (CS655-L, Campbell Scientific, Logan, UT) moisture sensor. VSWC was measured in the top 12 cm of the PVC tubes.

Statistical Analysis

The experimental design was a completely randomized design with six replications of each of the four turfgrasses. Repeated measure analysis with cultivar and replication as a repeated measure was done to generate an analysis of variance (ANOVA) using ‘PROC MIXED’ of Statistical Analysis System software (SAS, 2013) [SAS version 9.4., SAS Institute Inc., Cary, NC, USA]. The mean separation of all parameters: turf quality (TQ), leaf firing (LF), normalized difference vegetative index (NDVI), and percent green cover

(COVER), were done by Nelson- Hsu test at the 0.1, 0.05, 0.01, and 0.001 level of significance. Correlation analysis was done using the 'PROC CORR' procedure to examine the relationship between all the variables; TQ, LF, NDVI, COVER, and days after treatment (DAT).

RESULTS AND DISCUSSIONS

Bermudagrass

Results

Analysis of variance, correlation among the parameters, and mean separation of TQ, LF, COVER, and NDVI are presented in Tables 5 to 8.

Volumetric Soil Water Content

The mean volumetric soil water content (MVSWC) at 0 days of treatment (DAT) was 40.0 (Figure 1). MVSWC at 7 DAT, 14 DAT, and 21 DAT were 10.9, 3.4, and 2.2 respectively. There were no significant differences among the entries for MVSWC at 0 DAT, 14 DAT, and 21 DAT (data not shown). This suggests that though all the entries had uniform water content before the treatment and water expenditure by each entry differed when stress was imposed. A rapid and steady fall in the water content was found as exposure and stress progressed from 0 to 7 days. After 7 days water content was decreasing but at a slower rate.

Turf Quality

All the entries had an acceptable TQ, ranging from 6.5 to 7.6 (Table 7) before the onset of drought treatment. The experimental lines OSUB 1131 and OSUB 1156 were significantly different at 0 DAT. There was no significant difference among the lines at 7 DAT except for the line OSUB 1131 (Table 8). At 14 DAT, none of the lines were significantly different for their TQ. The mean TQ ranged from 2.3 to 3.5 on day 14. OKC 1302 and OSUB 1117 were significantly different for their TQ at 21 DAT. The mean TQ of OKC 1302 and OSUB 1117 were 2.7 and 2.8 respectively. The mean TQ ranged from 1.5 to 2.8 on day 21.

Leaf Firing

There was no LF at 0 DAT (Table 7). There were no significant differences among the lines for their leaf firing on day 7 and day 14 (Table 8). The mean LF on day 7 ranged from 5.7 to 7.6. At 14 DAT, the mean LF ranged from 2.7 to 3.8. At 21 DAT, the mean LF ranged from 2.5 to 3.3. The mean LF of OKC 1302 was significantly different to rest of the entries at 21 DAT.

NDVI

There was no significant difference at 0 DAT among entries for their green color (Table 7). The mean NDVI value ranged from 0.78 to 0.84 at 0 DAT. There were no significant differences among the entries for NDVI value on day 7 and day 14. The mean NDVI value at 7 DAT ranged from 0.71 to 0.79. At 14 DAT, the mean NDVI value ranged from 0.41 to 0.50. At 21 DAT, the mean NDVI value ranged from 0.19 to 0.32. The mean

NDVI value of OKC 1302 and OSU B1117 were significantly different from other entries at 21 DAT.

Digital Image Analysis

There was no significant difference for COVER at 0 DAT; mean COVER was 99.8 (Table 7). At 7 DAT, the mean COVER of OSUB 1131 was significantly different from other entries: the mean COVER was 74.2 (Table 8). The mean COVER ranged from 74.2 to 95.2 at 7 DAT. There was no significant difference among the entries for their COVER at 14 DAT. The mean COVER ranged from 19.3 to 32.0 on day 14. At 21 DAT, the mean COVER of OKC 1302 and OSUB 1117 were significantly different from other entries. The mean COVER of OKC 1302 and OSUB 1117 were 20.7 and 20.4 respectively. On day 21, the mean COVER ranged from 8.4 to 20.7.

Discussion

Drought resistance is commonly assessed by visual characteristic such as turf quality (McCann and Huang, 2008), leaf firing (Carrow, 1996), or survival period (Zhou et al., 2009). Thirteen bermudagrass entries were evaluated for their drought resistance. Parameters considered for this study were TQ, LF, NDVI, and COVER. All the parameters were strongly correlated (> 90%) with each other when Pearson's Correlation coefficient was calculated (Table 5). A decrease in all the parameters were found as the days after drought stress advances (Table 5). Significant difference in TQ at 0 DAT is due to the inherent difference in their turf quality (uniformity, texture, and density) under non-stressed conditions (Table 7). The greater the number of days during which green cover can be maintained in the grasses after the introduction of drought stress is an important measure for selecting superior drought resistance (Zhou et al., 2015). At 7 DAT, all the grasses were green but not all the grasses maintained an acceptable TQ (Table 8). The volumetric soil water content in all the grasses were same (no significance difference) before the onset of drought stress (Figure 1). After using the available moisture, these grasses might have an adaptive water saving mechanism against drought to stay green for a longer period of time. A sharp decrease in TQ, LF, COVER, and NDVI was observed in all the grasses as the drought stress advanced. This was expected because as drought stress proceeds, sooner or later all grasses suffer a decline in quality (Stienke et al., 2011). The performance of all the grasses continuously declined at day 14 and day 21. This indicates that as the drought period advances, all the grasses are highly affected and eventually become dormant. The quick response of all the grasses to drought stress within a week of the initiation of drought treatment can be attributed to the shallow root development of the grasses. The mean TQ and COVER of OSUB 1131 were significantly lower than rest of the entries at 7 DAT (Table 8). On day 21, drought resistance of OSUB 1117 and OKC 1302 were better than rest of the entries. With the limitation of root length extension, these entries had used tolerance mechanism against drought stress. Further study on OSUB 1117, OKC 1302, and OSUB 1131 may provide an insight on the specific reasons for the differential performance while under drought stress. The length of the root systems were not measured in our study, so it is not clearly understood if all the entries had similar root length at the time of drought treatment.

After 90 days of drought stress, all of the grasses were watered and fertilized. After three weeks of watering and fertilizing, there was no sign of new shoots from the grasses. When roots and rhizomes of the stressed plants were examined, no living organs were found. It was concluded that 90 days of the drought stress and limitation of root extension had severe effect on the grasses and the grasses succumbed to death.

Seashore Paspalum

Results

Analysis of variance, correlation between the parameters, and mean separation of TQ, LF, COVER, and NDVI are presented in tables 9 to 12.

Volumetric Soil Water Content

There was no significant difference in the volumetric soil water content among the entries throughout the drought period (data not shown). However, a significant difference was seen between dates (Figure 2). The MVSWC at 0 DAT, 7 DAT, 14 DAT, and 21 DAT were 42.4, 9.7, 2.6, and 2.2 respectively. There was an abrupt decrease in the moisture content from day 0 to day 7. Plants try to avoid stress by utilizing available moisture from soil by increasing root length and root density (Huang, 2008). However, after day 14, there was only a slight decrease in the moisture content. We can infer that, plants tried to use available moisture and after it was no longer available it entered to an inactive phase i.e. dormant period.

Turf Quality

There was no significant difference among the entries at 0 DAT (Table 11). The mean turf quality ranged from 6.5 to 7.5. At 7 DAT, the mean TQ ranged from 4.7 to 5.8 (Table 12). The mean TQ of the entry UGP 38 was significantly different from others at 7 DAT. At 14 DAT, the mean TQ of UGP 3, UGP 10, and UGP 38 were significantly different from other lines. The mean TQ of UGP 3 and UGP 10 were 2.8, whereas the mean TQ of UGP 38 was 1.8. At 21 DAT, the mean TQ of UGP 73, UGP 10, and UGP 38 were significantly different from rest of the entries. At 21 DAT, the mean TQ value ranged from 1.0 to 2.3.

Leaf Firing

The mean LF of the grasses at 0 DAT was 9 (Table 11). At 7 DAT, a significant difference was observed in the entries UGP 10 and UGP 38 for their LF (Table 12). The mean LF ranged from 5.7 to 7.3 at 7 DAT. At 14 DAT, the mean LF of SeaStar, and UGP 10 were significantly different from other entries. The mean LF ranged from 2.3 to 3.3 at 14 DAT. On day 21, the mean LF of UGP 10 and SeaStar were significantly different from other entries. The mean LF ranged from 2.3 to 2.8 at 21 DAT.

NDVI

The mean NDVI value ranged from 0.72 to 0.78 at 0 DAT (Table 11). At 7 DAT, the mean NDVI value ranged from 0.71 to 0.74 (Table 12). There were no significant differences among the entries for their NDVI value throughout the drought cycle. The mean NDVI value on day 14 and day 21 ranged from 0.33 to 0.39 and 0.13 to 0.15 respectively.

Digital Image Analysis

There was no significant difference among the entries for their COVER at 0 DAT (Table 11). At 7 DAT, the mean COVER of UGP 38 was significantly different from other entries (Table 12). The mean COVER ranged from 80.0 to 99.4 on day 7. At 14 DAT, the mean COVER of SeaStar, UGP 3, UGP 73, and UGP 10 were significantly different from rest of the entries; the mean percent green cover ranged from 11.0 to 25.2. At 21 DAT, the mean COVER of UGP 73 and UGP 10 were significantly different. The mean COVER of UGP 73 and UGP 10 were 3.4 and 19.5 respectively.

Discussion

Drought resistance is commonly assessed by visual characteristic such as turf quality (McCann and Huang, 2008), leaf firing (Carrow, 1996), or survival period (Zhou et al., 2009). Seven genotypes of seashore paspalum were evaluated for their drought resistance. Parameters considered for this study were TQ, LF, NDVI, and percent green cover. All the parameters were highly correlated with each other when Pearson's correlation coefficient was calculated (Table 10). A decrease in all the parameters were found as the days after drought stress advances (Table 10). The number of days green cover can be seen in the grasses after the introduction of drought stress is an important measure for selecting superior drought resistance grass (Zhou et al., 2015). The volumetric soil water content in all the grasses were same (no significance difference) before the onset of drought stress (Figure 2). There was no significant difference among the entries for their TQ before the initiation of drought stress (Table 11). The phenotypic differences in seashore paspalum entries were hard to find under non -stressed conditions (Duncan and Carrow, 2000). At 7 DAT, the mean TQ, LF, and COVER of UGP 38 were significantly lower than other entries (Table 12). The mean LF of UGP 10 was significantly better than rest of the entries on day 7. Differences in the phenotypic performance of the entries may be related with their genetic differences. Detailed study on genetic background of these entries will provide a better explanation for their response to drought stress. On day 14, UGP 73 and UGP 38 were the most leaf fired entries. The mean COVER of SeaStar, UGP 3, and UGP 10 were significantly higher than rest of the entries at 14 DAT. A sharp decrease in TQ and LF was observed in all the grasses which were good drought resistors at 7 DAT. This was expected because as drought stress proceed sooner or later the quality of all grasses declines (Stienke et al., 2011). The performance of all of the grasses continuously declined when assessed at day 14 and day 21. This indicates that as the drought period advanced, all of the grasses were highly affected and eventually became dormant. All the grasses lost their green color by 28 days and UGP 10 was the last one to reach 100% brown cover (data not included visual observation only). Experimental entry UGP 10 outperformed other entries at 21 days of drought stress in terms of TQ, LF, and COVER. Though Sea Isle 1 has good drought resistance (Huang et al., 1997), commercial cultivar SeaStar showed better drought resistance in terms of LF and COVER than Sea Isle 1 in our study.

After 90 days of drought stress, all the grasses were watered and fertilized. The dead shoots were clipped before they were re-watered. After three weeks of watering and fertilizing, there was no sign of new shoots from the grasses. When roots and rhizomes of the stressed plants were examined no living organs were found. It was concluded that 90 days of the drought stress and limitation of root extension had severe effect on the grasses and grasses succumbed to the death.

Zoysiagrass

Results

Analysis of variance, correlation between the parameters, and mean separation of TQ, LF, COVER, and NDVI are presented in Tables 13 to 16.

Volumetric Soil Water Content

The mean volumetric soil water content at 0 DAT, 7 DAT, 14 DAT, and 21 DAT were 40.2, 5.2, 2.3, and 2.2 respectively (Figure 3). The moisture content highly decreased as the drought proceeds from day 0 to day 7. There was no significant difference in the volumetric water content between the entries throughout the drought period (data not shown). However, a significant difference was seen between dates (days after drought stress).

Turf Quality

At 0 DAT, the mean TQ ranged from 6.7 to 8.0 (Table 15). The mean TQ of Empire, FAES 1303, FAES 1305, FAES 1306, and DALZ 1312 were significantly different from rest of the entries. At 7 DAT, the mean TQ of Zeon, Palisades, Empire, FAES 1307, DALZ 1310, DALZ 1311, DALZ 1312, and DALZ 1313 were significantly different from the rest of the lines (Table 16). The mean TQ values were, Empire = 3.8; Palisades = 3.2; Zeon = 5.6; FAES 1307 = 5.8; DALZ 1310 = 4.0; DALZ 1311 = 3.5; DALZ 1312 = 5.6; DALZ 1313 = 5.3 at 7 DAT. At 14 DAT, the mean TQ of Zeon, Palisades, Empire, FAES 1305, DALZ 1310, DALZ 1312, and DALZ 1314 were significantly different from rest of the entries. The mean TQ were Zeon = 4.2; Palisades = 1.7; Empire = 1.7; FAES

1305 = 3.3; DALZ 1310 = 1.5; DALZ 1312 = 3.5; and DALZ 1314 = 3.7. The mean TQ ranged from 1.5 to 4.2 on day 14. At 21 DAT, the mean TQ of Zeon, Palisades, Empire, FAES 1304, FAES 1307, DALZ 1310, DALZ 1311, DALZ 1312, and DALZ 1314 were significantly different from rest of the entries. The mean TQ were, Zeon = 2.8; Palisades = 1.0; Empire = 1.0; FAES 1304 = 2.0; FAES 1307 = 1.0; DALZ 1310 = 1.0; DALZ 1311 = 1.0; DALZ 1312 = 1.5; and DALZ 1314 = 1.7 at 21 DAT. The mean TQ ranged from 1.0 to 2.8 on day 21.

Leaf Firing

The mean LF at 0 DAT was 9 (Table 15). At 7 DAT, the mean LF of Zeon, Palisades, Empire, FAES 1307, DALZ 1310, DALZ 1311, and DALZ 1313 were significantly different from the rest of the entries (Table 16). The mean LF were, Zeon = 6.5; Palisades = 3.8; Empire = 4.3; FAES 1307 = 6.7; DALZ 1310 = 4.7; DALZ 1311 = 4.5; and DALZ 1313 = 6.2 on day 7. At 14 DAT, the mean LF of Zeon, Palisades, Empire, FAES 1306, DALZ 1310, DALZ 1311, DALZ 1312, and DALZ 1314 were significantly different from the rest of the entries. The mean LF were, Zeon = 5.0; Palisades = 2.2; Empire = 2.3; FAES 1306 = 2.5; DALZ 1310 = 2.2; DALZ 1311 = 2.5; DALZ 1312 = 3.8; and DALZ 1314 = 3.8 on day 14. At 21 DAT, the mean LF of Zeon, Palisades, FAES 1306, and DALZ 1311 were significantly different from the rest of the entries. The mean LF were, Zeon = 3.8; Palisades = 1.8; FAES 1306 = 1.8; and DALZ 1311 = 1.8 on day 21.

NDVI

The mean NDVI value ranged from 0.8 to 0.85 at 0 DAT (Table 15). At 7 DAT, the mean NDVI value ranged from 0.45 to 0.68 (Table 16). The mean NDVI value of Zeon, Palisades, Empire, FAES 1307, DALZ 1310, and DALZ 1311 were significantly different on day 7. The mean NDVI were, Zeon = 0.68; Palisades = 0.45; Empire = 0.5; FAES 1307 = 0.66; DALZ 1310 = 0.48; and DALZ 1311 = 0.47 at 7 DAT. At 14 DAT, the mean NDVI value ranged from 0.14 to 0.3. The mean NDVI value of Zeon, Palisades, DALZ 1310, DALZ 1311, and DALZ 1312 were significantly different from rest of the entries on day 14. At 21DAT, the mean NDVI value of Zeon, Palisades, and DALZ 1310 were significantly different from rest of the entries. The mean NDVI value were, Zeon = 0.21; Palisades = 0.03; and DALZ 1310 = 0.03 at 21 DAT.

Digital Image Analysis

There was no significant difference for percent green cover on day 0 (Table 15). The mean percent green cover was 99.93. At 7 DAT, the mean COVER of Zeon, Palisades, Empire, FAES 1305, FAES 1307, DALZ 1310, DALZ 1311, DALZ 1312, and DALZ 1313 were significantly different from other entries (Table 16). The mean COVER ranged from 70.1 to 89.2. The mean COVER were, Zeon = 89.2; Palisades = 38.5; Empire = 53.2; FAES 1305 = 84.0; FAES 1307 = 89.0; DALZ 1310 = 52.3; DALZ 1311 = 47.1; DALZ 1312 = 87.8; and DALZ 1313 = 83.9 on day 7. At 14 DAT, the mean COVER of Zeon, Palisades, Empire, FAES 1305, FAES 1306, DALZ 1310, DALZ 1311, DALZ 1312, and DALZ 1314 were significantly different from rest of the entries. The mean COVER were, Zeon = 43.6; Palisades = 7.1; Empire =7.4; FAES 1305 = 32.0; FAES 1306 = 12.1; DALZ 1310 = 5.6; DALZ 1311 = 8.5; DALZ 1312 = 30.7; and DALZ 1314 = 34.4 on day 14. At 21 DAT, the mean COVER ranged from 3.1 to 27.7. The mean COVER of Zeon, Palisades, Empire, FAES 1305, FAES 1306, DALZ 1310, DALZ 1311 were significantly different from rest of the entries at 21 DAT. The mean

COVER were, Zeon = 27.7; Palisades = 3.1; Empire = 4.4; FAES 1305 = 15.3; FAES 1306 = 5.2; DALZ 1310 = 4.7; DALZ 1311 = 3.2; and DALZ 1314 = 13.8 on day 21.

Discussion

Drought resistance is commonly assessed by visual characteristics such as turf quality (McCann and Huang, 2008), leaf firing (Carrow, 1996), or survival period (Zhou et al., 2009). Thirteen genotypes of zoysiagrass were evaluated for their drought resistance. Parameters considered for this study were TQ, LF, NDVI, and percent green cover. All the parameters were highly correlated with each other when Pearson's correlation coefficient was performed (Table 14). A decrease in all the parameters were found as the days after drought stress advances. The number of days green cover can be seen in the grasses after the introduction of drought stress is an important measure for selecting superior drought resistance grass (Zhou et al., 2015). A significant difference was found in TQ among the entries before the initiation of the drought stress (Table 15). In this study, entries from the *Zoysia japonica* and *Z. matrella* species were included. *Z. japonica*, being coarse textured than the *Z. matrella*, differences in the visual quality was expected even before the initiation of drought stress. However, this difference was attributed to an inherent differences between the species of the zoysiagrass. At 7 DAT, on the basis of TQ, LF, COVER, and NDVI value, FAES 1307 and Zeon were good drought resistant than other entries (Table 16). The entries DALZ 1312 and DALZ 1313 were significantly better performer than rest of the entries in terms of TQ, LF, and COVER. Palisades, Empire, DALZ 1310, and DALZ 1311 showed poor performance on the same day. They were significantly poor performer than rest of the entries on 7 days of drought stress. Throughout the study, the mean TQ, LF, COVER, and NDVI value of Zeon were more than the rest of the entries, whereas the mean TQ, LF, COVER, and NDVI value of DALZ 1310, DALZ 13111, and Palisades were less than the rest of the entries. The volumetric soil water content in all the grasses were the same (no significance difference) before the onset of drought stress (Figure 3). A sharp decrease in TQ and LF was observed in all the grasses which were good drought resistors at 7 DAT. This was expected because as drought stress proceeded, sooner or later the quality of all grasses declines (Stienke et al., 2011). Those grasses which showed good drought response at day 14 showed good resistance at day 21 as well. The performance of all the grasses continuously declined at day 14 and day 21. This indicates that as the drought period advances, all the grasses are highly affected and eventually become dormant. All the grasses lost their green color by day 28 and Zeon was the last one to reach 100% brown cover (visual observation: data not shown).

After 90 days of drought stress, all of the grasses were watered and fertilized. The dead shoots were clipped before they were re-watered. After three weeks of watering and fertilizing, there was no sign of new shoots from the grasses. When roots and rhizomes of the stressed plants were examined no living organs were found. It was concluded that 90 days of exposure to drought stress and limitation of root extension had severe effect on the grasses and the grasses succumbed to death. Our study supports the study of findings of a 60 days drought stress trial on warm season grasses in San Antonio, TX where no grasses recovered when grown in shallow soil profile (10 cm) (Stienke et al., 2010).

St. Augustinegrass

Results

Analysis of variance, mean separation of TQ, LF, COVER, and NDVI value were presented in Tables 17 to 20.

Volumetric Soil Water Content

The mean volumetric soil water content was 40.0, 12.3, 4.2, and 3.1 at 0 DAT, 7 DAT, 14 DAT, and 21 DAT respectively (Figure 4). A sharp fall in the moisture content was seen as drought stress proceeded from day 0 to day 7. There was no significant difference in the volumetric water content between the entries throughout the drought period (data not shown). However, a significant difference was seen between dates (days after drought stress).

Turf Quality

At 0 DAT, the mean TQ of Floratam, DALSA 1316, DALSA 1317, DALSA 1318, and NCSA 17 were significantly different from rest of the entries (Table 19). At 7 DAT, the mean TQ of Raleigh and NCSA 43 were significantly different from rest of the entries with a mean TQ of 5.0 and 6.5 respectively (Table 20). At 14 DAT, the mean TQ of NCSA 17 was significantly different from rest of the entries: the mean TQ was 3.5. The mean TQ ranged from 2.0 to 3.5 at 14 DAT. At 21 DAT, none of the entries were significantly different from each other for their TQ. The mean TQ ranged from 1.3 to 2.0 on day 21.

Leaf Firing

At 0 DAT, all the entries were in the same group. The mean leaf firing was 9 (Table 19). At 7 DAT, the mean LF of Raleigh was significantly different from rest of the entries; the mean LF was 5.8 (Table 20). The mean LF ranged from 5.8 to 7.7 at 7 DAT. At 14 DAT, the mean LF of DALSA 1316 and NCSA 17 were significantly different from rest of the entries with a mean LF of 2.3 and 3.8 respectively. At 21 DAT, the mean LF of Raleigh was significantly different from rest of the entries with a mean LF 3.3. The mean LF ranged from 2.0 to 3.3 at 21 DAT.

NDVI

The mean NDVI value ranged from 0.75 to 0.80 at 0 DAT (Table 19). The mean NDVI value of DALSA 1318 was significantly different from rest of the entries. At 7 DAT, the mean NDVI value of Floratam was significantly different from rest of the entries with a mean NDVI value of 0.61. The mean NDVI value ranged from 0.61 to 0.7 on day 7. At 14 DAT, the mean NDVI value of DALSA 1316 and NCSA 43 were significantly different from rest of the entries with a mean NDVI value of 2.3 and 3.8 respectively. At 21 DAT, the mean NDVI value of Raleigh was significantly different from rest of the entries. The mean NDVI value of Raleigh was 0.22. The mean NDVI value ranged from 0.12 to 0.22 on day 21.

Digital Image Analysis

The mean percent green cover at 0 DAT was 99.79 (Table 19). At 7 DAT, the mean COVER of Floratam was significantly different to rest of the entries (Table 20). The mean COVER of Floratam was 92.0. The mean COVER ranged from 92.0 to 99.6 on day

7. At 14 DAT, the mean COVER of DALSA 1316 and NCSA 17 were significantly different from rest of the entries. The mean COVER of DALSA 1316 and NCSA 17 were 9.2 and 27.3 respectively on day 14. At 21 DAT, the mean COVER of Raleigh and DALSA 1316 were significantly different from rest of the entries. The mean COVER of DALSA 1316 and Raleigh were 5.0 and 17.2 respectively.

Discussion

Drought resistance is commonly assessed by visual characteristic such as turf quality (McCann and Huang, 2008), leaf firing (Carrow, 1996), or survival period (Zhou et al., 2009). Twelve genotypes of St. Augustinegrass were evaluated for their drought resistance. Parameters considered for this study were TQ, LF, NDVI, and COVER. All the parameters were highly correlated with each other when Pearson's Correlation coefficient was calculated (Table 18). A decrease in all the parameters were found as the days after drought stress advances. The number of days green cover can be seen in the grasses after the introduction of drought stress is an important measure for selecting superior drought resistance grass (Zhou et al., 2015). A significant difference at 0 DAT was observed among the entries (Table 19). This may be due to the inherent quality of the grasses (uniformity, texture, and density). At 7 DAT, a significant difference was found in Floratam (COVER), Raleigh (TQ and LF), and NCSA 43 (TQ) from rest of the entries (Table 20). The visual ranking of Raleigh was significantly lower than rest of the entries at 7 DAT. DALSA 1316 showed poor performance on day 14 and day 21 of drought stress. Our results did not match with the study by Stienke et al (2010) for the Floratam cultivar. In their study, Floratam was the most drought tolerant cultivar than Palmetto and Raleigh, however in our study, the COVER and NDVI value of Floratam was significantly lower than rest of the entries on day 7. This may be partially explained by the resistance mechanism that Floratam cultivar used against drought stress. Limitation of root length expansion or root density might be one of the probable reasons. At 14 and 21 days of the drought stress there were no significant differences between Floratam and Palmetto for their drought resistance. The volumetric soil water content in all the grasses were same (no significance difference) before the onset of drought stress (data not shown). A sharp decrease in TQ and LF was observed in all the grasses which were good drought resistors at 7 DAT. This was expected because as drought stress proceed sooner or later all grasses quality declines (Stienke et al., 2011). The performance of all the grasses continuously declined at day 14 and day 21. This indicates that as the drought period advances, all the grasses are highly affected and eventually become dormant. All the grasses lose their green color by day 28 (data not shown) and NCSA 43, NCSA 80, NCSA 17, Raleigh, DALZ 1315, and Palmetto were the last one to have 100% brown cover. The ranking of the grasses for drought resistance varied from high to low. Similar observation was found in a study by Carrow (1996) where the performance of Raleigh St. Augustinegrass varied from low to high. In our study, drought performance of the Raleigh was significantly different on day 7 and day 21 to rest of the entries. On day 7, visual assessment of Raleigh was significantly lower than other entries for drought resistance. As the drought stress advanced, on 21 days, drought resistance of Raleigh was the best than other entries. After the drought stress started, Raleigh might have experienced the stress as a ‘shock’ that is why the quality assessment was lower than other entries. As the days proceeded, Raleigh might have expressed its resistance mechanism to stay green for longer period than others. Further study about the stress response and resistance mechanism will provide a definitive conclusion in the characteristic behavior shown by Raleigh during drought stress. After 90 days of drought stress, all the grasses were watered and fertilized. The dead shoots were clipped before they were re-watered. After three weeks of watering and fertilizing, there was no sign of new shoots from the grasses. When roots and rhizomes of the stressed plants were examined no living organs were found. It was concluded that 90 days of the drought stress and limitation of root length extension had severe effect on the grasses and grasses succumbed to the death. Similar results were found in a study of 60 days drought stress on the grasses when grown in shallow soil profile (Stienke et al., 2010).

CONCLUSIONS

As drought stress was intensified, all the entries exhibited reduced turf quality, high leaf firing, less green cover, and reduced NDVI value. There was variation in the drought resistance expression among the entries. Results from bermudagrass study reveal that the experimental lines OKC 1302, and OSUB 1117 showed better drought resistance than rest of other experimental lines. The drought performance of UGP 10 seashore paspalum was better than rest of the seashore paspalum entries. None of the experimental entries of zoysiagrass had better drought resistance in comparison to the commercial cultivar Zeon in 21 days drought period. The performance of St. Augustinegrass, Raleigh, fluctuated form low to high during drought stress. Though Raleigh was quick to respond to the drought stress, it maintained green verdure longer than rest of the entries. Similar to the zoysiagrass, none of the experimental entries were better performer in drought stress than Raleigh in this drought trial. Though all the grasses were completely leaf fired by 28 days, drought stress was extended up to 90 days for recovery study of the grasses. Ninety days drought stress coupled with limited root length expansion was highly stressful for plants. None of the grasses were able to recover when they were re-watered and fertilized after 90 days of drought stress. With a limitation of root length expansion, drought tolerance mechanism was showed by the grasses against drought stress.

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Table 5. Analysis of variance for the effects of cultivar (C), date (D) and their interaction on turf quality (TQ), leaf firing (LF), percent green cover (COVER), normalized difference vegetative index (NDVI) during the drought stress of bermudagrass.

	TQ		LF		NDVI		COVER	
	df	sign	df	sign	df	sign	df	Sign
C	12	**	12	***	12	***	12	**
D	1	****	1	****	1	****	1	****
D x D	1	**	1	****	1	****	1	NS^{y}
D x D x D	1	****	1	****	1	****	1	****
C x D	12	****	12	NS	12	****	12	**
C x D x D	12	***	12	NS	12	NS	12	NS
C x D x D x D	12	NS	12	NS	12	NS	12	NS
Error	260		260		260		260	

*, **, ***, **** significant at p = 0.1, 0.05, 0.01, and 0.001 respectively.

^{y}NS (non-significant) at p = 0.1, 0.05, 0.01, and 0.001 respectively.

Table 6. Pearson's correlation coefficient of bermudagrasses for turf quality (TQ^z), leaf firing (LF^y), percent green cover (COVER^x), normalized difference vegetative index (NDVI^w), and days after drought stress (DATE^v).

	TQ	LF	COVER	NDVI
TQ	1	0.96***	0.96***	0.93***
LF		1	0.98***	0.92***
COVER			1	0.95***
NDVI				1
DATE	-0.91***	-0.93***	-0.94***	-0.94***

^{z}TQ = Turf quality ratings were based on 1-9 scale where 1 = lowest quality, 6 = acceptable quality and 9 = excellent quality.

^{y}LF = Leaf firing ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

^{x}COVER = Percent green cover (COVER) was measured using SigmaScan software.

^{w}NDVI = Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

^{v}DATE = Days after drought stress (DATE) started.

*** Significant at P = 0.001 level of significance.

Table 7. Mean turf quality (TQ[z]), leaf firing (LF[y]), percent green cover (COVER[x]), and normalized difference vegetative index (NDVI[w]) of 13 bermudagrass entries before drought stress.

ENTRY	0DAT[v]			
	TQ	LF	COVER	NDVI
Tifway	7.0	9	99.8	0.80
Celebration	6.5	9	99.8	0.80
OSUB 1131	7.5*[u]	9	99.8	0.85
OSUB 1163	6.8	9	99.9	0.82
OKC 1302	7.3	9	99.8	0.81
OSUB 111	6.3	9	99.8	0.80
OSUB 1117	6.5	9	99.8	0.79
OSUB 1156	7.6***	9	99.8	0.84
UGB 8	7.1	9	99.8	0.84
UGB 14	7.0	9	99.8	0.80
UGB 42	6.7	9	99.8	0.82
UGB 70	7.0	9	99.8	0.81

UGB 79	6.0***	9	99.8	0.81

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

[y] Leaf firing (LF) ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

[x] Percent green cover (COVER) was measured using SigmaScan software.

[w] Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[v] Days after drought stress (DAT) started.

[u] Means within the same column followed by *, **, ***, **** are significantly different at p= 0.1, 0.05, 0.01, 0.001 level respectively using Nelson-Hsu mean comparisons

Table 8. Mean turf quality (TQ[z]), leaf firing (LF[y]), percent green cover (COVER[x]), and normalized difference vegetative index (NDVI[w]) of 13 bermudagrass entries at 7 through 21 days of drought stress.

ENTRY	7DAT[v]				14DAT				21DAT			
	TQ	LF	COVER	NDVI	TQ	LF	COVER	NDVI	TQ	LF	COVER	NDVI
Tifway	5.8	7.3	89.8	0.76	2.5	2.8	23.8	0.43	2.3	2.7	15.3	0.26
Celebration	5.8	7.2	88.5	0.71	2.8	3.5	28.4	0.45	2.7	2.7	19.1	0.23
OSUB 1131	5.2*[u]	5.7	74.2**	0.70	2.3	2.5	19.3	0.43	1.5	2.2	8.4	0.20
OSUB 1163	5.5	6.7	81.3	0.74	2.8	3.0	25.2	0.47	2.2	2.7	15.5	0.27
OKC 1302	6.7	7.6	95.2	0.78	3.5	3.8	32.0	0.50	2.7*	3.4*	20.7*	0.32**
OSUB 111	5.8	7.2	87.1	0.74	2.8	3.2	28.7	0.46	1.8	2.5	12.2	0.19
OSUB 1117	6.0	7.6	90.6	0.78	3.2	3.5	27.7	0.50	2.8*	3.1	20.4*	0.32**
OSUB 1156	5.8	6.5	83.6	0.77	2.7	3.0	26.1	0.50	2.0	2.5	10.6	0.23
UGB 8	6.3	7.6	90.8	0.79	2.5	2.7	20.0	0.45	2.0	2.5	11.5	0.21
UGB 14	5.5	6.3	80.8	0.73	2.5	3.0	23.2	0.41	1.5	2.3	10.1	0.20
UGB 42	5.8	7.5	85.2	0.75	2.5	3.0	25.2	0.44	1.8	2.5	11.9	0.19
UGB 70	6.2	7.3	87.1	0.74	2.8	3.3	28.2	0.44	2.0	2.7	13.6	0.22
UGB 79	6.0	7.6	93.1	0.76	3.3	3.7	30.8	0.47	1.8	2.5	11.7	0.25

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

[y] Leaf firing (LF) ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

[x] Percent green cover (COVER) was measured using SigmaScan software.

[w] Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[v] Days after drought stress (DAT) started.

[u] Means within the same column followed by *, **, ***, **** are significantly different at p= 0.1, 0.05, 0.01, 0.001 level respectively using Nelson-Hsu mean comparison.

Table 9. Analysis of variance for the effects of cultivar (C), date (D) and their interaction on turf quality (TQ), leaf firing (LF), percent green cover (COVER), normalized difference vegetative index (NDVI) during the drought stress on seashore paspalum grass.

	TQ		LF		NDVI		COVER	
	df	sign	df	sign	df	sign	df	Sign
C	6	****	6	****	6	NS	6	****
D	1	****	1	****	1	****	1	****
D x D	1	****	1	****	1	****	1	***
D x D x D	1	****	1	****	1	****	1	****
C x D	6	***	6	NS	6	NS	6	****
C x D x D	6	NS[y]	6	**	6	NS	6	***
C x D x D x D	6	NS	6	NS	6	NS	6	**
Error	140		140		140		140	

*, **, ***, **** significant at p = 0.1, 0.05, 0.01, and 0.001 respectively.

[y] NS (non-significant)at p = 0.1, 0.05, 0.01, and 0.001 respectively.

Table 10. Pearson's correlation analysis of seashore paspalum grass for turf quality (TQ^z), leaf firing (LF^y), percent green cover (COVER^x), normalized difference vegetative index (NDVI^w), and days after drought stress (DATE^v).

	TQ	LF	COVER	NDVI
TQ	1	0.97***	0.96***	0.91***
LF		1	0.96***	0.89***
COVER			1	0.96***
NDVI				1
DATE	-0.93***	-0.94***	-0.93***	-0.93***

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

[y] LF = Leaf firing ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

[x] COVER = Percent green cover (COVER) was measured using SigmaScan software.

[w] NDVI = Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[v] DATE = Days after drought stress (DATE) started.

*** Significant at P = 0.001 level of significance.

Table 11. Mean turf quality (TQ[z]), leaf firing (LF[y]), percent green cover (COVER[x]), and normalized difference vegetative index (NDVI[w]) of 7 seashore paspalum grass entries before drought stress.

ENTRY	0 DAT[v]			
	TQ	LF	NDVI	COVER
SeaStar	7.2[u]	9.0	0.78	99.9
SeaIsle1	7.2	9.0	0.77	99.9
UGP3	7.3	9.0	0.79	99.9
UGP73	7.5	9.0	0.72	99.9
UGP10	6.5	9.0	0.73	99.9
UGP38	7.5	9.0	0.78	99.9
UGP1	6.7	9.0	0.77	99.9

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

[y] Leaf firing (LF) ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

[x] Percent green cover (COVER) was measured using SigmaScan software.

[w] Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[v] Days after drought stress (DAT) started.

[u]Means within the same column not followed by *, **, ***, **** are not significantly different at p= 0.1, 0.05, 0.01, 0.001 level respectively using Nelson-Hsu mean comparison.

Table 12. Mean turf quality (TQ[z]), leaf firing (LF[y]), percent green cover (COVER[x]), and normalized difference vegetative index (NDVI[w]) of 7 seashore paspalum grass entries at 7 through 21 days of drought stress.

ENTRY	7 DAT[v]				14 DAT				21 DAT			
	TQ	LF	NDVI	COVER	TQ	LF	NDVI	COVER	TQ	LF	NDVI	COVER
SeaStar	5.8	6.8	0.74	90.3	2.5	3.0	0.33	24.0**[u]	2.0	2.8**	0.13	14.1
Sea Isle 1	5.6	6.5	0.75	89.2	2.0	2.7	0.36	12.8	1.3	2.3	0.13	8.2
UGP3	5.8	6.5	0.77	90.1	2.8***	3.2	0.39	24.6**	1.7	2.3	0.14	10.2
UGP73	5.3	6.5	0.75	99.4	2.2	2.3**	0.36	11.0**	1.0*	2.0	0.12	3.4***
UGP10	5.8	7.3*	0.77	90.7	2.8***	3.3**	0.36	25.2**	2.3**	2.8**	0.15	19.5****
UGP38	4.7**	5.7*	0.71	80.0***	1.8**	2.3**	0.33	12.2	1.0*	2.0	0.13	5.7
UGP1	5.3	6.2	0.77	87.5	2.0	2.7	0.33	13.8	1.5	2.3	0.13	8.3

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

[y] Leaf firing (LF) ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

[x] Percent green cover (COVER) was measured using SigmaScan software.

[w] Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[v] Days after drought stress (DAT) started.

[u] Means within the same column followed by *, **, ***, **** are significantly different at p= 0.1, 0.05, 0.01, 0.001 level respectively using Nelson-Hsu mean comparison.

Table 13. Analysis of variance for the effects of cultivar (C), date (D) and their interaction on turf quality (TQ), leaf firing (LF), percent green cover (COVER), normalized difference vegetative index (NDVI) during the drought stress on zoysiagrass.

	TQ		LF		NDVI		COVER	
	df	sign	df	sign	df	sign	Df	sign
C	12	***	12	***	12	***	12	***
D	1	***	1	***	1	***	1	***
D x D	1	***	1	***	1	***	1	***
D x D x D	1	***	1	NS[y]	1	***	1	***
C x D	12	***	12	***	12	***	12	***
C x D x D	12	***	12	***	12	***	12	***
C x D x D x D	12	***	12	***	12	***	12	***
Error	260		260		260		260	

*, **, *** significant at p = 0.05, 0.01, and 0.001 respectively.

[y] NS (non-significant) at p = 0.05, 0.01, and 0.001 respectively.

Table 14. Pearson's correlation coefficient of zoysiagrass for turf quality (TQ^z), leaf firing (LF^y), percent green cover (COVER^x), normalized difference vegetative index (NDVI^w), and days after drought stress (DATE^v).

	TQ	LF	COVER	NDVI
TQ	1	0.97***	0.97***	0.96***
LF		1	0.95***	0.95***
COVER			1	0.97***
NDVI				1
DATE	-0.92***	-0.92***	-0.92***	-0.96***

^{z}TQ = Turf quality ratings were based on 1-9 scale where 1 = lowest quality, 6 = acceptable quality and 9 = excellent quality.

^{y}LF = Leaf firing ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

^{x}COVER = Percent green cover (COVER) was measured using SigmaScan software.

^{w}NDVI = Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

^{v}DATE = Days after drought stress (DATE) started.

*** Significant at P = 0.001 level of significance.

Table 15. Mean turf quality (TQ[z]), leaf firing (LF[y]), percent green cover (COVER[x]), and normalized difference vegetative index (NDVI[w]) of 13 zoysiagrass entries before drought stress.

ENTRY	0DAT[v]			
	TQ	LF	COVER	NDVI
Zeon	7.2	9.0	99.9	0.83
Palisades	7.0	9.0	99.9	0.82
Empire	6.7**[u]	9.0	99.9	0.81
FAES1303	7.8****	9.0	99.9	0.85
FAES1304	7.0	9.0	99.9	0.82
FAES1305	7.7***	9.0	99.9	0.83
FAES1306	8.0****	9.0	99.9	0.84
FAES1307	6.8	9.0	99.9	0.82
DALZ1310	7.0	9.0	99.8	0.82
DALZ1311	6.8	9.0	99.9	0.79
DALZ1312	6.6**	9.0	99.9	0.80
DALZ1313	7.2	9.0	99.9	0.81
DALZ1314	6.8	9.0	99.8**	0.80

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

[y] Leaf firing (LF) ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

[x] Percent green cover (COVER) was measured using SigmaScan software.

[w] Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[v] Days after drought stress (DAT) started.

[u] Means within the same column followed by *, **, ***, **** are significantly different at p= 0.1, 0.05, 0.01, 0.001 level respectively using Nelson-Hsu mean comparison.

Table 16. Mean turf quality (TQ^{z}), leaf firing (LF^{y}), percent green cover (COVER^{x}), and normalized difference vegetative index (NDVI^{w}) of 13 zoysiagrass entries at 7 through 21 days of drought stress.

ENTRY	7 DAT^{v}				14 DAT				21 DAT			
	TQ	LF	COVER	NDVI	TQ	LF	COVER	NDVI	TQ	LF	COVER	NDVI
Zeon	5.6****^{u}	6.5****	89.2****	0.68****	4.2****	5.0****	43.6****	0.28**	2.8****	3.8****	27.7****	0.21****
Palisades	3.2****	3.8****	38.5****	0.45****	1.7***	2.2****	7.1****	0.17**	1.0***	1.8*	3.1****	0.03*
Empire	3.8****	4.3***	53.2****	0.50**	1.7***	2.3***	7.4****	0.2	1.0***	2.0	4.4***	0.04
FAES1303	4.5	5.2	70.1	0.56	2.5	3.0	15.7	0.25	1.3	2.3	7.3	0.09
FAES1304	4.8	5.2	74.1	0.61	2.7	3.3	23.4	0.25	2.0***	2.8	11.8	0.14
FAES1305	5.0	5.5	84.0**	0.64	3.3**	3.7	32.0****	0.24	1.7	2.7	15.3***	0.12
FAES1306	5.0	5.7	81.0	0.61	2.0	2.5**	12.1**	0.24	1.2	1.8*	5.2**	0.06
FAES1307	5.8****	6.7****	89.0****	0.66***	2.5	3.0	22.5	0.23	1.0***	2.2	7.4	0.07
DALZ1310	4.0***	4.7*	52.3****	0.48***	1.5****	2.2****	5.6****	0.14****	1.0***	2.0	4.7**	0.03*
DALZ1311	3.5****	4.5**	47.1****	0.47****	2.0	2.5**	8.5****	0.15****	1.0***	1.8*	3.2****	0.04
DALZ1312	5.6****	6.0	87.8***	0.63	3.5***	3.8**	30.7***	0.30****	1.5***	2.5	12.5	0.12
DALZ1313	5.3**	6.2**	83.9**	0.61	2.8	3.3	22.4	0.25	1.3	2.2	10.0	0.13
DALZ1314	5.1	5.5	79.4	0.58	3.7***	3.8**	34.4****	0.25	1.7***	2.7	13.8*	0.12

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

[y]Leaf firing (LF) ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

[x]Percent green cover (COVER) was measured using SigmaScan software.

[w]Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[v]Days after drought stress (DAT) started.

[u]Means within the same column followed by *, **, ***, **** are significantly different at p= 0.1, 0.05, 0.01, 0.001 level respectively using Nelson-Hsu mean comparison.

Table 17. Analysis of variance for the effects of cultivar (C), date (D) and their interaction on turf quality (TQ), leaf firing (LF), percent green cover (COVER), normalized difference vegetative index (NDVI) during the drought stress on St. Augustinegrass.

	TQ		LF		NDVI		COVER	
	df	sign	df	sign	df	sign	Df	Sign
C	11	****[z]	11	****	11	****	11	****
D	1	****	1	****	1	****	1	****
D x D	1	**	1	****	1	NS[y]	1	****
D x D x D	1	****	1	****	1	****	1	****
C x D	11	****	11	**	11	****	11	***
C x D x D	11	**	11	**	11	***	11	**
C x D x D x D	11	****	11	***	11	****	11	****
Error	240		240		240		240	

*, **, ***, **** significant at p = 0.1, 0.05, 0.01, and 0.001 respectively.

[y] NS (non-significant) at p = 0.1, 0.05, 0.01, and 0.001 respectively.

Table 18. Pearson's correlation coefficient of St. Augustinegrass for turf quality (TQ^z), leaf firing (LF^y), percent green cover (COVER^x), normalized difference vegetative index (NDVI^w), and days after drought stress (DATE^v).

	TQ	LF	COVER	NDVI
TQ	1	0.96***	0.95***	0.95***
LF		1	0.94***	0.95***
COVER			1	0.95***
NDVI				1
DATE	-0.92***	-0.94***	-0.90***	-0.93***

^{z}TQ = Turf quality ratings were based on 1-9 scale where 1 = lowest quality, 6 = acceptable quality and 9 = excellent quality.

^{y}LF = Leaf firing ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

^{x}COVER = Percent green cover (COVER) was measured using SigmaScan software.

^{w}NDVI = Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

^{v}DATE = Days after drought stress (DATE) started.

*** Significant at P = 0.001 level of significance.

Table 19. Mean turf quality (TQ[z]), leaf firing (LF[y]), percent green cover (COVER[x]), and normalized difference vegetative index (NDVI[w]) of 12 St. Augustinegrass entries before drought stress.

Entry	0DAT[v]			
	TQ	LF	COVER	NDVI
Palmetto	6.5	9.0	99.8	0.75
Floratam	6.2***[u]	9.0	99.4****	0.75
Raleigh	6.8	9.0	99.8	0.78
DALSA1315	6.8	9.0	99.9	0.77
DALSA1316	6.3*	9.0	99.8	0.77
DALSA1317	7.3*	9.0	99.9	0.78
DALSA1318	7.8****	9.0	99.9	0.80**
DALSA1319	6.5	9.0	99.7	0.76
NCSA43	7.5	9.0	99.9	0.79
NCSA17	6.3*	9.0	99.8	0.75
NCSA80	6.8	9.0	99.9	0.76
NCSA65	7.0	9.0	99.3	0.77

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

[y] Leaf firing (LF) ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

[x] Percent green cover (COVER) was measured using SigmaScan software.

[w] Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[v] Days after drought stress (DAT) started.

[u] Means within the same column followed by *, **, ***, **** are significantly different at p= 0.1, 0.05, 0.01, 0.001 level respectively using Nelson-Hsu mean comparisons.

Table 20. Mean turf quality (TQ[z]), leaf firing (LF[y]), percent green cover (COVER[x]), and normalized difference vegetative index (NDVI[w]) of 12 St. Augustinegrass entries at 7 through 21 days of drought stress.

ENTRY	7 DAT[v]				14 DAT				21 DAT			
	TQ	LF	COVER	NDVI	TQ	LF	COVER	NDVI	TQ	LF	COVER	NDVI
Palmetto	6.2	7.7	99.5	0.69	3.2	3.7	23.8	0.30	2.0	2.7	12.7	0.21
Floratam	5.5	6.5	92.0****	0.61*	2.2	2.8	12.0	0.19	1.7	2.0	9.5	0.09
Raleigh	5.0*[u]	5.8*	97.7	0.66	3.2	3.7	23.8	0.33	2.3	3.3****	17.2***	0.20**
DALSA1315	6.2	7.3	99.6	0.72	2.5	3.3	17.2	0.29	2.0	2.2	12.2	0.13
DALSA1316	5.3	6.7	97.6	0.64	2.0	2.3***	9.2*	0.17*	1.3	2.0	5.0**	0.12
DALSA1317	6.3	7.7	99.5	0.67	2.2	3.0	12.6	0.22	1.5	2.2	8.9	0.13
DALSA1318	5.7	6.7	97.7	0.65	2.8	3.3	17.2	0.26	1.8	2.3	9.1	0.20
DALSA1319	6.0	7.7	99.0	0.67	2.5	2.7	13.3	0.27	1.7	2.0	8.4	0.15
NCSA43	6.5*	7.7	99.1	0.7	2.5	3.2	15.8	0.38**	2.0	2.3	13.6	0.18
NCSA17	5.7	7.2	98.8	0.65	3.5***	3.8**	27.3***	0.42	2.3	2.3	13.0	0.20
NCSA80	5.5	6.8	99.1	0.66	2.8	3.2	19.3	0.22	1.8	2.2	9.0	0.18
NCSA65	5.3	6.7	98.1	0.65	2.3	3.0	15.4	0.20	1.7	2.2	10.0	0.12

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

[y] Leaf firing (LF) ratings were based on 1-9 scale where 1 = total leaf firing and 9 = no leaf firing.

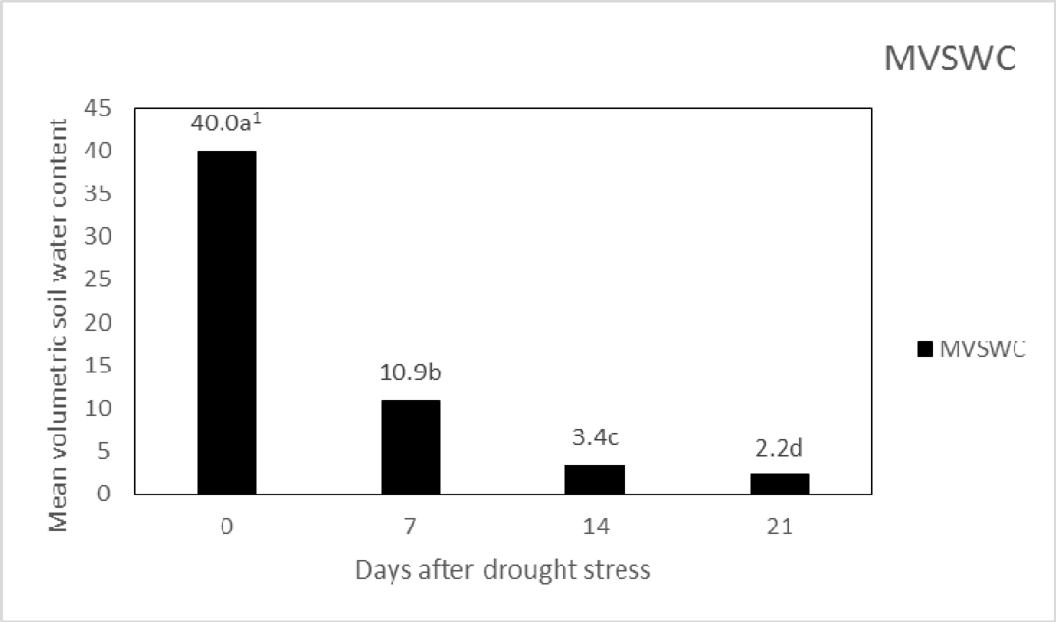
[x] Percent green cover (COVER) was measured using SigmaScan software.

[w] Normalized difference vegetative index (NDVI) was measured using CM1000 NDVI meter (Spectrum Technologies, Plainfield, IL).

[v] Days after drought stress (DAT) started.

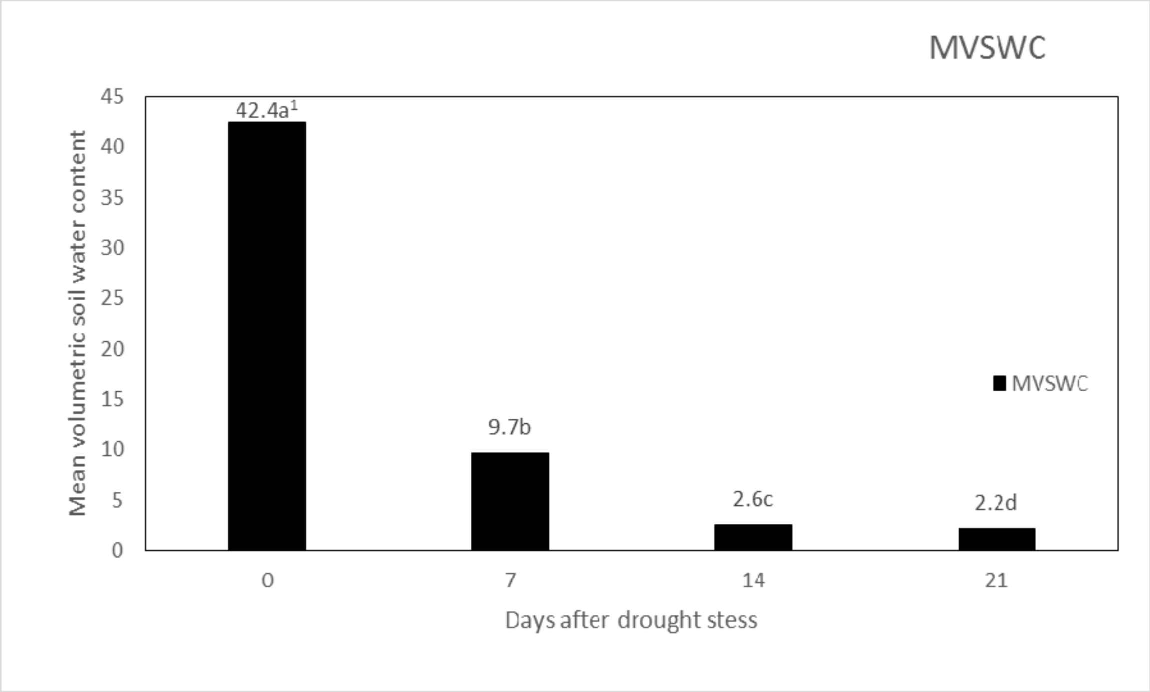
[u] Means within the same column followed by *, **, ***, **** are significantly different at p= 0.1, 0.05, 0.01, 0.001 level respectively using Nelson-Hsu mean comparison.

Figure 1. Mean volumetric soil water content of bermudagrass during drought. Data were taken at 0, 7, 14, and 21 days of drought stress.



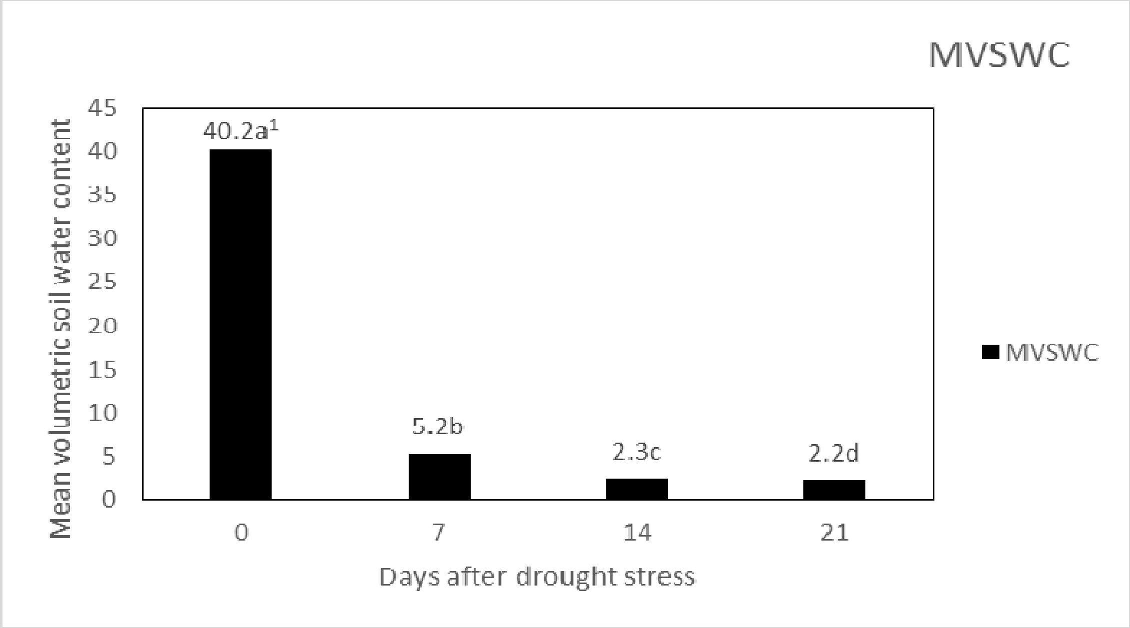
[1] Means followed by different letters indicate significant difference at p=0.05 level using Fischer's least significant difference (LSD) test.

Figure 2. Mean volumetric soil water content of seashore paspalum grass during drought. Data were taken at 0,7,14 and 21 days of drought stress.



[1] Means followed by different letters indicate significant difference at p=0.05 level using Fischer's least significant difference (LSD) test.

Figure 3. Mean volumetric soil water content of zoysiagrass during drought. Data were taken at 0, 7, 14, and 21 days of drought stress.



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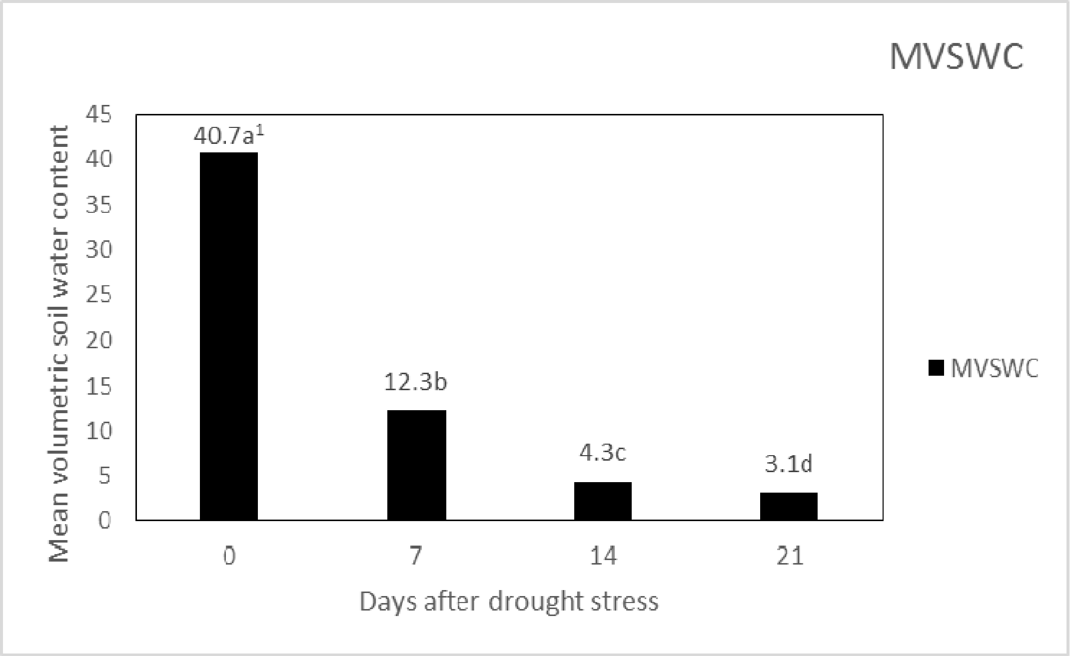
[1] Means followed by different letters indicate significant difference at $p=0.05$ level using Fischer's least significant difference (LSD) test.

Figure 4. Mean volumetric soil water content of St. Augustinegrass during drought. Data were taken at 0, 7, 14, and 21 days of drought stress.



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[1] Means followed by different letters indicate significant difference at p=0.05 level using Fischer's least significant difference (LSD) test.

Figure 5: Comparison of the digital images between the worst and the best bermudagrass entries during drought stress. Number in parentheses represent the percentage of green tissue in the PVC tubes, as determined by SigmaScan software.

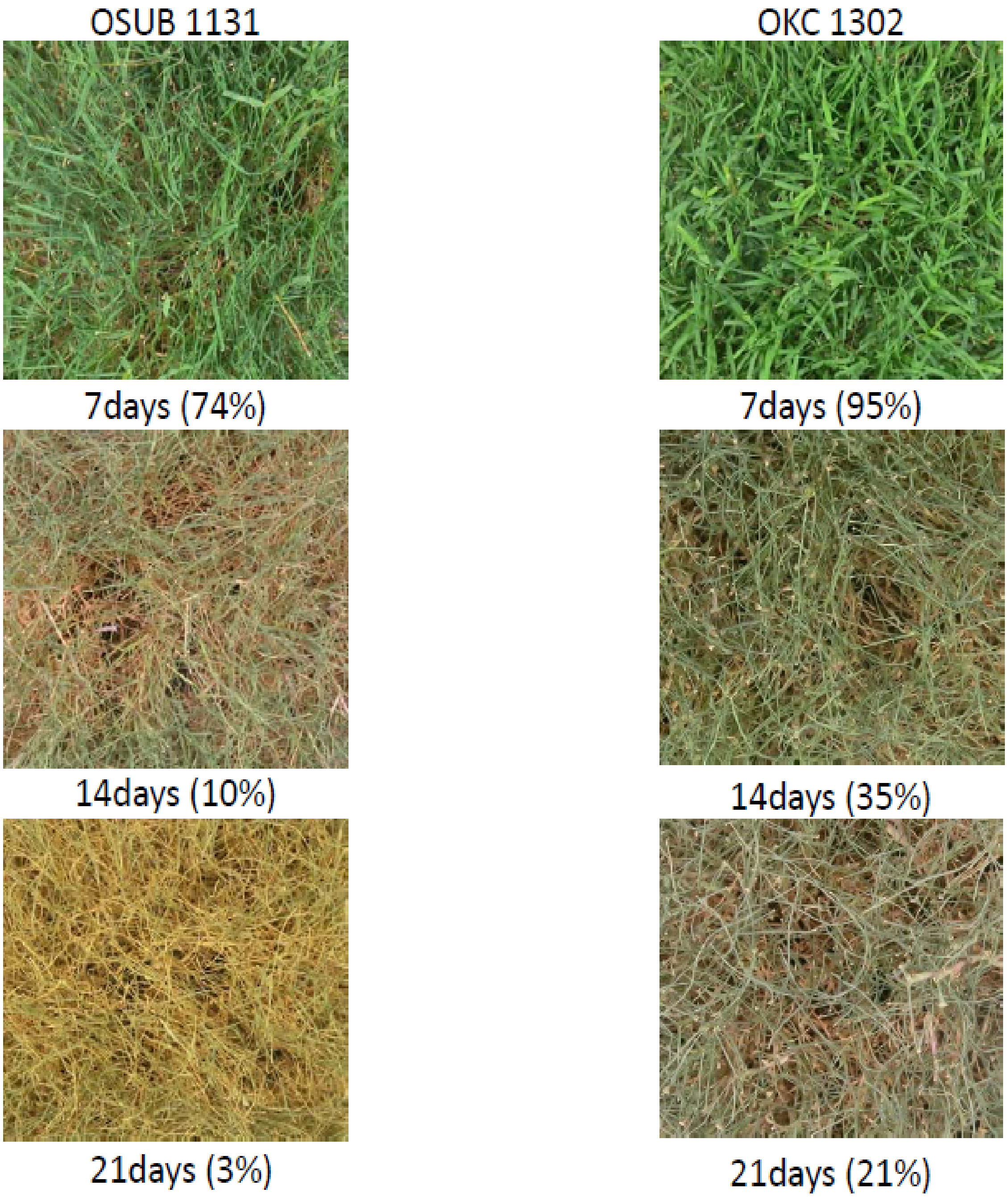


Figure 6: Comparison of the digital images between the worst and the best seashore paspalum entries during drought stress. Number in parentheses represent the percentage of green tissue in the PVC tubes, as determined by SigmaScan software.

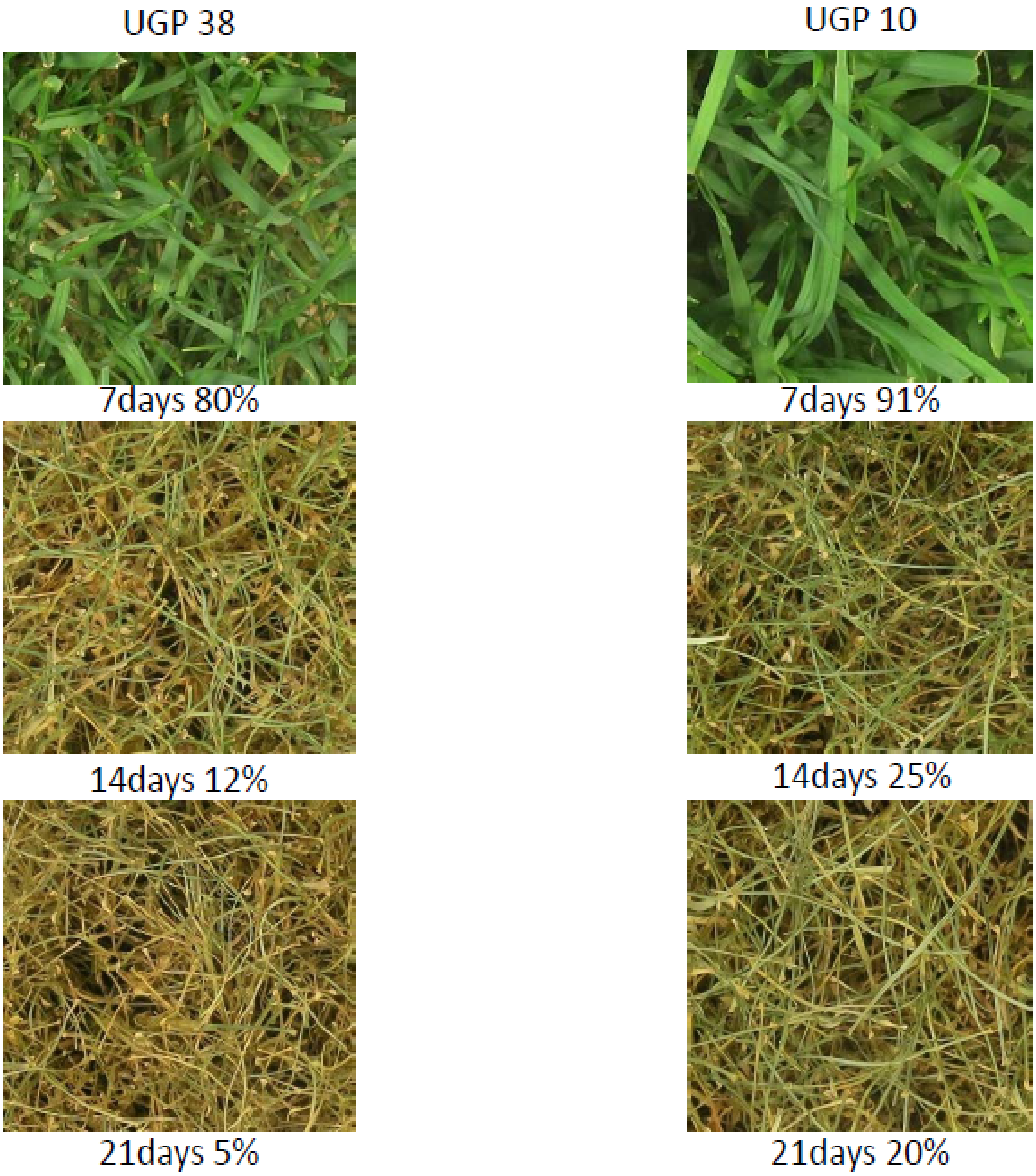


Figure 7: Comparison of the digital images between the worst and the best zoysiagrass entries during drought stress. Number in parentheses represent the percentage of green tissue in the PVC tubes, as determined by SigmaScan software.

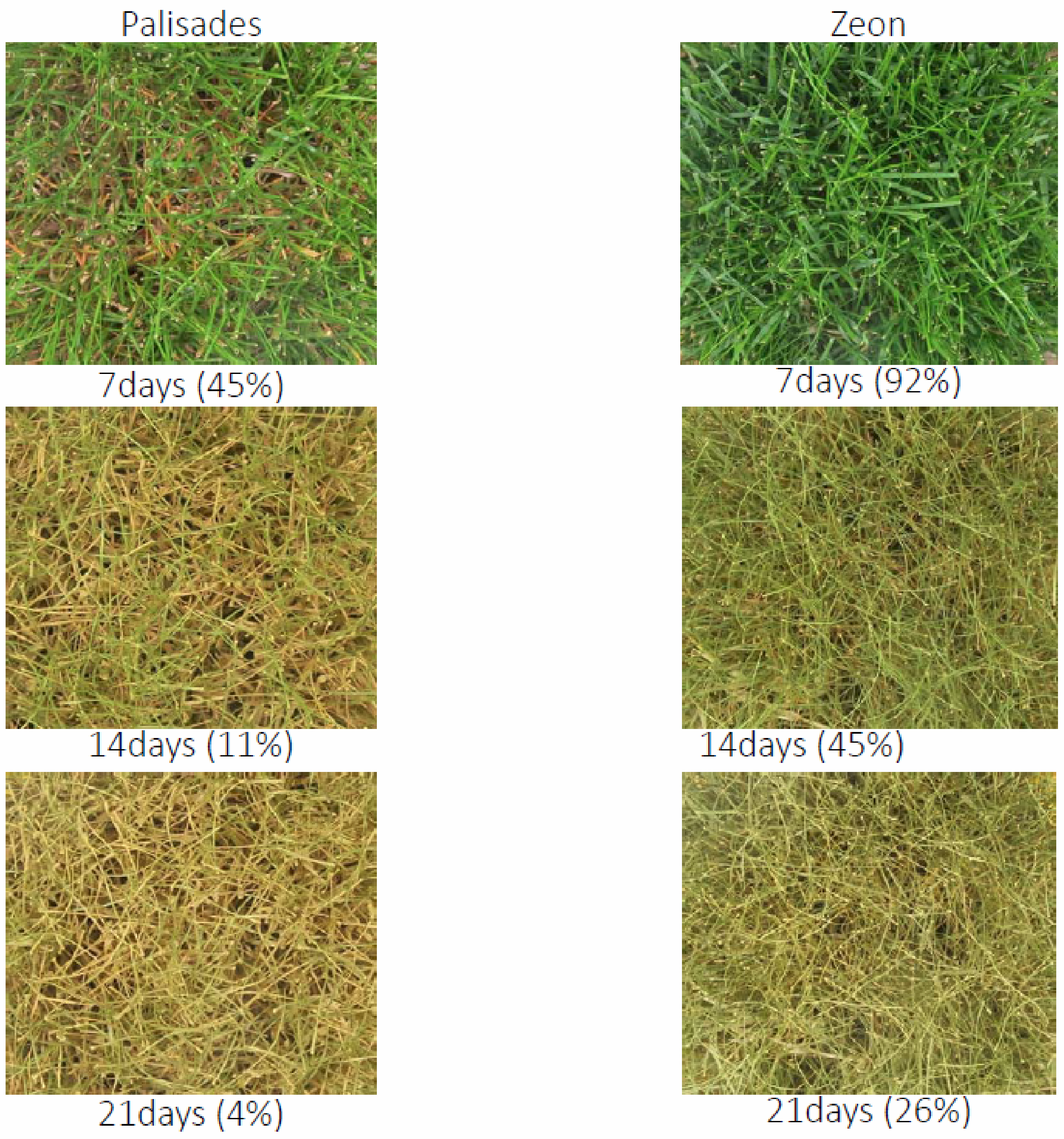
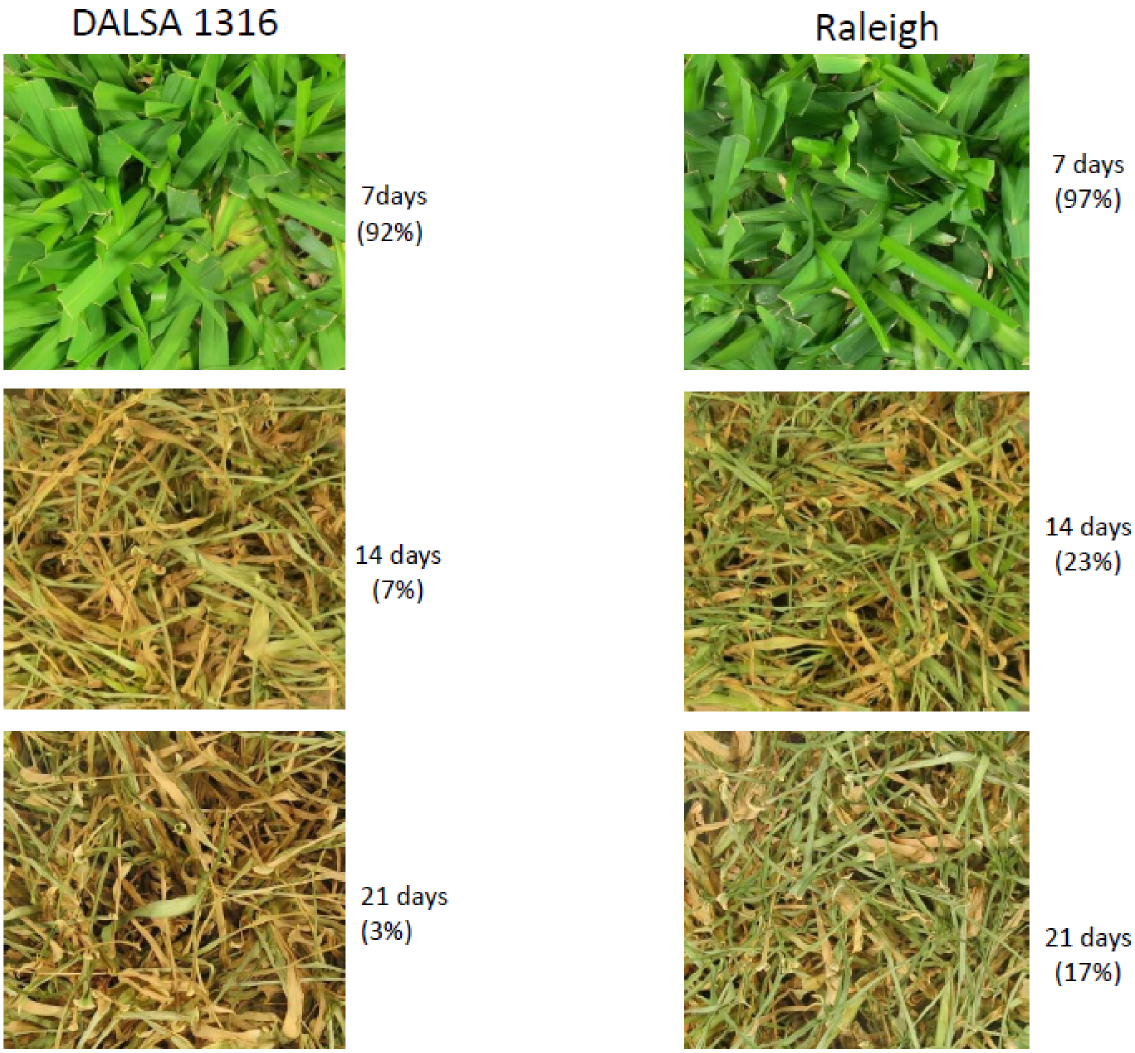


Figure 8: Comparison of the digital images between the worst and the standard St. Augustinegrass entries during drought stress. Number in parentheses represent the percentage of green tissue in the PVC tubes, as determined by SigmaScan software.



VITA

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