AN ASSESSMENT OF THE SOD HANDLING QUALITY AND TENSILE STRENGTH OF THIRTY-NINE TURF BERMUDAGRASSES

By

LAKSHMY GOPINATH

Bachelor of Science in Horticulture
Tamil Nadu Agricultural University
Coimbatore, India
2012

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
December, 2015

AN ASSESSMENT OF THE SOD HANDLING
QUALITY AND TENSILE STRENGTH OF THIRTY-
NINE TURF BERMUDAGRASSES

Thesis Approved:

Dr. Dennis Martin

Thesis Advisor

Dr. Justin Moss

Dr. Yanqi Wu

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my advisor and mentor Dr. Dennis Martin for the continuous support of my research, for his patience, motivation, enthusiasm, and immense knowledge. I would like to thank the rest of my thesis committee: Dr. Justin Moss and Dr. Yanqi Wu for their encouragement and insightful comments.

I would like to thank all of the faculty and staff members and student workers at the OSU Turfgrass Research Station and within the Horticulture Department for their support and technical assistance throughout my graduate program. Particularly, I would like to thank Bart Frie, Kent Elsener, Dan Valdez, Kyungjoon Koh, Steve Batten, Chrissie Segars, Dustin Harris and Wenwen Liu. This project would have not been completed without the help and support of Shuhao Yu. I would also like to thank Jimi Underwood for squeezing some time out of his busy schedule to assist me with this project. You both have been such a blessing in a way that I will never be able to repay.

Most importantly, none of this would have been possible without the love and patience of my parents (Mr. Vettath Gopinath and Mrs. Jalaja Gopinath) and my sister and brother-in-law (Ms. Parvathy Gopinath and Mr. Vivek Balan) and also for all the strength and motivation they have given during many moments of crisis. I take this opportunity to thank my friend and roommate, Ms. Zeel Maheshwari for all the help and support provided during this period. I would also like to thank a bunch of wonderful friends for always lending their ears to listen to my complaints and for always being there to cheer me up. They are unnamed for the sake of space, but my heart is forever grateful to you all. Above all, I would like to thank god for giving me the perseverance and strength to overcome the many obstacles and adversities that were placed in my path and for showering me with blessings in the form of people I have mentioned above.

Acknowledgements reflect the views of the author and are not endorsed by committee members or Oklahoma State University.

Name: LAKSHMY GOPINATH

Date of Degree: DECEMBER, 2015

Title of Study: AN ASSESSMENT OF THE SOD HANDLING QUALITY AND TENSILE STRENGTH OF THIRTY-NINE TURF BERMUDAGRASSES

Major Field: HORTICULTURE

Abstract:

Turfgrass sod is a pad of grass with its intermingled shoots, rhizomes and roots as well as adhering soil. To be successfully used as a sod crop, a turfgrass must have a suitable production cycle and sod handling/transport quality characteristics. Thirty-nine cultivars of bermudagrass (*Cynodon* sp) were evaluated for sod handling quality (SHQ) and sod tensile strength (STS). Sod tensile strength is the amount of longitudinal force required to shear the sod pad. Commercially available cultivars evaluated included ‘Tifway’, ‘Latitude 36’, ‘Celebration’, ‘Quickstand’, ‘Astro’, ‘Patriot’ and ‘TifGrand’ as standards. The SHQ (a qualitative parameter) was evaluated using a 1 to 5 scale with 1 = complete separation during handling, not harvestable, 3 = moderate separation (cracking), suggested minimum acceptable rating, and 5 = no cracking, excellent quality. Sod tensile strength (a quantitative parameter) was measured in kg dm^{-2} as the peak force required toshear the sod pad using a sod tensile strength measuring device. Three sod harvests were conducted. The harvests were conducted at 14 months after planting, after 22 months after planting at 100% green up and at 24 months after planting. The harvest date and entry had a significant effect on STS. The Oklahoma State University’s experimental variety ‘OKC 1302’ and '12-TSB-1' had higher mean STS than the standard Patriot but were lower than the STS of the other standards Latitude 36, Tifway, Astro and TifGrand. The seeded variety ‘PST-R6T9S’ had the lowest STS and SHQ. The results of this research will help in comparative ranking of the experimental lines and commercial cultivars for their STS and SHQ and will aid product developers in decision making concerning possible commercializing of the experimental cultivars tested.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

LITERATURE REVIEW

Introduction

Bermudagrass Characteristics

Bermudagrass Adaptation, Use and Distribution

Warm-season turfgrasses are adapted to subtropical and tropical regions and have an optimum growing temperature around 25 to 35°C (Turgeon, 1996). Bermudagrasses (*Cynodon* sp) are some of the most important, widely adapted warm-season turfgrasses. They are commonly used on home lawns, athletic fields, golf courses, and other utility turf areas. Bermudagrasses have their origin around the Indian Ocean ranging from eastern Africa to the East Indies (Beard, 1973). Bermudagrasses are known by different names in different regions, including 'couch' or 'green couch' in Australia, 'dhoub' in India and Bangladesh and 'quick' and 'kweek' in South Africa (Hurcombe, 1948; Kneebone, 1966, Skerman and Riveros, 1990). They tolerate the often hot and humid summers of the United States transition zone, however they enter a dormancy period with the onset of winter (Wharton, 1999).

Taxonomic and Genetic Classification

The revised species classification of *Cynodon* L.C. Rich by Harlan et al. (1970a) led to recognition of nine species and 10 botanical varieties. The *Cynodon* taxa which are valued for use as turfgrasses are common bermudagrass (*Cynodon dactylon* [L.] Pers. var. *dactylon*) and African bermudagrass (*Cynodon transvaalensis* Burtt-Davy) (Taliaferro et al., 2004) and their interspecific hybrids (*C. dactylon* X *C. transvaalensis*). The base chromosome number per genome of the *Cynodon* species is nine (Forbes and Burton, 1963; Harlan et al., 1970b). *Cynodon dactylon* was classified as being tetraploid by Harlan et al. (1970a), however, hexaploid and pentaploids were reported in germplasm collected from China by Wu et al. (2006). *Cynodon dactylon* cv. Tifton 10 (also known as 'Shanghai') is a natural hexaploid plant collected in Shanghai, China in 1974 by Burton (Burton, 1991; Hanna et al., 1990). *Cynodon dactylon* is propagated through stolons, rhizomes and seed. The seed generation is considered to be highly outcrossed due to cross pollination and a high degree of self-incompatibility (Burton and Hart, 1967). Seed propagated varieties usually possess an upright growth habit and medium to coarse leaf texture due to increased internode length **(**Cattani et al., 1996)**.**

Cynodon transvaalensis is considered to be diploid in chromosome number. It has small, erect leaves, short stature, fine texture, and yellow-green color (Hanna, 1986; Harlan et al., 1966, 1970a, 1970b; Juska and Hanson, 1964). It is vegetatively propagated by sprigs, stolons, or sod. The interspecific hybrids of bermudagrass often form vigorous and aggressive turf with many having high shoot density, as well as improved turf quality and color as well as fine-textured leaves (Beard, 1973). Unlike the euploidy (2n=2x=18, 4x=36, and 6x=54) *Cynodon* species, the interspecific hybrids rarely produce viable seed and they must be propagated vegetatively by sprigs, stolons, or sod.

Morphological and Physiology

There are various vegetative features that can be used to identify bermudagrasses such as a narrow and continuous collar with hairs and a ligule with a fringe of hairs about 1 to 3 mm long (Christians, 2004). The leaves are linear-lanceolate and stolons usually range from very fine to coarse (Taliaferro et al., 2004). Auricles are absent. Due to their prostrate growth habit they have good tolerance to close mowing (Beard, 1973). The rapid establishment rate and recovery from injury of bermudagrass is due to its ability to spread rapidly by stolons (aboveground stems) and rhizomes (underground stems) (Higgins, 1998). Warm-season grasses contain the C4 photosynthetic pathway and they fix carbon dioxide from the atmosphere into four carbon intermediate compounds initially (Moore et al., 2004a). As these grasses have a C4 photosynthetic pathway, the nitrogen concentration in the foliar tissues are generally low (Moore et al., 2004). Bermudagrasses require relatively high levels of nitrogen for higher biomass yield (Taliaferro et al., 2004). Bermudagrasses are regarded as having excellent tolerance to heat and drought, but low tolerance to freezing temperature (Beard, 1973).

Edaphic Adaptation

Bermudagrasses are best adapted to moderately well drained, fertile, loamy soils; however, these grow well over a wide range of edaphic conditions (Casler and Duncan, 2003). Bermudagrasses prefer a pH between 6.0 – 6.5 (Higgins, 1998).

Overview of Oklahoma State University's Turf Bermudagrass Development Program

Oklahoma State University (OSU) has been actively engaged in bermudagrass breeding since the mid-1980s due largely in part to support from the United States Golf Association (USGA). The goal of the breeding program was multi-fold (Wu et al., 2009). These goals grew to include overtime 1) maintaining and assembling *Cynodon* germplasm which have the potential for contributing in breeding of improved turf cultivars, 2) development of cultivars which have improved seed production potential, cold tolerance, traffic tolerance, traffic stress recuperation potential, shade tolerance and drought resistance, and 3) the evaluation and release of improved seeded and vegetatively propagated bermudagrasses for use in the U.S transition zone. Some of the bermudagrasses with high quality and improved cold hardiness developed by OSU that are commercially available are 'Patriot', 'Yukon', 'Riviera', 'Latitude 36' and 'NorthBridge' (Wu and Martin, 2015).

Midlawn and Midfield interspecific hybrid bermudagrasses (Pair et al. 1994a and 1994b) were the first turf bermudagrass releases by the OSU program, being joint releases with Kansas State University (KSU) in 1991. These grasses were bred by the late Dr. Ray Keen of KSU. Yukon was the first turf berrmudagrass variety bred exclusively by the turfgrass team at OSU and it was released in 1997 (Taliaferro et al., 2003). It was seed propagated and was produced by the intercrossing of six highly out-crossing clonal parent plants (Taliaferro et al., 2004). Riviera, which was also a seeded variety, was released in 2001 (Taliaferro et al., 2004). Patriot was a vegetatively propagated tetraploid (2n=4x=36) interspecific hybrid (Taliaferro et al., 2006). Latitude 36 was a vegetatively propagated F1 hybrid that was produced by crossing *C. dactylon* accession ‘A 12198’ (2n=4X=36) and C. *transvaalensis* OSU selection ‘2747’ (2n=2X=18) (Wu et al., 2014). NorthBridge was a clonally propagated F1 hybrid from a cross of *C. transvaalensis* OSU selection 2747 (2n=2x=18) by *C. dactylon* var. *dactylon* OSU selection ‘3200E 4-1’ (Wu et al., 2013).

The 2013 National Turf Evaluation Program Bermudagrass Trial

The National Turf Evaluation Program (NTEP) is a non-profit, cooperative effort between the U.S. Department of Agriculture’s Beltsville Agricultural Research Center and the National Turfgrass Federation. The primary objective of NTEP is to coordinate evaluation of promising selections of turfgrasses in multiple locations in United States and Canada (Morris, 2000). The results of this evaluation are used by plant breeders to understand and determine the adaptation of a cultivar (Morris, 2000). There are 35 official entries in the 2013 NTEP bermudagrass test (Morris, 2015). There are 8 official standard entries and 27 entries that have never previously appeared as official entries in an NTEP bermudagrass trial (13 seeded and 14 vegetative). In this trial there are 23 experimental bermudagrass entries. Four of the commercially available lines in the current 2013 NTEP bermudagrass trial were not previously tested in NTEP cultivar trials.

The official standards in the 2013 NTEP Bermudagrass Trial were Latitude 36, Riviera, Yukon, Patriot, ‘NuMex Sahara’, ‘Princess 77’, ‘Tifway,’ and ‘Celebration.’ NuMex Sahara was a seed propagated bermudagrass released by the New Mexico Agricultural Experiment Station (Baltensperger, 1989). Princess 77 was a seeded variety produced by Seeds West, a division of Pennington Seed. It was developed by the late Dr.

Arden BaltenspergerNew Mexico State University (Aylward, 2003). Tifway bermudagrass, a triploid (2n=3X=27) hybrid, was a vegetatively propagated variety selected and released from the Tifton breeding program that was headed at that time by Dr. Glenn Burton (Alderson and Sharp, 1994 and Wu et al., 2011). Celebration bermudagrass was originally developed by Rod Riley, a turfgrass breeder in Australia. Celebration was released in the U.S. in 1999. At this time it is sold exclusively by producers licensed through Sod Solutions, Inc. The 2013 NTEP Bermudagrass Trial was conducted under contract at 17 locations across the U.S.A.

Sod Tensile Strength and Handling Quality:

Turgeon (2006) defined sod as the surface layer of turf harvested for transplanting. It consists of the interconnected parts of turfgrass plants, the soil adhering to their roots and the underground organs of the turf. Production of cultivated turfgrass sod on a commercial basis began around 1920 in the United States of America (Mitchell and Dickens, 1979). Significant expansion of the sod industry occurred in approximately 1950 due to the advancement in mechanization of production such as the development of the sod cutter and the release of improved sod forming varieties. The ability to achieve an instant quality turf in a very short period of time also contributed to the expansion of this industry. According to the 2007 Census of Agriculture released by the U.S. Department of Agriculture's National Agricultural Statistics Service (NASS), it was reported that there were 1,881 turfgrass sod farms in operation throughout the United States at the time of the census. The acres under sod production had increased to 409,440 acres in 2007 as compared to 386,504 acres in 2002.

The selection of turfgrass varieties to be grown for commercial sod production is based on their ability to form a suitable sod. Other desired characteristics of turfgrass that benefit both the end-user and sod producer include rapid establishment from seed or vegetative propagules, rapid and vigorous rhizome and stolon formation leading to an intact and well-knitted sod, and a tolerance to abiotic and biotic stresses. Turfgrasses can be harvested from the same site by allowing the remaining rhizomes and/or stolons of the previous harvest to re-grow (Barton et al., 2006).

The primary warm-season turfgrasses used for sod production are St Augustinegrass *(Stenotaphrum secundatum* (Walter) Kuntze), bermudagrass, centipedegrass (*Eremochloa ophiuroides* (Munro) Hack), zoysiagrass (*Zoysia spp.* Willd) and bahiagrass (*Paspalum notatum* Flüggé) (Christians, 2011). The predominant seed-propagated cool-season species that are grown in sod production are Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinaceae* Schreb) and their mixes (Beard et al., 1969, Hall and Bingham, 1993 and Shildrick, 1982). The rhizomatous nature of Kentucky bluegrass allows it to knit together and the sod could be harvested within 6 months if grown under good conditions (Rieke and Beard, 1968). Hence, enhancing the growth of roots, rhizomes or stolons is of prime importance as these are the organs that hold the sod intact and enables harvesting and handling of sod pads without them tearing apart. This can be substantiated with the studies conducted by Schmidt et al, (1986), in which it was concluded that the vertical force required to detach the sod was correlated with its root growth.

Sod tensile strength (STS) is defined as the resistance of sod to a minimum amount of longitudinal stress and maximum shear force required to separate the sod

(Heckman et al. 2001b and McCalla et al., 2009). The terms ’longitudinal stress’ and ’shear force’ represent two different physical concepts. Longitudinal stress acts perpendicular to the suface of the object whereas shear force acts parallel to the surface of the object. The STS is one of the major criterion for selection of turfgrasses (Krans et al., 1992). It determines the ease with which the sod could be harvested and transported. Sod with weak STS will break apart easily. Some of the products and techniques used in harvest of turfgrasses are the use of nylon netting and small sod slabbing (Han, 2009). Nylon netting is incorperated by one of two methods. First, either being applied to the surface of the seeded field and as the seedlings mature, the net and the vegetative growth of the turfgrass intermingles to form stronger sod (Giese, 1997) or netting is applied mechanically to the roll of sod as it is being harvested. Sod slabbing is the method of cutting sod into slabs or pads such that squares or rectangles are formed without rolling the sod (Han, 2009). The act of rolling can sometimes cause the pads to break. Netting or slabbing can incur additional production expenses. Therefore turfgrasses with good STS are more prefered by the sod producers.

Previous Studies on Methods of Measuring Sod Tensile Strength

Numerous studies have been conducted to determine the sod tensile strength (STS) of various turfgrasses. All of these studies included a device to measure the weight or peak force required to tear a sod piece. One of the earliest machines to have been designed to measure the weight required to break sod was developed by Rieke et al. (1968) at Michigan State University. This machine consisted of an immobile frame and a movable frame which was attached by a cable to a bucket. One end of the sod was clamped by the immobile frame and the other end was secured to the movable frame.

Silica sand was poured into the bucket at a constant rate to induce stress. This caused the movable frame to move apart and the weight of the sand at which the sod broke was recorded as the force required to break the sod. Many such STS measuring devices have been introduced using the same principle of a stationary frame and portable frame by replacing the bucket and sand with electric motors, push and pull gauge, load sensor etc.

Mississipi State University developed a hydraullically powered sod strength device consisting of the movable and immobile frames (Goatley et al., 1997). A force transducer attached to a chart recorder was used to measure the sod strength parameter such as average force, pull distance, total work, peak work and average maximum work in addition to peak force to determine if the accuracy of sod strength measurements could be improved (Goatley et al., 1997).

Another method that was introduced by Burns and Futral (1980) was the use of the Instron Universal Testing Instrument. This also works based on the principle used by Rieke et al. (1968). It consisted of a special box in which the sod was enclosed. The box was attached to the Instron testing intrument with a pull rod. The advantage of this system includes uniform pull, adjustable speed, gives the pattern of breakage and the amount the sod stretched prior to breaking. However this testing instrument is expensive and immobile.

Parish (1995) introduced a simple and inexpensive device to measure the tensile strength of turfgrasses. It had a steel framework, a stationary clamp to hold one end of the sod and a movable clamp on the other end. The movable clamp had a pivot mechanism that caused a horizontal displacement which resulted in stretching of the sod. A torque wrench was used as a force measuring device.

Effect of Management Practices on Sod Tensile Strength

Management practices like fertilization, mowing, and herbicides greatly influence sod formation. These cultural factors strongly influence the growth of the roots and the quality of sod greatly depends on the root growth of the turfgrasses. A higher height of cut is prefered as the greater the leaf area for photosynthesis, the more favorable conditions for root growth due to more production of carbohydrates (Beard, 2001). In the case of nitrogen application, moderate application of nitrogen encourages a balanced supply of carbohydrates to both roots and shoots. However, excessive nitrogen levels force shoot growth, thus reducing the supply of carbohydrates to the roots (Beard, 2001). The handling quality of sod is affected due to decreased rhizome growth (Koske, 1994).

Mitchell and Dickens (1979) conducted research to study the effect of nitrogen fertilization and mowing height on tensile strength of bermudagrass. The study was conducted for a period of three years at Auburn, AL, USA. The objectives of the study were to determine the effects of mowing height, rate and frequency of nitrogen application on the sod tensile strength of Tifway and 'Tifgreen' hybrid bermudagrasses. Nitrogen was applied at the rate of 0.25 kg acre^{-1}, 0.5 kg acre^{-1} and 1 kg acre^{-1}, at two and four week intervals. Results showed that nitrogen application at 0.25 kg acre^{-1} made 4 weeks apart produced sod with superior tensile strength. Thus, sod strength decreased with increasing amounts of nitrogen available to grass whether from increased rates of application or decreased intervals between applications. Varing mowing heights 1.25, 2.0

and 2.5 cm had little or no effect on sod tensile strength of both cultivars. Tifway was found to produce stronger sod and this was attributed to the numerous fine rhizomes and stolons that it produced.

A similar study was conducted by Lima et al. (2010) on Celebration bermudagrass. The results indicated that the highest resistance to breakage of sod occured at 365 kg ha^{-1} nitrogen. Higher rates of nitrogen decreased the resistance to breakage of sod. This was believed to be due to increased leaf growth at the expense of stolons, rhizomes, and roots.

Effect of Growth Regulator Trinexapac-Ethyl on Sod Tensile Strength

McCalla et al. (2009) conducted research to study the potential of seeded bermudagrasses to be used in sod production. The objective of that study was to determine the effects of sod netting and the use of the growth regulator trinexapac-ethyl (TE) on the time required from planting until harvest of sod using seeded bermudagrasses. The study was conducted at the University of Arkansas Research and Extension Center in Fayetteville, AR. Riviera was seeded at the rate of 48.7 kg ai ha^{-1}. A strip plot experimental design was used with netting/no netting being the whole plot treatment and two TE treatments (0.07 kg ai ha^{-1} every 2 weeks and 0.13 kg ai ha^{-1} every 4 weeks) as subplot treatments. The netting was provided to half of the whole plot area and the other half was maintained as the non-netted control. Sod was harvested 10, 12, 14, and 16 weeks after planting (WAP). The sod, which was harvested from plots that were netted, allowed for 100% harvestable sod product as early as 10 WAP. The non-netted plots were unable to produce harvestable sod even at 16 WAP. Both rates of TE increased the sod tensile strength of Riviera and also the percentage of harvestable sod. These results revealed that TE can be used to shorten the time from seeding until harvest of seeded-type bermudgrasses. This effect of TE on bermudagrasses was likely due to the ability of TE to increase the number of stolons in TE treated bermudagrasses as found by Fagerness et al. 2002. McCalla et al. (2009) also stated that it is more economical to use TE than the use of netting and in addition to that, netting used for sod production has a long decay period and this may create potential hazards to the athletes when used in athletic fields.

Sod is a perishable comodity. Sod quality deteriorates due to internal heating when stored (Heckman et al., 2001). The accumulation of heat in sod is due to the increase in carbon dioxide and decrease in oxygen which is a result of active plant respiration (King et al., 1982b). Darrah and Powell (1977) found that higher mowing height, nitrogen fertilization and presence of clipping residues increased the temperature within the sod. The preharvest application of TE to sod was found to reduced sod temperatures in Kentucky bluegrass sod (Heckman et al., 2001). The TE has been found to decrease the respiration of isolated wheat mitochondria (Heckman, 2002).

Effect of Herbicides on Sod Tensile Strength

Herbicides can impair root growth (Johnson, 1977). They may reduce the sod tensile strength of the turfgrasses. Sharpe et al. (1989) performed research to determine the effect of selected pre-emergence herbicide on the sod tensile strength and rooting of Tifway bermudagrass. The herbicides used for this experiment were atrazine, atrazine + tridaphane, bensulide, DCPA, DPX-6316, imazapyr, imazaquin, napropamide, oxadiazon, pendimethalin, sethoxydim, simazine, and sulfometuron. Sod was tested for tensile strength at 2, 4, and 8 weeks after treatment (WAT) after a single herbicide application. At 4 WAT tensile strength did not differ among the treatments. The tensile strength of the treated plots did not differ from the control at 8 WAT. The STS was not affected by the herbicide application. However, imazapyr did affect the top growth of bermudagrass and this may reduce its market value. Initial rooting was impaired by bensulide, imazapyr, napropamide, and sulfometuron at most rates and dates. However, the root length and number were similar to that of the control at 8 WAT except with imazapyr. Thus, the results revealed that bermudagrasses recovered within 8 weeks from the detrimental effects of all herbicides at the rates tested in that trial except for the treatment with imazapyr.

McCalla et al. (2009) tested the effect of Mesotrione on sod quality of Tifway bermudagrass. Mesotrione (2-[4-(methylsulfonyl)-2-nitrobenzoyl]-1,3-cyclohexanedione) is an herbicide with post and pre emergence activity on broadleaf weeds and annual grasses (Gardner, 2008). The herbicide was applied at five different rates (0.14 kg ai ha^{-1}. 0.17 kg ai ha^{-1}, 0.28 kg ai ha^{-1}, and 0.56 kg ai ha^{-1},). These treatments were applied at four different timings (initial treatment, 3 WAT, 6 WAT and 9 WAT). The sod was harvested three weeks after the final treatment. Each plot yielded ten sod pads and were tested for percent of harvestable sod. This was calculated by dividing the number of sod pads that were successfully lifted and transported by the total number of sod pads harvested from each plot (10 sod pads). Five samples amongst these plots were tested for sod tensile strength. The highest rate of mesotrione produced less harvestable sod than the rest of the treatments. The study concluded that it is safe to apply lower rates of mesotrione on bermudagrasses as it has minimal effects when compared to untreated bermudagrass.

McCullough et al. (2014) conducted research to find the effect of halosulfuron and sulfentrazone on warm-season turfgrasses. Halosulfuron and sulfentrazone are effective post emergent herbicides for controlling yellow nutsedge (Belcher et al. 2002; Gannon et al. 2012). The treatments were a factorial combination of four herbicides and four applications and a non-treated control. The treatments were halosulfuron at 0.07 kg ai ha^{-1} and sulfentrazone at 0.21, 0.42, or 0.84 kg ai ha^{-1}. These were applied 1, 2, 4, or 8 weeks before harvesting the sod (WBH). The tensile strength of the harvested sod was measured. The results revealed that sod tensile strength of bermudagrasses were not reduced when compared to non-treated checks for either of the herbicides at various application rates. The results also indicated that bermudagrasses could be harvested 1 WAT without any damage to tensile strength.

Brosnan et al. (2014) performed a study to understand the effects of pre-emergence herbicides on Tifway bermudagrass. The treatments for this study were pendimethalin (3.36 kg ai ha^{-1}), dithiopyr (0.56 kg ai ha^{-1}), prodiamine (0.6 kg ai ha^{-1}), oxadiazon (3.36 kg ai ha^{-1}), prodiamine + sulfentrazone (0.84 + 0.41 kg ai ha^{-1}), dimethenamid-*P* (1.68 kg ai ha^{-1}), and indaziflam (0.03 and 0.05 kg ai ha^{-1}) and a non-treated control. These were applied immediately before sprigging. Sod was harvested 377 days after sprigging and the tensile strength was measured. In the first year, indaziflam reduced the tensile strength of the hybrid bermudagrass when compared with the non-treated control. However, the rest of the treatments did not produce a reduced tensile strength when compared to the control. In the second year, no significant difference in sod strength was found due to herbicide treatment. The study concluded that the above mentioned herbicides did not negatively affect the sod tensile strength of Tifway bermudagrass.

A New Method for Assessing Sod Handling Quality

Han (2009) carried out research at Oklahoma State University in Stillwater to evaluate the sod tensile strength and sod handling quality (SHQ) of the interspecific bermudagrasses Patriot, and ’OKS 70-18’ relative to Tifway and Midlawn. Tifway represented the industry standard for a suitable cultivar in sod production. Midlawn represented the standard for poor sod tensile strength as it broke apart while being rolled, stacked, and transported [D.L. Martin, Oklahoma State University, unpublished, 2004 as cited in Han (2009)]. Sod handling quality, not previously tested in studies prior to Han (2009) to the best of our knowledge, was evaluated using a scale of 1 to 5 in which 1 had the least and 5 had the best handling quality. Five harvesting dates were included in the study. It was found that Patriot provided STS and SHQ greater than or equal to that of Tifway in four out of five total harvest dates. OKS 70-18 had a lower STS and SHQ in all harvest dates when compared to Tifway and was equal to or less than Midlawn in these parameters.

Problem Statement

The ability to achieve an instant high quality turf in a very short period of time and also turf with higher visual quality immediately upon installation, makes sod a popular means of establishing turf. In order for private industry and university developers to make decisions concerning the suitability of their bermudagrass products in sod production, information is needed concerning the sod handling quality and tensile strength of their products. Information concerning visual performance traits of bermudagrass such as color, quality, texture, density as well as spring green-up and color retention is also needed so that product developers can make commercialization decisions and product placement into various geographic areas. Once generated, the visual performance information also helps end users such as consumers, sports field managers and golf course superintendents in making comparisons amongst various cultivars presented for purchase in the market place.

Objectives

The objectives of this research were to evaluate the thirty-four official entries of the 2013 NTEP bermudagrass trial and five local entries for 1) sod tensile strength, 2) sod handling quality and for 3) visual performance parameters including visual quality, leaf texture, shoot density, color, spring green-up and fall color retention during 2014 and 2015.

CHAPTER II

MATERIALS AND METHODS

Sod Production Experiment:

Description of Research Site and Entries

The experimental site was located at the Oklahoma State University (OSU) Botanic Garden (latitude 36°07'27.4" N longitude 97°06'07.1" W). The soil type was an Easpur loam (Fine-loamy, mixed, superactive, thermic Flueventic Haplustoll) and a Pulaski fine sandy loam (coarse-loamy, mixed, superactive, nonacidic, thermic Udic Ustifluvents) (USDA-NRCS, 2015). There were 39 entries in this research trial. Thirty five of these were the official entries for the 2013 NTEP bermudagrass trial and the remaining four entries were local entries. Entries were planted by seeds and plugs respectively on 6 and 7 August, 2013. The commercially available official 2013 NTEP bermudagrass trial entries were Tifway, Latitude 36, Patriot, Celebration, NuMex Sahara, Princess 77, Riviera, Yukon, and 'North Shore SLT'. The local entries that were commercially available by the end of the trial included TifGrand, 'Astro', ‘U-3-NC’, ‘U-3-TGS’ and ‘Quickstand.’ The standards used for the sod experiment were Tifway, Latitude 36, Patriot, Celebration, Astro, TifGrand and Quickstand.

The trial area was originally planted as a single trial with each whole plot measuring 1.8 m by 1.8 m and three replications of each entry. Two experiments were conducted on the trial area with the intent from the outset to treat each trial and analyze its results as two separate experiments. The sod experiment was conducted on one half of the plot of size 0.9 m by 1.8 m. Only one of those experiments was the focus of this thesis.

Cultural Management

The sod production (SP) experiment was designed as a randomized complete block design with a split plot in time arrangement of treatments. Cultivars were the main plots with sod harvest dates as the subplots. Sod tensile strength and sod handling quality were assessed in this experiment. Each whole plot was maintained under simulated sod production conditions with entries mowed at a height of 6.4 cm using a rotary type mower three times thrice a week. The trial was irrigated frequently to avoid plant wilting and to provide optimized growing conditions. Oxadiazon herbicide (Ronstar Flo, Bayer Environmental Science, NJ) was applied by sprayer at 2.2 kg oxadiazon ha^{-1} in late winter prior to spring green-up to provide pre-emergent control of summer annual grasses. An application of oxadiazon herbicide in granular form (Ronstar 2G, Bayer Environmental science, NJ) was applied at 2.2 kg oxadiazon ha^{-1} in fall to provide pre-emergent control of winter annual grasses. A tank-mix combination of 2,4-D, MCPP and dicamba (Strike 3, Winfield Solutions, MN) at the rate of 3.5 kg of product ha^{-1} and glyphosate at the rate of 1.5 kg ha^{-1}, were applied in winter to provide post-emergent control of broadleaf and perennial winter weeds. The fertilizer regime was 244 kg N ha^{-1} yr^{-1} (46-0-0, N-P-K) applied in increments from April to September of 2014 and 2015. Phosphorus and potassium were found to be optimum which was determined after soil testing. Soil samples were collected from the site in 2014 and 2015. A basic soil test was conducted upon pooled experimental units within each replication respectively. Testing for pH, nitrogen, phosphorous and potassium was conducted at the Soil, Water and Forage Analytical Laboratory at OSU. In 2014 the phosphorous test index was 164 and the potassium test index was 414 using the Mehlich III method (Mehlich, 1984). In 2015 the phosphorous index was 137 and potassium index was 376 using the same testing methodology. Based on our chosen sufficiency indices of 65 and 250 respectively for phosphorus and potassium, no additional applications of phosphorous and potassium were made. Bermudagrass encroachment into the adjacent plots of another cultivar was controlled by spraying a solution of glyphosate in the borders as needed.

Sod Harvest Methodology and Evaluation

The plots were uniformly irrigated one to three days before harvest so that the soil moisture was optimum for harvesting sod. Irrigation was withheld during the course of a single harvest event. Three dates of sod harvest were conducted to assess the effect of entry maturity on sod condition. The first harvest was at 14 months after planting (MAP), with the first, second and third replications within the trial tested on 24, 29 and 31 October 2014, respectively. The second harvest was conducted at 22 MAP, after 100% green up, in early June 2015. During this harvest, the first, second and third replications were tested on 9, 10 and 12 June. The third harvest was conducted 24 MAP in August 2015. During this harvest, the first replication was completed on 25 August with the second and the third replications completed on 27 August. Sod pads measuring 38 cm in length were cut using a Ryan Junior sod cutter (Model 544844C, Textron, Racine, WI) with a blade width of 30.5 cm. The depth of cut was set at 1.5 cm. Two sub-samples per plot were then evaluated for sod handling quality (SHQ) and sod tensile strength (STS).

Sod Tensile Strength (STS) Measuring Device:

The tensile strength value of each of the sub-samples were recorded using a STS measuring device. The STS machine used in this research was developed at Oklahoma State University in 2003 and described by Han (2009) (Figure 1). It was a vertically mounted device that weighed 65 kg. The device measured 147 x 53 x 97 cm (height x width x depth) and operated using a similar principle to that described by Rieke et al. (1968) and Sorochan et al. (1999) at Michigan State University. It consisted of two plates, a stationary lower plate and a movable upper plate. Sod was clamped to be in contact with the lower and upper plates. When the device was turned on, the upper plate was pulled upwards causing the sod to tear apart. The point at which the sod pad tore was measured in peak force using a digital force meter (Chatillon Model DFIS, John Chatillon & Sons, Inc., Greensboro, NC). The value was converted to peak force per cross sectional area (kg dm^{-2}) using the specific width and depth of the sod pads used. This value, which reflects the force per cross sectional area at which the sod broke, is referred to as the sod tensile strength (STS) in this trial (Han, 2009).

Sod Handling Quality (SHQ) Measurements:

Sod handling quality (SHQ) is the ability of the harvested sod to remain intact while being lifted and transported to the site where it is ultimately used. Sod handling quality was rated on a scale of 1 to 5 (Han, 2009) where:

1 = complete breakage, inability to transport to sod tearing device (unacceptable quality);

2 = substantial cracking, but still transportable to sod tearing device;

3 = moderate cracking (our suggested minimum acceptable for industry handling);

4 = very mild cracking (our desired minimum rating for cultivar commercialization); and

5 = no cracking or defect of product (best handling quality).

Once the handling quality and the tensile strength were recorded, the cut sod was neatly placed into the specific, respective harvest sites within entry-replicates from which it had been harvested. Any loose sprigs were removed to prevent cross contamination of the plots. The plots were hand watered using a hand-held hose fitted with a spray head breaker until all the replications had been tested. The hose was connected to the nearest quick coupling valve through a hose key. Once the harvest was completed for all the three replications, the block was put back to the normal irrigation schedule.

Statistical Analysis for Sod Characteristics:

The STS and SHQ were statistically analyzed by conducting analysis of variance (ANOVA) on the dependent variables STS and SHQ for the data pooled over the three harvest dates using three forms of ANOVA. This approach was conducted because in the author's experience, different statisticians and scientists offer different opinions concerning which approach is most appropriate for the work being conducted. The three methods of ANOVA investigated were repeated measures analysis, PROC GLM, and PROC MIXED, all three methods using SAS software for Windows Software version 9.3 (SAS Institute, Cary, NC, v9.3 2011). These methods of analysis were compared before proceeding to cultivar mean separation. The main factors tested in the ANOVA were block, cultivar and harvest date. Depending upon the particular main effects and interactions found statistically significant, additional analysis was conducted. A mean separation (such as Fisher's Protected LSD) was conducted on the data pooled over three harvest dates. Due to the high significant effects of harvest date and cultivar and harvest interaction at p=0.05%, ANOVA was conducted within harvest dates as well. A mean separation of cultivars was also performed for STS and SHQ using Fisher's Protected LSD test within harvest dates.

Visual Evaluation Parameters:

Visual evaluations of turfgrass performance were made using the methods of the National Turfgrass Evaluation Program (NTEP) visual rating system (Morris, 2000). Other than for the parameter entitled percent live green plant material coverage, the scale used in visual evaluations was a 1 to 9 scale with 1 being the lowest rating for the particular parameter and 9 being the best or highest rating. The parameters taken into consideration for rating in this study were:

Turfgrass Quality:

The ratings were performed by taking into consideration the color, density, texture and uniformity of the turf. A rating of 6 was considered to be the minimally acceptable in these two studies. Quality was taken on a monthly basis starting from the month of April through November in 2014 and 2015.

Turfgrass Color:

The rating was taken based on the color of the entry cultivar. This rating assessed the darkness of color of the turfgrass when was actively growing and not under any stress. Color ratings were taken in spring, summer and fall of 2014 and 2015.

Turfgrass Density:

The density ratings were determined quantitatively based on the living plants and tillers present per unit area. These ratings were taken in spring, summer and fall of 2014 and 2015.

Turfgrass Texture:

The rating was based on the width of the leaf. The turfgrasses with broader leaf blades were considered coarser than ones with narrower leaf blades. These ratings were taken in spring, summer and fall of 2014 and 2015.

Fall color retention:

Fall color retention was measured on the basis of the ability of the turf to retain its color as the season changes. These ratings are helpful in understanding the response of the bermudagrasses to decreased temperature in fall on 4th November in 2014 and 8th November on 2015.

Spring green up:

Spring green up ratings were taken from late March to early April to measure the resumption of growth of turfgrasses following cessation of dormancy in winter. The ratings were taken on 31st March and 9th April in 2014 and 29th March and 14th April in 2015.

Living Ground Cover:

Living ground cover was measured as a percentage and was based on the area covered by the legitimate turfgrass species in the given area. These ratings were taken during spring, summer, and fall so that it allowed one to monitor the growth of the turfgrass and its response to various forms of stress.

Statistical Analysis for Visual Evaluation Parameters

The analytical design for visual parameters was a randomized complete block with thirty-nine cultivars (treatments) and three replications. As there were a variable number of rating dates within years and because there is typically always a cultivar x rating date effect in field cultivar performance trials (Han, 2009 and Segars, 2013) an individual analysis of variance (ANOVA) was performed by rating dates for the dependent variables turfgrass quality, genetic color, shoot density, leaf texture, spring green-up, fall color retention and percent living cover. The analysis was conducted using SAS software for Windows Software version 9.3 (SAS Institute, Cary, NC, v9.3 2011).

Both a fixed and a mixed ANOVA model procedure, PROC GLM and PROC MIXED, were used to construct the ANOVA model in all cases. The two methods were compared before proceeding to mean separations (ANOVA outcomes not presented). There was always a cultivar effect present ($P \leq 0.05$) on the parameter for both the procedures other than for percent live green cover. When the cultivar effect was found significant at $p \leq 0.05$, cultivar performance means were separated within each sampling date using Fisher's LSD test.

CHAPTER III

RESULTS AND DISCUSSION

Sod Production Experiment:

Repeated Measures Analysis

The data collected over three harvest dates were pooled together to conduct the statistical analysis. An analysis of variance (ANOVA) was performed using three methods. The first method was ANOVA using repeated measures analysis (SAS Institute, Cary, NC, v9.3 2011). This type of analysis is used when at least one of the factors consists of repeated measurement on the same subject or experimental units, under different conditions (Littell, 1998). In this experiment the cultivar replicates were considered to be the unit upon which the repeated measure (harvests) was conducted over time. In this analysis, the fixed effects were harvest dates and cultivar and the random effects were replication and sub-samples. The findings using this method of analysis revealed that harvest dates, cultivars and their interaction had highly significant effects on tensile strength (Table 3). The cultivar and the cultivar by harvest date interaction were not statistically significant but the harvest date had a highly significant effect on sod handling quality (Table 4).

Mixed Model Analysis

The second analytical approach investigated was to perform ANOVA with a mixed model using the SAS procedural statement PROC MIXED (SAS Institute, Cary, NC, v9.3 2011). In this approach the harvest dates and cultivars were treated as fixed effects and replication as a random effect. The author felt that the harvest date was best considered as fixed since it represented harvest after 1 year, the first harvest after the next green-up and at a full 2 years after planting. The analytical design was set up with cultivars and blocks as main plots with date as a subplot (split plot in time). Cultivar, harvest dates and their interaction were found to be highly significant with respect to the sod handling quality and tensile strength (Tables 5 and 6).

General Linear Model Analysis

The third model used for the analysis was the SAS general linear models procedure PROC GLM (SAS Institute, Cary, NC, v9.3 2011). The factors cultivars, replication and harvest date were considered as fixed effects. The analytical design was set up with cultivars and blocks as main plots with date as a subplot (split plot in time). The ANOVA using PROC GLM revealed that entry, replication, harvest date and entry x harvest date had highly significant effects on STS and SHQ (Table 7 and 8) similar to the results produced using the mixed model approach (PROC MIXED).

While the repeated measures analysis found the harvest date effect to be significant for SHQ, the stringency of this approach appeared to result in a masking of the effects of entry and the entry x harvest date effects that were found significant with both the Mixed Model split plot in time and the GLM split plot in time analyses with entry and harvest dates treated as fixed effects. Because the major focus of this research was to find entry effects and identify important performance differences amongst the cultivars, the latter two models appeared more suitable for this goal. Since the sod harvest dates took place on different stages of maturity of these bermudagrasses that could be expected to be duplicated in additional experiments and because harvest at these ages might be expected to be able to be duplicated by sod producers practicing our management regime, even though different weather conditions might prevail, it was appropriate to consider harvest date as a fixed effect. Furthermore, because of the same main and interactive effects being significant regardless of whether PROC MIXED or PROC GLM was used, the more familiar approach of the PROC GLM procedure was used in conducting all additional analyses for SHQ, STS and all visual parameters. Due to the significant entry x harvest date interaction, a separate ANOVA was conducted on SHQ and STS data from each of the three sod harvest dates using PROC GLM (Tables 9 and 10). As cultivar effects in the ANOVA were found to be highly significant ($p \leq 0.01$), cultivar means were separated at the 95% certainty level using Fisher's LSD test.

The overall mean (pooled over dates) STS and SHQ of the 39 bermudagrass entries included in this study are reported in Table 11. The cultivar mean separation tests for STS and SHQ for each harvest date are reported in Table 12.

Sod Handling Quality Results

ANOVA performed on SHQ revealed that entry, replication and the date of harvest had a highly significant effect on the handling quality (Table 8). The overall mean bermudagrass SHQ ratings by harvest date were harvest 3 (4.3 rating) > harvest 1

(4.1 rating), > harvest 2 (3.8 rating) respectively (LSD=0.2, p=0.05). The mean SHQ of the 39 bermudagrasses within each of the three harvest dates included in this study are reported in Table 11. The mean SHQ for the cultivars for all three harvest dates ranged from 1.7 to 5.0. Fifty-six percent of the cultivars provided good to excellent sod handling quality (means greater than or equal to 4.0).

Due to the significant effect of harvest date and the entry by harvest date interaction on SHQ a separate ANOVA was conducted within each harvest date (Table 10) and the cultivar mean separation for SHQ values within harvests are reported in Table 12. This table also shows the number of times a cultivar appeared in the top statistical group. Tifway, Latitude 36, Patriot, Princess 77, 12-TSB-1, TifTuf (DT-1), FAES 1326, OKC 1163, OKC 1302, Astro, Quickstand, Celebration, TifGrand, U-3-SIU, FAES 1327, 11-T-510 and FAES 1325 were in the top statistical group for all three harvest dates. Among these cultivars, Tifway, Latitude 36, Patriot, Princess 77, 12-TSB-1, TifTuf, FAES 1326, OKC 1163, OKC 1302, Astro and Quickstand consistently scored a SHQ of 5 during all harvests. Cultivars Latitude 36, Tifway, and Patriot, being the entries held in common between the work of Han (2009) and this work,were notably found to be in the top statistical group in both this study and work conducted by Han (2009).

It is important to note that Princess 77 and 12-TSB-1 were the only seeded cultivars to have scored a mean of 5 and were in the top statistical group for all three harvests. Seeded cultivars are generally believed to have a lower STS and SHQ due to reduced rhizome development (Hensler et al., 1998). However, in this study the cultivars which never appeared in the top statistical group for all three harvest dates were the seeded cultivars PST-R6T9S, PST-R6PO, PST-R6CT, Yukon and Riviera, BAR C291, JSC 2009-6, OKS 2009-3, MBG 002, and the clonal cultivar 11-T-251. However, not being in the top statistical group for all the three harvest dates does not mean that these cultivars must have a low value for the SHQ value. Table 12 also shows the number of times a cultivar scored a minimum SHQ value of 4 at each harvest date. Forty-nine percent of the cultivars were able to provide a mean handling quality of 4 and above in all the three harvest dates. Apart from the cultivars that appeared in the top statistical group during all three harvest dates, cultivars that scored a minimum SHQ value of 4 in all the three harvest dates were MBG 002, OKS 2011-1, OKS 2011-4 and U-3-NC. NuMex Sahara, JSC 2009-2, FAES 1327, PST-R6T9S, PST-R6T9S, U-3-NC, 11-T-251 and U-3-TGS had a lower handling quality in the second harvest than in first and third harvests. This trend could be attributed to the slow recovery of the shoot system responsible for SHQ such as the recovery of rhizomes and stolons. PST-R6PO, PST-R6CT, OKC 1131, JSC 2007-13, Yukon, JSC-2009-6 and North Shores SLT showed an increasing trend in their mean SHQ from the first to the third harvest date. JSC 2007-13 and North Shore SLT were able to reach the top statistical group in the final harvest date. By the final harvest date, Yukon, PST-R6CT, and PST-R6PO were able to achieve an SHQ value that was the minimum suggested for satisfactory handling. This trend could be explained due to a more mature and robust stand by the third harvest date.

Sod Tensile Strength Results

The overall mean bermudagrass STS by harvest date were harvest 3 (43.9 kg dm^{-2}) > harvest 1 (39.6 kg dm^{-2}) > harvest 2 (34.1 kg dm^{-2}) respectively (LSD =3.2, p=0.05). This could be due to the fact that, even though the canopy showed 100% green-up, the shoot system responsible for STS had not yet reached the stage of development in 2015 that was present at the time of harvest in 2014. Digital images reveal the 2-D appearance from the top of the canopy and are not an assessment of shoot development at various levels within the turfgrass canopy. The mean STS by cultivar averaged over the three harvest dates is reported in Table 9. The overall mean STS of cultivars ranged from a low of 9.6 kg dm^{-2} (PST-R6T9S) to a high of 74.6 kg dm^{-2} (Latitude 36). The top performers were the standards Latitude 36, TifGrand, Tifway, Astro, Patriot, and Celebration. Latitude 36 with an overall STS value of 76.7 kg dm^{-2} was the best performing cultivar and was significantly different from all other cultivars. Riviera, a standard seeded type in the 2013 NTEP trial, was found in a lower statistical group. These results are consistent with the findings of Han (2009). In that trial, Latitude 36 (synonym OKC 1119 in Han [2009]) was in the top statistical group and Riviera was in the lowest statistical group. After Latitude 36, TifTuf had significantly higher overall STS than the rest of the cultivars except for Astro. Tifway and Astro were not significantly different.

Due to the significant effect of harvest date on STS a separate ANOVA was conducted on data within each harvest date (Table 11) and the cultivar mean separation for STS values for individual harvests are reported in Table 13. The STS results are grouped and presented by each harvest date.

Harvest 1

The STS values ranged from 5.1 - 76.6 kg dm^{-2}. Latitude 36 and Astro were in the top statistical group and the cultivars in the lowest statistical group were PST-R6T9S, PST-R6PO, JSC 2007-13, and Yukon. Cultivars which were not statistically different from the official vegetative industry standards Tifway and Patriot were Princess 77, OKC 1302, OKC 1163, FAES 1325, FAES 1326, FAES 1327, 12-TSB-1, and U-3-NC.

Harvest 2

The STS values ranged from 6.5 – 74.3 kg dm^{-2}. Latitude 36 was in the top statistical group. Cultivars in the lowest statistical group were PST-R6T9S, PST-R6PO, PST-R6CT, JSC 2009-2, 11-T-251, U-3-TGS, and U-3-NC. Cultivars which were not statistically different from the industry standards Tifway and Patriot were Princess 77, OKC 1302, OKC 1163, FAES 1325, FAES 1326, FAES 1327, and 12-TSB-1.

Harvest 3

The mean STS values of entries ranged from 7.2 - 76.6 kg dm^{-2} during harvest date 3. The cultivars in the top statistical group during this harvest were Latitude 36, Celebration, Astro, and TifGrand. The cultivars in the lowest two statistical groups were PST-R6CT, PST-R6T9S, PST-R6PO, Riviera, Yukon and 11-T-251. Entries OKC 1302, OKC 1131, FAES 1325, FAES 1326, FAES 1327, and 12-TSB-1 had mean STS not statistically different from the industry standards, Tifway and Patriot at the time of the third harvest.

Cultivars that exhibited a trend of increasing numeric STS over harvests 1 through 3 were Celebration, JSC 2007-8, JSC 2007-13, JSC 2009-6, Yukon, PST-R6PO, OKC 1131, and Quickstand. This could be attributed to these cultivars being better established by the third harvest date compared to their maturity at the two earlier harvest dates.

The vegetatively propagated varieties were overall the top performers in this study. This was as expected as the vegetative entries would be expected to produce enhanced vegetative growth in leaves, stolons, rhizomes and roots relative to seeded types which tend to continue to invest in increased seedhead production relative to vegetatively propagated types. The exact mechanisms responsible for overall differences in STS and SHQ between seeded and vegetatively propagated clones needs further study. While seeded varieties generally exhibited lower mean STS values throughout the trial as compared to vegetatively propagated entries, the seeded entries 12-TSB-1 and Princess-77 exhibited a higher STS value and were not statistically different from the vegetative standards Tifway and Patriot over the three harvest dates. The experimental cultivars OKC 1302, 12-TSB-1, and FAES 1327 and the local commercialized bermudagrass U-3-NC while not in the highest statistical group had mean STS not statistically different than industry standards Tifway and Patriot at the time of the first harvest. This is of paramount importance as these cultivars were capable of performing well at only one year after establishment.

Predictive Linear Relationship between Sod Handling Quality and Tensile Strength

A predictive linear relationship between overall mean STS and overall SHQ that used the data for each entry averaged over the three harvest dates was developed using SAS procedure PROC CORR (SAS Institute, Cary, NC, v9.3 2011). The relationship was then plotted in Figure 2. The SHQ (independent variable) was plotted on the X-axis and STS (dependent variable) was plotted on the Y axis. As the data were pooled over the three harvest dates, there were no mean STS values to plot for an SHQ value of 1. Also, STS values for an SHQ value 5 were dropped from the data set to reduce potential biasing produced by an unbounded STS when SHQ reached but could not exceed a value of 5. However the scale from 1 to 5 has been included in the graph for the visual display of the predicted equation line on the chart. Pearson's correlation coefficient for the relationship between mean sod handling quality and mean sod tensile strength was $r = 0.92$ at $p < 0.001$, revealing a strong positive correlation between the two parameters. The r^2 of this equation was 0.85***. The predicted mean STS as a function of SHQ was 8.5, 22.6, 36.8 and 51.0 kg dm^{-2} for SHQ of 2, 3, 4 and 5. The predicted mean STS value was not calculated for an SHQ of 1 because sod with an SHQ of 1 falls apart, indicating an STS of 0 as it cannot be transported to the STS measuring device for testing. It is important to note that the equation did not pass through the origin (y=0, x=1). This is probably due to the fact that there were inadequate observations of overall means sod tensile strength of 0 and handling quality of 1 to weight the equation near the origin as opposed to the large number of observations of high SHQ and high STS as a large number of highly advanced experimental and commercial vegetatively propagated varieties were under test.

Visual Evaluation Parameters

Turfgrass Quality

The turfgrass quality (TQ) rating is given based on the functional and the aesthetic features of the turf. Different cultivars may receive the same numeric quality rating, but the factors influencing that rating may differ. Turfgrass quality ratings were taken on 8 rating dates (April to November) each in 2014 and 2015. A significant cultivar and cultivar x date effect was found in TQ data in both years (Tables 14 and 15). All cultivars maintained acceptable ($\geq$ 6) turfgrass quality in the months June, July and August of 2014 and 2015. A lower quality was recorded for all cultivars in April and May of 2014. This could be explained by the fact that the entries had not yet fully established by those rating dates and the turf had only greened up beginning in mid to late March. A lower TQ was reported in late season ratings taken in November of 2014 and 2015. This was likely due to the lower temperatures and reduced day length relative to the late spring, summer and early fall environmental conditions. Monthly TQ for TifTuf were in the top statistical group on all rating dates in 2014. The clonally-propagated experimental cultivars from OSU including OKC 1131, OKC 1163 and OKC 1302 had high TQ during most of the rating dates in 2014 and 2015. The other top performers in 2014 were JSC 2-21-18, 11-T-251, 11-T-510, and TifGrand. In 2015, the other top performers were JSC 2-211, JSC 2-21-18, TifTuf, and Latitude 36.

Genetic color

Genetic color of each entry was collected in spring, summer and fall of 2014 and 2015. Analysis of variance was conducted individually for each rating date. There was a significant cultivar effect on color (Table 16). The block effect was not found significant. The mean value of color in 2014 ranged from 5.7 to 7.0 in spring, 6.3 to 8.0 in summer and 6.3 to 8.0 in fall. Similarly, the mean value of color in 2015 ranged from 5.7 to 8.0 in spring, 5.7 to 8.0 in summer and 4.7 to 6.0 in fall. The cultivars were found to have a better mean color in summer of 2014 and 2015 than in spring and fall of both years. This could be explained by the more ideal air temperatures for bermudagrass growth during these periods. The standards Tifway and Latitude 36 were the top performers in 2014 with respect to color ratings (Table 16). Patriot, TifGrand and Riviera had a numeric but not statistically lower mean color ratings than Tifway and Latitude 36. The experimental cultivars OKC 1302, OKC 1131, JSC 2-21-1, FAES 1325, FAES 1326 and 11-T-510 were top performers and their mean color ratings were not significantly different from the top performing industrial standards, Patriot, Celebration, Tifway, Latitude 36, and TifGrand. In 2015, Celebration was found to be in the top statistical group for color in all the three rating dates. The top performers in spring of 2015 were Patriot, Celebration, and 11-T-251. The cultivars U-3-SIU, FAES 1325, and celebration were in the top statistical group in summer and celebration was the only cultivar to be on the top statistical group in fall of 2015. All the cultivars had a lower color rating in fall than in spring and summer. The experimental cultivars OKC 1131 and 11-T-510 were not statistically different from Tifway.

Shoot Density

The number of leaves and shoots per area of the ground is a measure of turf density. There was a significant cultivar effect on shoot density (Table 17). The experimental cultivars JSC 2-21-1, JSC 2-21-18, OKC 1131, OKC 1163 and OKC 1302 had a high shoot density rating in both years (Table 17). Industry standards Tifway, Latitude 36, Patriot, Celebration, TifGrand, Astro, Riviera, and Yukon were also found to have a higher shoot density rating in 2014 than in 2015. The cultivars with a lower mean shoot density rating in both years were seeded entries, North Shore SLT, PST-R6T9S, NuMex Sahara, and OKS 2011-1. All the cultivars were found to have a better shoot density rating in 2014 than in 2015. The fall ratings in 2014 were taken prior to the first sod harvest. The lower shoot density rating in 2015 could be due to the effect of sod harvests performed upon the plot.

Leaf Texture

Leaf texture (LT) data was collected in spring, summer and fall of 2014 and 2015. Analysis of variance was conducted individually for each rating date. There was a significant cultivar effect with respect to the LT ratings (Table 18). The block effect was not found to be significant. The experimental cultivar OKC 1163 was found to be the cultivar with the finest LT in this study and it had a mean LT rating of 8.0 for all rating dates except in spring 2014. Also, it was in the top statistical for all the rating dates and was significantly different from the rest of the cultivars except for the experimental cultivars OKC 1131 and OKC 1302. The industry standards Tifway, Latitude 36, Riviera, Yukon, Patriot, TifGrand, and TifTuf were fine textured but their LT ratings were not significantly different from OKC 1131 and OKC 1303. Similarly, the experimental varieties from the University of Florida, FAES 1325, FAES 1326 and FAES 1327 and the cultivar JSC 2-21-18 were also present in the same statistical group. The cultivars with the lowest mean LT ratings were PST-R6PO, PST-R6T9S, PST-R6CT, MBG 002, OKS 2009-3, OKS 2011-1, OKS 2011-4, 12-TSB-1, and industrial standards Princess 77, North Shore and NuMex Sahara. These were all seeded cultivars. This is in accordance with the fact that seeded cultivars are generally coarser textured than modern vegetatively propagated cultivars (Beard, 1973 and Croce et al., 1999).

Spring Green-Up

Spring green-up is initiated when carbohydrates, accumulated during depressed activity in fall, are metabolized and are used as energy for growth of new roots (Rogers et al. 1975, Di Paola and Beard 1992). The spring green-up ratings were taken from late

March to early April each year. Two sets of ratings were taken each year. There was a significant cultivar effect on spring green-up (Table 19). The cultivars in this trial had a mean spring green-up value that ranged from 2.0 to 5.3 in 2014 and 2.0 to 6.7 in 2015. The experimental cultivar OKC 1131 had the highest mean spring green-up. The standards Tifway, TifGrand, and Princess 77 and experimental cultivars 12-TSB-1, 11-T-251, FAES 1327, PST-R6CT were slowest to green up in 2014 and 2015. The mean spring green-up value for these cultivars ranged from 2.0 to 2.7. The standards Latitude 36, Patriot, North Shore SLT and Celebration had a mean spring green-up value that ranged from 3.0 to 3.3 and these cultivars had ratings that were not significantly different from Tifway, TifGrand, and Princess 77 at the time of the first rating taken in 2014. Latitude 36 had a better spring green-up value in the first rating taken in 2015 and was significantly different from the other standards Tifway, TifGrand, and Princess 77, Patriot, North Shore SLT and Celebration. The delayed spring green-up rate of Princess 77 in this trial is in accordance with the results of Giolo et al. (2013) and Schiavon et al. (2015). The mean spring green-up values were higher in the second rating date in both years. The cultivars which had a lower spring green-up in the second rating date of 2014 were NuMex Sahara, JSC2-21-18, and U-3-TGS. In 2015, the cultivars with lower mean spring green-up were Tifway, Princess 77, 12-TSB-1, FAES 1326 and U-3-TGS.

Fall Color Retention

There was a significant cultivar effect on fall color retention in both years (Table 20). TifGrand ranked highest in fall color retention in 2014 and this cultivar was statistically different from the rest of the cultivars except TifTuf and FAES 1326. The other cultivars which ranked high in fall color retention in 2014 were 12 TSB-1, Celebration, and FAES 1325. The mean fall color retention rating in 2014 ranged from 4.0 to 7.3 and 5.0 to 7.3 in 2015. The cultivars had a better color retention in 2015 than in 2014. This could be explained by the delay in time of first frost (Figure 3 and 4). TifTuf was the top performer in 2015; however, it was not statistically different from Tifway, Latitude 36, Celebration, Princess 77, TifGrand, Astro, OKS 2011-1, JSC 2-21-1, JSC 2007-8, JSC 2007-13, FAES 1325, and PST-R6PO. The cultivars with a lower fall color retention in 2014 and 2015 were Patriot, NuMex Sahara, Yukon, PST-R6T9S, U-3-NC and Quickstand.

Living Ground Cover:

The living ground cover or the percent live cover data were collected in spring, summer and fall in 2014 and 2015. There was a significant cultivar effect on percent live cover (Table 20). The trial was planted in August of 2013. This reduced the growing season for these cultivars and resulted in slow establishment rate. Due to the slow establishment rate, the spring data for percent living cover in 2014 was very low when compared to other rating dates. In spring of 2014, OKC 1131 had the highest mean percent live cover of 91.7 percent (%). At that time, the cultivars with a mean percent living cover of more than 80% were JSC 2007-8, JSC 2007-13, JSC 2009-2, JSC 2009-6, and JSC 2-21-1. The cultivars with a mean percent living cover of more than 70% in spring 2014 were OKC 1163, OKC 1302, OKS 2011-1, Astro, U-3-TGS, TifTuf, and JSC 2-21-18. The cultivars which had a lower mean percent live cover were NuMex Sahara, Princess 77, Latitude 36, TifGrand, 12-TSB-1 and North Shore SLT. In summer of 2014, cultivars with a lower mean percent living cover were Latitude 36, NuMex Sahara, Yukon, 12-TSB-1 and TifGrand. However, all cultivars achieved a 99% live cover by fall of 2014. The higher levels of live cover during fall of 2014 could be explained by the elapse of adequate duration of time that the cultivars were exposed to suitable growing temperatures during the summer. These cultivars continued to have 99% live cover during all rating dates in 2015. There was no sign of winterkill in this study as the mean percent live cover in fall 2014 and spring in 2015 were 99%.

Table 1. Thirty-nine bermudagrass entries for sod tensile strength and sod handling quality.

Entry number	Cultivar	Propagation Method	Source
1	Tifway	Vegetative	Standard Entry
2	Latitude 36	Vegetative	Standard Entry
3	Patriot	Vegetative	Standard Entry
4	Celebration	Vegetative	Standard Entry
5	NuMex Sahara	Seeded	Standard Entry
6	Princess 77	Seeded	Standard Entry
7	MBG 002	Seeded	Pennington Seed
8	OKS 2009-3	Seeded	Oklahoma Ag. Expt. Station
9	OKS 2011-1	Seeded	Oklahoma Ag. Expt. Station
10	OKS 2011-4	Seeded	Oklahoma Ag. Expt. Station
11	JSC 2-21-1	Vegetative	Johnston Seed Company
12	JSC 2-21-18	Vegetative	Johnston Seed Company
13	JSC 2007-8	Seeded	Johnston Seed Company
14	JSC 2007-13	Seeded	Johnston Seed Company
15	JSC 2009-2	Seeded	Johnston Seed Company
16	JSC 2009-6	Seeded	Johnston Seed Company
17	Riviera	Seeded	Standard Entry
18	Yukon	Seeded	Standard Entry
19	North Shore SLT	Seeded	Standard Entry
20	12-TSB-1	Seeded	Georgia Seed Development Commission
21	11-T-251	Vegetative	Georgia Seed Development Commission
22	11-T-510	Vegetative	Georgia Seed Development Commission
23	TifTuf	Vegetative	Georgia Seed Development Commission
24	FAES 1325	Vegetative	University of Florida
25	FAES 1326	Vegetative	University of Florida
26	FAES 1327	Vegetative	University of Florida
27	PST-R6PO	Seeded	Pure-Seed Testing Inc.
28	PST-R6T9S	Seeded	Pure-Seed Testing Inc.
29	PST-R6CT	Seeded	Pure-Seed Testing Inc.
30	BAR C291	Seeded	Barenbrug USA
31	OKC 1131	Vegetative	Oklahoma Ag. Expt. Station
32	OKC 1163	Vegetative	Oklahoma Ag. Expt. Station
33	OKC 1302	Vegetative	Oklahoma Ag. Expt. Station
34	Astro	Vegetative	Standard Entry
35	U-3-SIU	Vegetative	Southern Illinois University
36	U-3-NC	Vegetative	Tulsa Grass and Sod farm source
37	U-3-TGS	Vegetative	Northcutt sod farm source
38	TifGrand	Vegetative	Standard Entry
39	Quickstand	Vegetative	Standard Entry

Table 2: Fertilizer schedule for the sod production experiment in 2014 and 2015.

Year	Date	Fertilizer†
2014	1-April	46-0-0
	1-May	46-0-0
	19-May	46-0-0
	3-June	46-0-0
	19-June	46-0-0
	3-July	46-0-0
	20-July	46-0-0
	2-August	46-0-0
	18-August	46-0-0
	1- September	46-0-0
2015	6-April	46-0-0
	24-April	46-0-0
	11- May	46-0-0
	25- May	46-0-0
	10- June	46-0-0
	30-June	46-0-0
	15-July	46-0-0
	31-July	46-0-0
	15-August	46-0-0
	4-September	46-0-0

†As phosphorus and potassium levels were determined to be sufficient by soil testing all fertilizer applications were made using the quick release, granular fertilizer urea 46-0-0 (N-P-K).

Table 3. Repeated measures analysis of sod handling quality of thirty-nine bermudagrass entries using PROC MIXED.

Source	Degrees of freedom	Mean square
Entry (E)	38	1.2†NS
Harvest Date (D)	2	31.0***
E*D	76	1.4*

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

†NS, not significant at the 0.05 level.

Table 4. Repeated measures analysis of sod tensile strength of thirty-nine bermudagrass entries using PROC MIXED.

Source	Degrees of freedom	Mean square
Entry (E)	38	96.0***
Harvest Date (D)	2	123.2 ***
E*D	76	8.5 ***

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

Table 5. Analysis of variance for sod handling quality of thirty-nine bermudagrasses over three harvest dates using PROC MIXED.

Source	Degrees of freedom	Mean square
Entry (E)	38	211.5 ***
Harvest Date (D)	2	201.0***
E*D	76	33.3***

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

Table 6. Analysis of variance for sod tensile strength of thirty-nine bermudagrasses over three harvest dates using PROC MIXED.

Source	Degrees of freedom	Mean square
Entry (E)	38	257.1***
Harvest Date (D)	2	338.2 ***
E*D	76	23.2 ***

*, **, *** significant at P = 0.05, 0.01, and 0.001 respectively

Table 7. Analysis of variance for sod handling quality of thirty-nine bermudagrasses over three harvest dates using PROC GLM.

Source	Degrees of freedom	Mean squares
Entry (E)	38	211.5***
Block (B)	2	6.7***
E*B [Error A]	76	9.3***
Harvest Date (D)	2	201.0***
E*D	76	33.3***
B*D(E) [Error B]	156	6.9***

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

Table 8. Analysis of variance for sod tensile strength of thirty-nine bermudagrasses over three harvest dates using PROC GLM.

Source	Degrees of freedom	Mean squares
Entry (E)	38	257.1***
Block (B)	2	10.6***
E*B[Error A]	76	5.4***
Harvest Date (D)	2	338.2***
E*D	76	23.2***
B*D(E) [Error B]	156	5.3***

*, **, *** significant at P = 0.05, 0.01, and 0.001 respectively

Table 9. Sod tensile strength and handling quality of thirty-nine bermudagrasses averaged over three harvest dates.

Entry	Tensile Strength†	Handling Quality‡
	Kg dm^{-2}§	(1-5 scale)
Tifway	57.5ed¶	5.0a
Latitude 36	74.6a	5.0a
Patriot	51.7e-g	5.0a
Celebration	56.6ed	4.7ab
NuMex Sahara	32.3k-n	3.9ef
Princess 77	49.2fg	5.0a
MBG 002	34.2h-k	4.0d-f
OKS 2009-3	32.0k-n	3.6fg
OKS 2011-1	34.1h-k	4.2b-e
OKS 2011-4	38.5h-j	4.5a-d
JSC 2-21-1	30.8k-n	3.9ef
JSC 2-21-18	35.2h-k	4.2c-e
JSC 2007-8	34.0h-l	4.1c-f
JSC 2007-13	22.8o-q	3.2gh
JSC 2009-2	26.9m-p	3.9ef
JSC 2009-6	32.6i-m	3.7e-g
Riviera	23.6op	3.0hi
Yukon	15.2rs	2.4j
North Shore SLT	27.8l-o	3.6fg
12-TSB-1	54.4e-f	5.0a
11-T-251	16.6rq	2.6ij
11-T-510	39.8h	4.5a-d
TifTuf -1	66.5b	5.0a
FAES 1325	47.2g	4.9a
FAES 1326	51.2e-g	5.0a
FAES 1327	51.4e-g	4.9a
PST-R6PO	16.0r	2.4j
PST-R6T9S	9.6s	1.7j
PST-R6CT	21.2r-q	2.7h-j
BAR C291	26.1n-p	3.0hi
OKC 1131	35.6h-k	3.8ef
OKC 1163	48.7fg	5.0a
OKC 1302	54.1e-f	5.0a
Astro	64.5bc	5.0a
U-3-SIU	38.6hi	4.6a-c
U-3-NC	36.6h-k	3.8ef
U-3-TGS	33.3i-l	3.8ef
TifGrand	60.2cd	4.9a
Quickstand	46.7g	5.0a
+ LSD (0.05)	6.3	0.5

† Sod was harvested in Oct 2014, June 2015 and August 2015, using a walk behind sod cutter in three replications per harvest date with three sub-samples per observation.

‡ Sod handling quality was measured on a 1 to 5 scale where 1=poor quality, complete breakage of sod during handling; 2=fair, not commercially recommended, substantial cracking of sod during handling; 3=good, our suggested minimum for industry handling, moderate cracking of the sod occurred; 4=very good, minimal cracking, our suggested minimum for cultivar commercialization; and 5 = excellent, very tight, no cracking.

§ Sod tensile strength reported in kg dm^{-2} for sod harvested at 1.5 cm depth and 30.5 cm width.

¶ Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Table 10. Analysis of variance for sod handling quality of thirty-nine bermudagrass entries using PROC GLM for three individual harvest dates.

Source	Harvest 1		Harvest 2		Harvest 3	
	df	Mean squares	df	Mean squares	df	Mean squares
Entry (E)	38	7.1**	38	8.1**	38	4.6**
Block (B)	2	0.01*	2	2.1**	2	0.03*
E*B[Error]	76	0.6**	76	0.7**	76	0.3**

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

Table 11. Analysis of variance for sod tensile strength of thirty-nine bermudagrass entries using PROC GLM for three individual harvest dates.

Source	Harvest 1		Harvest 2		Harvest 3	
	df	Mean squares	df	Mean squares	df	Mean squares
Entry (E)	38	1859.5**	38	1577.4**	38	1640.3**
Block (B)	2	460.2**	2	277.6**	2	19.1NS
E*B[Error]	76	100.6**	76	98.2**	76	58.1**

*, **, *** significant at *P* = 0.05, 0.01, and 0.001 respectively.
† NS, nonsignificant at the 0.05 level.

Table 12. Mean sod handling quality of thirty-nine bermudagrasses within three individual sod harvest dates.

	Sod Handling Quality (1-5 scale) †				
Cultivar	Harvest 1‡	Harvest 2	Harvest 3	Times in top statistical group	Times with a minimum SHQ value of 4
Tifway	5.0a§	5.0a	5.0a	3	3
Latitude 36	5.0a	5.0a	5.0a	3	3
Patriot	5.0a	5.0a	5.0a	3	3
Celebration	4.5a-c	5.0a	4.7ab	3	3
NuMex Sahara	4.8ab	2.7h-g	4.2b-d	1	2
Princess 77	5.0a	5.0a	5.0a	3	3
MBG 002	4.0b-e	4.0b-e	4.0cd	0	3
OKS 2009-3	3.7d-f	3.7d-f	3.3ef	0	0
OKS 2011-1	4.7ab	4.0b-e	4.0cd	1	3
OKS 2011-4	5.0a	4.2a-e	4.3bc	2	3
JSC 2-21-1	4.3a-d	3.8c-e	3.7de	1	1
JSC 2-21-18	4.3a-d	4.3a-d	3.8c-e	2	2
JSC 2007-8	3.5d-f	3.7d-f	5.0a	1	1
JSC 2007-13	1.7h	3.7d-f	4.7ab	1	1
JSC 2009-2	4.7ab	2.3h-j	4.7ab	2	2
JSC 2009-6	3.3ef	3.8c-f	4.0cd	0	1
Riviera	2.8fg	3.3e-g	2.8fg	0	0
Yukon	1.8h	2.3h-j	3.0fg	0	0
North Shore SLT	3.2ef	3.0f-h	4.7ab	1	1
12-TSB-1	5.0a	5.0a	5.0a	3	3
11-T-251	2.8fg	2.3h-j	2.8fg	0	0
11-T-510	5.0a	4.2a-e	2.5g	2	2
TifTuf	5.0a	5.0a	5.0a	3	3
FAES 1325	5.0a	4.8ab	5.0a	3	3
FAES 1326	5.0a	5.0a	5.0a	3	3
FAES 1327	5.0a	4.7a-c	5.0a	3	3
PST-R6PO	1.8h	2.0i-k	3.3ef	0	0
PST-R6T9S	2.0gh	1.3k	1.8h	0	0
PST-R6CT	2.8fg	2.3h-j	3.0fg	0	0
BAR C291	3.0f	3.0f-h	3.0f	0	0
OKC 1131	3.0f	3.5d-g	5.0a	1	1
OKC 1163	5.0a	5.0a	5.0a	3	3
OKC 1302	5.0a	5.0a	5.0a	3	3
Astro	5.0a	5.0a	5.0a	3	3
U-3-SIU	4.7ab	4.0b-e	5.0a	2	3
U-3-NC	5.0a	3.8ef	5.0a	2	2
U-3-TGS	4.7ab	1.8i-k	5.0a	2	2
TifGrand	4.7ab	5.0a	4.7ab	3	3
Quickstand	5.0a	5.0a	5.0a	3	3
LSD value (0.05)	0.9	0.9	0.6		

† Sod handling quality was measured on a 1 to 5 scale where 1=poor quality, complete breakage of sod during handling; 2=fair, not commercially recommended, substantial cracking of sod during handling; 3=good, our suggested minimum for industry handling, moderate cracking of the sod occurred; 4=very good, minimal cracking, our suggested minimum for cultivar commercialization; and 5 = excellent, very tight, no cracking

‡ Sod was harvested in Oct 2014, June 2015 and August 2015, using a walk behind sod cutter in three replications per harvest date with three sub-samples per observation.

§.Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Table 13. Mean sod tensile strength of thirty-nine bermudagrasses within three individual sod harvest dates.

	Sod Tensile Strength† (kg dm^{-2}) ‡		
Cultivar	Harvest 1	Harvest 2	Harvest 3
Tifway	56.3cd§	57.8bc	58.4c-e
Latitude 36	76.6a	74.3a	75.2a
Patriot	54.3c-e	50.2cd	50.7e-h
Celebration	47.1d-i	48.8cd	74.0a
NuMex Sahara	37.8g-l	22.1j-l	36.9kl
Princess 77	51.6c-f	48.9cd	46.9hi
MBG 002	36.6i-n	33.2f-j	32.9k-n
OKS 2009-3	30.9k-o	33.3f-j	31.7k-n
OKS 2011-1	33.6j-o	34.2f-i	34.5k-m
OKS 2011-4	40.7g-k	33.7f-i	41.2i-k
JSC 2-21-1	32.2j-o	30.8f-j	29.6l-o
JSC 2-21-18	37.3h-m	34.0f-i	34.2k-m
JSC 2007-8	27.7l-p	27.3h-k	47.1hi
JSC 2007-13	5.1s	28.8g-j	34.6k-m
JSC 2009-2	38.0g-l	8.31m	34.4k-m
JSC 2009-6	27.4l-p	32.9f-j	37.4j-l
Riviera	18.4p-r	27.2h-k	25.1n-p
Yukon	8.0sr	14.2lm	23.4op
North Shore SLT	25.0o-q	23.4i-l	35.0k-m
12-TSB-1	59.4bc	50.4cd	53.4d-h
11-T-251	17.7p-r	14.8lm	17.2p
11-T-510	47.8d-i	36.5e-h	35.1k-m
TifTuf	74.2a	62.3b	60.5cd
FAES 1325	45.2d-i	39.8d-g	56.6c-g
FAES 1326	49.1c-g	47.8c-e	56.8c-g
FAES 1327	51.3c-f	40.5d-f	62.3bc
PST-R6PO	8.9rs	13.9lm	25.0n-p
PST-R6T9S	15.2q-s	6.5m	7.2q
PST-R6CT	23.8o-q	16.8k-m	23.0op
BAR C291	25.2n-q	26.5h-k	26.7m-o
OKC 1131	26.1m-q	29.9f-j	50.8e-h
OKC 1163	48.2c-h	47.3c-e	49.6f-i
OKC 1302	56.2cd	47.9cd	58.0c-f
Astro	69.2ab	47.7c-e	76.6a
U-3-SIU	43.4g-j	26.5h-k	46.0h-j
U-3-NC	53.7c-e	7.1m	48.8g-i
U-3-TGS	41.0g-k	8.5m	50.4e-h
TifGrand	56.2cd	54.0bc	70.2ab
Quickstand	47.3d	39.8d-g	53.0d-h
LSD value (0.05)	11.5	11.4	8.8

†Sod was harvested in Oct 2014, June 2015 and August 2015, using a walk behind sod cutter in three replications per harvest date with three sub-samples per observation.
‡ Sod tensile strength reported in kg dm^{-2} for sod harvested at 1.5 cm depth and 30.5 cm width
§.Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Table 14. Mean turfgrass quality of thirty-nine bermudagrass entries in 2014 at Stillwater, OK.

	Turfgrass Quality†							
Cultivar	21-April	20-May	23-Jun	22-Jul	25-Aug	22-Sep	21-Oct	14-Nov
Tifway	4.3c-f‡	5.3a-c	6.7b-d	6.3b-d	6.0bc	6.0a-c	5.0bc	5.0b-d
Latitude 36	4.7b-e	4.0ef	6.3c-e	6.0c-e	6.0bc	5.7a-c	5.3a-c	5.7ab
Patriot	4.3c-f	4.7c-e	7.0a-d	6.0c-e	6.0bc	5.7a-c	5.0bc	4.3de
Celebration	4.0d-g	5.7ab	6.0d-f	6.0c-e	5.7b-d	5.7a-c	5.0bc	5.3a-c
NuMex Sahara	2.6hi	3.0g	5.0fg	5.0f	5.0d	5.0c	4.7c	4.0ef
Princess 77	5.0a-d	5.0b-d	6.3c-e	6.0c-e	6.0bc	6.0a-c	5.0bc	5.0b-d
MBG 002	4.3c-f	5.7ab	6.3c-e	6.3b-d	5.3cd	5.7a-c	5.0bc	5.0b-d
OKS 2009-3	4.0d-g	5.3a-c	6.0d-f	5.7d-f	5.3cd	6.0a-c	5.0bc	5.3a-c
OKS 2011-1	5.3a-c	6.0a	6.7b-d	6.0c-e	5.7b-d	6.0a-c	5.0bc	5.3a-c
OKS 2011-4	4.7b-e	5.3a-c	6.0d-f	5.3ef	5.3cd	5.7a-c	5.0bc	5.0b-d
JSC 2-21-1	5.7ab	6.0a	8.0a	7.3a	6.3ab	5.7a-c	6.0a	6.0a
JSC 2-21-18	5.3a-c	6.0a	8.0a	7.3a	6.0bc	6.0a-c	5.3a-c	5.3a-c
JSC 2007-8	5.7ab	6.0a	6.3c-e	5.7d-f	6.0bc	5.7a-c	5.0bc	5.0b-d
JSC 2007-13	5.3a-c	6.0a	6.3c-e	6.0c-e	6.0bc	6.0a-c	5.0bc	5.0b-d
JSC 2009-2	5.7ab	5.7ab	6.7b-d	6.0c-e	6.0bc	5.7a-c	5.0bc	5.0b-d
JSC 2009-6	6.0a	5.7ab	6.3c-e	6.0c-e	6.0bc	6.0a-c	5.0bc	5.0b-d
Riviera	5.3a-c	6.0a	6.7b-d	6.0c-e	5.7b-d	6.0a-c	5.0bc	5.3a-c
Yukon	3.7e-h	3.7fg	4.7g	6.3b-d	5.7b-d	5.3bc	5.3a-c	4.7c-e
North Shore SLT	3.3f-h	4.3d-f	5.3e-g	5.0f	5.3cd	5.7a-c	5.0bc	4.3de
12-TSB-1	3.0g-i	4.3d-f	6.0d-f	6.0c-e	6.0bc	6.0a-c	5.0bc	5.0b-d
11-T-251	5.0a-d	5.7ab	7.0a-d	6.7a-c	5.7b-d	6.0a-c	5.3a-c	5.0b-d
11-T-510	4.7b-e	6.0a	7.3a-c	6.7a-c	6.0bc	5.7a-c	5.3a-c	5.7ab
TifTuf	5.3a-c	6.0a	8.0a	7.0ab	7.0a	6.3ab	6.0a	5.7ab
FAES 1325	3.7e-h	5.7ab	7.7ab	6.0c-e	6.0bc	6.0a-c	5.3a-c	5.3a-c
FAES 1326	4.0d-g	5.0b-d	7.0a-d	6.0c-e	5.7b-d	6.0a-c	5.3a-c	4.3de
FAES 1327	4.3c-f	5.0b-d	7.0a-d	6.3b-d	5.7b-d	5.7a-c	5.0bc	5.0b-d
PST-R6PO	5.0a-d	5.0b-d	6.0d-f	5.3ed	5.7b-d	5.7a-c	5.0bc	4.3de
PST-R6T9S	5.0a-d	5.0b-d	6.0d-f	5.7d-f	5.7b-d	5.3bc	5.0bc	4.7c-e
PST-R6CT	4.0d-g	4.7c-e	6.0d-f	5.7d-f	5.3cd	6.0a-c	5.3a-c	4.3de
BAR C291	3.3f-g	5.0b-d	6.3c-e	5.7d-f	5.7b-d	5.7a-c	5.0bc	5.0b-d
OKC 1131	6.0a	6.0a	7.3a-c	6.7a-c	6.0bc	6.7a	5.7ab	5.0b-d
OKC 1163	5.7ab	6.0a	8.0a	7.0ab	6.0bc	5.7a-c	5.3a-c	5.7ab
OKC 1302	5.0a-d	5.7ab	7.7ab	6.7a-c	5.7b-d	5.7a-c	5.3a-c	5.3a-c
Astro	5.3a-c	6.0a	6.3c-e	6.0c-e	5.3cd	5.0c	5.0bc	5.3a-c
U-3-SIU	4.3c-f	5.0b-d	6.7b-d	5.7d-f	5.7b-d	5.3bc	5.0bc	5.0b-d
U-3-NC	5.0a-d	6.0a	6.3c-e	5.7d-f	5.3cd	5.7a-c	5.0bc	4.3de
U-3-TGS	4.7b-e	6.0a	6.3c-e	6.0c-e	5.7b-d	5.7a-c	4.7c	4.3de
TifGrand	3.3f-h	4.0ef	7.0a-d	6.7a-c	6.0bc	6.0a-c	5.7ab	6.0a
Quickstand	4.7b-e	5.3a-c	6.3c-e	6.0c-e	5.7b-d	5.7a-c	5.0bc	4.3de
LSD value (0.05)	1.0	0.8	1.3	0.8	0.8	1.0	0.7	0.8

† Turfgrass quality was rated on a 1 to 9 scale where 9 was considered to have exceptionally high quality and 1 was considered to have exceptionally low quality.

‡Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Table 15. Mean turfgrass quality of thirty-nine bermudagrass entries in 2015 at Stillwater, OK.

	Turfgrass Quality†							
Cultivar	15-April	15-May	17-Jun	18-Jul	18-Aug	17-Sep	16-Oct	Nov
Tifway	4.3e‡	6.3c-e	6.0de	6.3bc	6.3ab	5.7ab	5.7bc	5.7b-d
Latitude 36	5.7a-c	7.3ab	7.0ab	7.0a	6.7a	6.0a	6.0ab	6.3ab
Patriot	5.3b-d	6.3c-e	6.0de	6.0cd	6.0a-c	5.0bc	5.7bc	4.7e-g
Celebration	4.3e	6.0d-f	5.3fg	6.0cd	6.0a-c	5.7ab	6.0ab	4.7e-g
NuMex Sahara	5.0c-e	5.0g	5.0g	5.0f	5.0d	5.0bc	4.0e	4.7e-g
Princess 77	4.7de	5.7e-g	6.0de	6.0cd	6.0a-c	5.3ab	5.0cd	5.0d-f
MBG 002	5.7a-c	5.7e-g	6.0de	6.0cd	5.7b-d	5.7ab	5.3b-d	5.3c-e
OKS 2009-3	5.0c-e	5.0g	6.0de	5.3ef	5.3cd	5.0bc	5.3b-d	5.0d-f
OKS 2011-1	5.3b-d	6.0d-f	6.3cd	5.7de	5.7b-d	5.0bc	4.7de	5.0d-f
OKS 2011-4	5.3b-d	5.0g	6.0de	5.7de	5.3cd	5.3ab	4.7de	5.0d-f
JSC 2-21-1	6.0ab	7.0bc	7.0ab	7.0a	6.7a	6.0a	6.0ab	6.0a-c
JSC 2-21-18	5.3b-d	7.3ab	7.3a	7.0a	6.3ab	6.0a	5.3b-d	5.7b-d
JSC 2007-8	6.0ab	6.0d-f	6.0de	6.0cd	5.7b-d	5.3ab	5.0cd	5.0d-f
JSC 2007-13	5.7a-c	6.0d-f	6.0de	6.0cd	5.7b-d	5.3ab	6.0ab	5.3c-e
JSC 2009-2	5.7a-c	6.0d-f	6.0de	6.0cd	5.3cd	5.0sc	5.0cd	5.0d-f
JSC 2009-6	6.0ab	6.0d-f	6.0de	6.0cd	5.7b-d	5.7ab	6.0ab	5.3c-e
Riviera	6.0ab	6.0d-f	6.0de	6.0cd	5.3cd	6.0a	5.0cd	5.3c-e
Yukon	5.0c-e	5.7e-g	6.0de	5.7de	5.0d	5.0bc	4.7de	4.7e-g
North Shore SLT	5.0c-e	5.0g	5.7ef	5.3ef	5.0d	5.7ab	5.0cd	4.7e-g
12-TSB-1	4.7de	6.0d-f	6.0de	5.7de	5.7b-d	5.7ab	5.3b-d	5.3c-e
11-T-251	4.3e	6.7b-d	7.0ab	6.7ab	6.3ab	5.3ab	6.0ab	5.7b-d
11-T-510	4.7de	6.7b-d	6.7ac	6.0cd	5.7b-d	5.3ab	6.0ab	5.7b-d
TifTuf	5.7a-c	7.0bc	7.0ab	7.0a	6.3ab	6.0a	5.7bc	5.7b-d
FAES 1325	4.7de	6.0d-f	6.0de	5.7de	5.7b-d	6.0a	5.7bc	5.7b-d
FAES 1326	4.3e	6.3c-e	6.3cd	5.7de	6.0a-c	6.0a	5.7bc	5.7b-d
FAES 1327	4.7de	6.0d-f	6.0cd	6.0cd	6.0a-c	5.3ab	5.0cd	6.0a-c
PST-R6PO	5.0c-e	5.0g	5.7ef	6.0cd	5.3cd	5.3ab	5.0cd	5.0d-f
PST-R6T9S	4.7de	5.3fg	6.0de	6.0cd	5.3cd	6.0a	5.0cd	5.0d-f
PST-R6CT	5.0c-e	5.3fg	5.7ef	6.0cd	5.3cd	5.3ab	5.0cd	5.0d-f
BAR C291	5.3b-d	5.7e-g	6.0de	5.7de	6.0a-c	5.3ab	5.3b-d	5.0d-f
OKC 1131	6.3a	8.0a	7.0ab	7.0a	6.3ab	6.0a	6.7a	6.3ab
OKC 1163	5.7a-c	7.0bc	7.0ab	7.0a	6.3ab	5.7ab	5.7bc	6.0a-c
OKC 1302	6.0ab	7.0bc	7.0ab	6.7ab	5.7b-d	6.0a	6.0ab	5.7b-d
Astro	5.7a-c	6.0d-f	6.3cd	6.0cd	5.3cd	5.3ab	5.0cd	6.0a-c
U-3-SIU	5.0c-e	6.0d-f	6.7bc	6.0cd	5.3cd	5.3ab	5.0cd	5.0d-f
U-3-NC	5.0c-e	5.3fg	6.0de	5.7de	5.0d	5.7ab	5.3b-d	4.0g
U-3-TGS	5.3b-d	5.3fg	6.0de	5.7de	5.3cd	5.7ab	5.0cd	4.3fg
TifGrand	4.7de	6.3c-e	6.7bc	6.0cd	6.0a-c	6.0a	6.0ab	6.7a
Quickstand	5.0c-e	5.7e-g	6.0de	5.7de	5.3cd	5.0bc	5.0cd	4.3fg
LSD value (0.05)	0.8	0.7	0.6	0.6	0.7	0.7	0.7	0.9

† Turfgrass quality was rated on a 1 to 9 scale where 9 was considered to have exceptionally high quality and 1 was considered to have exceptionally low quality.

‡Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Table16. Mean genetic color for thirty- nine bermudagrass in 2014 and 2015 at Stillwater, OK.

	Genetic Color †					
	2014			2015		
Cultivar	Spring‡	Summer	Fall	Spring	Summer	Fall
Tifway	7.0a§	8.0a	7.0b-d	7.0cd	7.0cd	6.0bc
Latitude 36	7.0a	8.0a	7.3a-c	6.7de	7.0cd	5.0ef
Patriot	6.7ab	7.7ab	7.0b-d	7.7ab	7.0cd	6.0bc
Celebration	6.0bc	7.0a-c	7.0b-d	7.7ab	8.0a	7.0a
NuMex Sahara	6.3a-c	7.0a-c	6.3d	5.7g	7.0cd	4.7f
Princess 77	6.0bc	6.7bc	7.0b-d	6.7de	7.0cd	5.0ef
MBG 002	6.7ab	7.3a-c	7.3a-c	6.0fg	7.0cd	5.0ef
OKS 2009-3	6.0bc	7.0a-c	6.7cd	6.0fg	6.0fg	5.3de
OKS 2011-1	6.3a-c	7.0a-c	6.7cd	6.0fg	6.7de	5.7cd
OKS 2011-4	6.7ab	7.3a-c	7.3a-c	6.3ef	7.0cd	5.3de
JSC 2-21-1	7.0a	8.0a	7.7ab	5.0h	6.3ef	4.7f
JSC 2-21-18	6.0bc	7.0a-c	6.3d	5.0h	5.3h	5.0ef
JSC 2007-8	6.0bc	7.0a-c	7.0b-d	6.0fg	7.0cd	5.7cd
JSC 2007-13	6.0bc	7.0a-c	7.0b-d	7.0cd	7.0cd	5.7cd
JSC 2009-2	6.3a-c	7.0a-c	6.7cd	6.0fg	7.0cd	5.0ef
JSC 2009-6	6.0bc	7.0a-c	7.0b-d	6.7de	7.0cd	5.3de
Riviera	6.3a-c	7.3a-c	6.7cd	6.0fg	7.0cd	5.0ef
Yukon	6.0bc	7.0a-c	6.7cd	6.7de	7.3bc	6.0bc
North Shore SLT	6.0bc	7.0a-c	7.0b-d	6.0fg	6.0fg	5.0ef
12-TSB-1	6.0bc	7.0a-c	7.0b-d	6.7de	7.0cd	6.0bc
11-T-251	6.3a-c	7.3a-c	7.0b-d	7.7ab	7.3bc	6.3b
11-T-510	7.0a	8.0a	8.0a	7.0cd	7.0cd	6.0bc
TifTuf	6.3a-c	6.7bc	6.7cd	6.3ef	6.0fg	5.3de
FAES 1325	6.3a-c	7.3a-c	7.7ab	7.3bc	7.7ab	6.0bc
FAES 1326	6.3a-c	7.3a-c	7.0b-d	6.3ef	6.7de	5.7cd
FAES 1327	5.7c	6.7bc	6.7cd	7.0cd	7.0cd	5.3de
PST-R6PO	6.3a-c	7.3a-c	7.0b-d	6.0fg	7.0cd	5.0ef
PST-R6T9S	6.3a-c	5.3d	6.7cd	6.3ef	7.0cd	5.3de
PST-R6CT	6.3a-c	7.0a-c	7.0b-d	6.0fg	6.0fg	5.0ef
BAR C291	6.0bc	7.0a-c	7.0b-d	6.3ef	6.0fg	5.0ef
OKC 1131	7.0a	8.0a	7.7ab	7.0cd	7.0cd	5.7cd
OKC 1163	6.3a-c	7.3a-c	7.0b-d	5.0h	5.7hg	5.0ef
OKC 1302	6.7ab	7.7ab	7.7ab	6.0fg	6.7de	5.3de
Astro	5.7c	6.7bc	7.0b-d	6.0fg	6.3ef	5.3de
U-3-SIU	5.7c	6.7bc	6.7cd	7.0cd	8.0a	6.0bc
U-3-NC	6.0bc	7.0a-c	6.7cd	6.0fg	6.7de	5.0ef
U-3-TGS	5.7c	6.7bc	6.3d	6.0fg	6.0gh	5.0ef
TifGrand	6.7ab	7.7ab	7.3a-c	7.0cd	7.0cd	5.7cd
Quickstand	6.0bc	6.3cd	6.7cd	6.0fg	6.3ef	5.0ef
LSD Value (0.05)	0.8	1.1	0.9	0.6	0.5	0.6

† Genetic Color measures the degree of dark green of the cultivar during healthy active growth. It was rated during in spring, summer and fall. Genetic color was rated on a 1 to 9 scale where 1 was light or pale green and 9 was very dark green.

‡ In 2014, ratings were taken on 15th May, summer rating was taken on 24th July and fall rating was taken on 24th September. In 2015, ratings were taken on 4th May, summer rating was taken on 15th July and fall rating was taken on 4th October

§Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Table 17. Mean shoot density for thirty- nine bermudagrass entries in 2014 and 2015 at Stillwater, OK.

	Density†					
	2014			2015		
Cultivar	Spring‡	Summer	Fall	Spring	Summer	Fall
Tifway	7.0b§	7.7ab	7.0b-d	5.7f-h	6.3b-d	6.0b-d
Latitude 36	7.0b	8.0a	8.0a	7.3a-c	7.0b	6.7ab
Patriot	7.0b	7.7ab	7.7ab	6.0e-g	6.0c-e	5.7c-e
Celebration	7.0b	7.3a-c	7.3a-c	6.3d-e	5.3ef	6.0b-d
NuMex Sahara	6.0d	6.3d	6.0e	4.3j	5.0f	4.7f
Princess 77	7.0b	7.0b-d	7.0b-d	5.7f-h	6.0c-e	5.3d-f
MBG 002	7.0b	7.0b-d	6.3de	5.7f-h	5.3ef	5.3d-f
OKS 2009-3	6.0d	6.7cd	6.7c-e	5.0h-j	5.3ef	5.0ef
OKS 2011-1	6.0d	6.3d	6.7c-e	5.3g-i	5.3ef	5.0ef
OKS 2011-4	7.0b	7.0b-d	8.0a	5.3g-i	5.7d-f	5.3d-f
JSC 2-21-1	7.0b	8.0a	8.0a	8.0a	7.0b	6.0b-d
JSC 2-21-18	7.0b	8.0a	7.3a-c	8.0a	7.0b	6.0b-d
JSC 2007-8	7.0b	7.0b-d	7.0b-d	5.7f-h	5.7d-f	5.7c-e
JSC 2007-13	7.0b	7.0b-d	7.0b-d	5.7f-h	5.7d-f	5.7c-e
JSC 2009-2	7.0b	7.0b-d	7.0b-d	6.0e-g	6.0c-e	5.7c-e
JSC 2009-6	7.0b	7.0b-d	7.0a-c	6.3d-f	6.0c-e	5.7c-e
Riviera	7.0b	7.3a-c	7.3a-c	5.7f-h	5.7d-f	5.3d-f
Yukon	7.0b	7.0b-d	7.0b-d	5.3g-i	5.7d-f	5.3d-f
North Shore SLT	6.3cd	6.3d	6.3de	5.0h-j	5.7d-f	5.0ef
12-TSB-1	7.0b	7.3a-c	7.3a-c	5.3g-i	5.7d-f	5.7c-e
11-T-251	7.0b	7.7ab	7.7ab	7.0b-d	7.0b	5.7c-e
11-T-510	6.7bc	7.3a-c	7.3a-c	6.7c-e	6.0c-e	5.7c-e
TifTuf	7.0b	8.0a	8.0a	7.3a-c	7.0b	6.0b-d
FAES 1325	7.0b	7.3a-c	7.3a-c	6.0e-g	5.7d-f	5.7c-e
FAES 1326	7.0b	7.7ab	7.7a-c	5.7f-h	6.0c-e	6.0b-d
FAES 1327	7.0b	7.3a-c	7.3c-e	5.7f-h	6.0c-e	5.7c-e
PST-R6PO	6.7bc	7.0b-d	6.6de	5.0h-j	5.7d-f	5.7c-e
PST-R6T9S	6.3cd	6.3d	6.3de	4.7ij	5.3ef	5.3d-f
PST-R6CT	7.0b	7.0b-d	7.0b-d	5.0h-j	5.0f	5.0ef
BAR C291	6.7bc	6.7cd	6.7c-e	5.7f-h	5.7d-f	5.0ef
OKC 1131	7.0b	8.0a	8.0a	7.7ab	7.0b	6.3a-c
OKC 1163	8.0a	8.0a	8.0a	7.3a-c	8.0a	7.0a
OKC 1302	7.0b	7.3a-c	7.3a-c	7.7ab	6.7bc	6.0b-d
Astro	7.0b	7.0b-d	7.0b-d	6.0e-g	6.0c-e	5.3d-f
U-3-SIU	6.7bc	6.7cd	6.7c-e	6.0e-g	6.0c-e	5.0ef
U-3-NC	6.7bc	6.7cd	7.0b-d	5.0h-j	5.3ef	5.3d-f
U-3-TGS	6.7bc	6.7cd	6.7c-e	5.3g-i	5.0f	5.7c-e
TifGrand	8.0a	8.0a	8.0a	7.0b-d	6.7bc	6.3a-c
Quickstand	6.7bc	6.7cd	6.7c-e	5.0h-j	5.3ef	5.0ef
LSD value (0.05)	0.6	0.7	0.7	0.8	0.7	0.8

† Shoot density visually estimates the number of tillers per unit area. It was rated visually on a 1 to 9 scale such that 1 was a very sparse canopy and 9 was a very dense canopy.

‡ In 2014, ratings were taken on 15th May, summer rating was taken on 24th July and fall rating was taken on 24th September. In 2015, ratings were taken on 4th May, summer rating was taken on 15th July and fall rating was taken on 4th October

§Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Table 18. Mean leaf texture for thirty-nine bermudagrass entries in 2014 and 2015 at Stillwater, OK.

	Leaf Texture†					
	2014			2015		
Cultivar	Spring‡	Summer	Fall	Spring	Summer	Fall
Tifway	6.7b-d§	7.0cd	7.0cd	7.0bc	6.7bc	6.3bc
Latitude 36	7.0bc	7.3bc	7.3bc	6.7cd	7.0b	6.3bc
Patriot	7.0bc	7.0cd	7.0cd	6.7cd	6.3cd	5.0f
Celebration	7.0bc	6.7de	6.7de	7.0bc	5.3fg	6.0cd
NuMex Sahara	6.0de	6.0f	6.0f	6.0de	5.0g	5.0f
Princess 77	6.3c-e	6.3ef	6.0ef	6.0de	6.0de	6.0cd
MBG 002	6.3c-e	6.0f	6.0f	6.3c-e	6.0de	6.3bc
OKS 2009-3	6.0de	6.0f	6.0f	6.0de	5.0g	5.0f
OKS 2011-1	6.0de	6.0f	6.0f	6.0de	5.3fg	5.7de
OKS 2011-4	6.0de	6.0f	6.0f	6.0de	5.0g	5.0f
JSC 2-21-1	6.7b-d	7.7ab	7.0cd	6.3c-e	7.0b	6.3bc
JSC 2-21-18	7.0bc	7.0cd	8.0a	7.7ab	7.0b	6.3bc
JSC 2007-8	6.3c-e	6.3ef	6.3ef	6.3c-e	5.7ef	5.7de
JSC 2007-13	6.3c-e	6.3ef	6.3ef	6.0de	6.0de	5.3ef
JSC 2009-2	6.7b-d	6.7de	6.7de	6.7cd	6.0de	5.3ef
JSC 2009-6	6.3c-e	6.3ef	6.3ef	6.3c-e	6.0de	6.0cd
Riviera	6.7b-d	6.7de	6.7de	6.7cd	5.7ef	6.0cd
Yukon	6.7b-d	6.0f	6.0f	6.0de	5.3fg	5.0f
North Shore SLT	6.0de	6.0f	6.0f	6.0de	5.0g	5.0f
12-TSB-1	6.3c-e	6.0f	6.0f	6.3c-e	5.7ef	6.0cd
11-T-251	6.7b-d	7.0cd	7.0cd	6.7cd	6.7bc	6.7b
11-T-510	6.7b-d	7.0cd	7.0cd	6.3c-e	7.0b	6.3cb
TifTuf	7.0bc	7.0cd	7.0cd	7.0bc	7.0b	6.0cd
FAES 1325	7.0bc	7.0cd	7.0cd	7.0bc	6.0de	6.0cd
FAES 1326	6.7b-d	7.0cd	7.0cd	6.7cd	6.3cd	6.0cd
FAES 1327	7.0bc	7.0cd	7.0cd	7.0bc	7.0b	6.3bc
PST-R6PO	5.7e	6.0f	6.0f	5.7e	5.0g	5.3ef
PST-R6T9S	6.0de	6.0f	6.0f	6.3c-e	5.0g	5.3ef
PST-R6CT	6.0de	6.0f	6.0f	6.0de	5.3fg	5.0f
BAR C291	6.7b-d	6.3ef	6.3ef	6.3c-e	5.7ef	5.3ef
OKC 1131	7.0bc	7.0cd	7.0cd	6.3c-e	7.0b	6.0cd
OKC 1163	7.3ab	8.0a	8.0a	8.0a	8.0a	8.0a
OKC 1302	7.0bc	7.0cd	7.0cd	6.7cd	6.3cd	6.0cd
Astro	6.7b-d	6.3ef	6.3ef	6.3c-e	5.7ef	6.0cd
U-3-SIU	6.7b-d	6.0f	6.0f	6.3c-e	6.0de	5.0f
U-3-NC	6.0de	6.0f	6.0f	6.3c-e	5.0g	5.0f
U-3-TGS	6.0de	6.0f	6.0f	6.0de	5.3fg	5.0f
TifGrand	7.3ab	7.7ab	7.0cd	7.0bc	7.0b	6.7b
Quickstand	6.0de	6.0f	6.0f	6.0de	5.0g	5.0f
LSD value (0.05)	0.9	0.5	0.5	0.8	0.6	0.6

† Leaf texture visually estimates the average width of the leaf blade for a cultivar. It was rated once annually on a scale of 1 to 9 where 1 was very coarse (wide leaf blades) and 9 was very fine leaves.
‡ In 2014, ratings were taken on 15th May, summer rating was taken on 24th July and fall rating was taken on 24th September. In 2015, ratings were taken on 4th May, summer rating was taken on 15th July and fall rating was taken on 4th October
§Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Table 19. Mean spring green-up for thirty-nine bermudagrass entries in 2014 and 2015 at Stillwater, OK.

	Spring green up†			
	2014		2015	
Cultivar	31- Mar	9-April	29- Mar	14-April
Tifway	2.7e-g‡	7.0b-d	2.0i	5.7f
Latitude 36	3.3c-e	7.3a-c	4.3b-d	7.3a-e
Patriot	3.3c-e	7.0b-d	3.0f-h	6.7c-f
Celebration	3.0d-f	7.0b-d	2.7g-i	6.0ef
NuMex Sahara	3.7b-d	6.3d	4.0c-e	6.3d-f
Princess 77	2.0g	7.0b-d	2.0i	5.7f
MBG 002	3.0d-f	7.3a-c	3.7d-f	7.7a-d
OKS 2009-3	4.0bc	6.7cd	4.0c-e	7.3a-e
OKS 2011-1	3.3c-e	6.7cd	3.7d-f	7.3a-e
OKS 2011-4	3.3c-e	7.3a-c	4.0c-e	7.7a-d
JSC 2-21-1	4.0bc	7.7ab	5.0b	8.7a
JSC 2-21-18	3.3c-e	6.3d	3.7d-f	7.0b-f
JSC 2007-8	4.0bc	7.0b-d	5.0b	8.3ab
JSC 2007-13	4.0bc	7.0b-d	5.0b	8.3ab
JSC 2009-2	3.7b-d	6.7cd	4.7bc	8.3ab
JSC 2009-6	4.3b	7.0b-d	5.0b	8.0a-c
Riviera	4.3b	6.7cd	5.0b	8.0a-c
Yukon	4.0bc	6.7cd	4.3b-d	7.0b-f
North Shore SLT	3.3c-e	7.0b-d	3.3e-g	7.3a-e
12-TSB-1	2.7e-g	7.0b-d	2.3hi	5.7f
11-T-251	2.3fg	7.0b-d	2.0i	6.0ef
11-T-510	3.0d-f	8.0a	3.0f-h	7.3a-e
TifTuf	3.3c-e	6.7cd	4.0ce	8.3ab
FAES 1325	3.0d-f	7.7ab	2.7g-i	6.0ef
FAES 1326	3.3c-e	7.0b-d	3.0f-h	5.7f
FAES 1327	2.3fg	6.7cd	2.3hi	6.0ef
PST-R6PO	3.3c-e	7.0b-d	3.7d-f	7.3a-e
PST-R6T9S	4.0bc	6.7cd	4.0c-e	7.0b-f
PST-R6CT	2.3fg	7.0b-d	3.0f-h	6.7c-f
BAR C291	3.3c-e	7.0b-d	4.0c-e	7.7a-d
OKC 1131	5.3a	7.7ab	6.7a	7.7a-d
OKC 1163	3.0d-f	7.0b-d	3.7d-f	8.0a-c
OKC 1302	4.0bc	7.7ab	5.0b	8.7a
Astro	4.3b	7.0b-d	5.0b	7.3a-e
U-3-SIU	4.0bc	6.7cd	4.0c-e	6.7c-f
U-3-NC	3.7b-d	6.7cd	3.7d-f	7.0b-f
U-3-TGS	3.3c-e	6.3d	3.7d-f	5.7f
TifGrand	2.7e-g	7.3a-c	2.0i	7.0b-f
Quickstand	3.7b-d	6.7cd	3.7d-f	7.0b-f
LSD value(0.05)	0.9	0.9	1.0	1.4

† Spring green-up rating measures the transition from dormancy to active growth in the spring. It was evaluated once annual spring green-up was rated on a 1 to 9 scale where 1 equaled tan dormant turf and 9 equaled fully green turf.

‡ Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Table 20. Mean fall color retention for thirty-nine bermudagrass entries in 2014 and 2015 at Stillwater, OK.

Cultivar	Fall Color Retention†	
	2014‡	2015
Tifway	6.0c-e§	6.7a-c
Latitude 36	5.7d-f	6.7a-c
Patriot	4.0i	5.7c-f
Celebration	6.3b-d	6.3a-d
NuMex Sahara	4.7g-i	5.7c-f
Princess 77	5.0f-h	6.3a-d
MBG 002	6.0c-e	6.3a-d
OKS 2009-3	4.7g-i	6.0b-e
OKS 2011-1	5.0f-h	6.3a-d
OKS 2011-4	5.3e-g	6.0b-e
JSC 2-21-1	5.0f-h	6.7a-c
JSC 2-21-18	5.3e-g	6.0b-e
JSC 2007-8	5.0f-h	6.3a-d
JSC 2007-13	5.0f-h	6.3a-d
JSC 2009-2	5.0f-h	6.0b-e
JSC 2009-6	5.3e-g	6.3a-d
Riviera	5.7d-f	6.0b-e
Yukon	4.3hi	5.3d-g
North Shore SLT	5.0f-h	5.3d-g
12-TSB-1	6.3b-d	6.0b-e
11-T-251	5.7d-f	6.0b-e
11-T-510	5.3e-g	6.7a-c
TifTuf	7.0ab	7.3a
FAES 1325	6.3b-d	7.0ab
FAES 1326	6.7a-c	6.0b-e
FAES 1327	6.0c-e	5.7c-f
PST-R6PO	4.7g-i	6.3a-d
PST-R6T9S	4.0i	5.7c-f
PST-R6CT	4.7g-i	6.0b-e
BAR C291	5.0f-h	6.3a-d
OKC 1131	5.7d-f	7.0ab
OKC 1163	6.0c-e	5.7c-f
OKC 1302	5.7d-f	6.0b-e
Astro	6.0c-e	6.7a-c
U-3-SIU	5.0f-h	5.7c-f
U-3-NC	4.7g-i	5.0e-g
U-3-TGS	5.0f-h	4.7fg
TifGrand	7.3a	6.7a-c
Quickstand	4.7g-i	4.3g
LSD value (0.05)	0.8	1.1

†Fall color retention is measured on the basis of the ability of the turf to retain its color as the season. It was rated on a 1 to 9 scale where 9 equaled no damage with fully green turf and 1 equaled most severe damage with straw-brown and completely dormant turf.

‡ In 2014 the rating was taken on 4th November and in 2015, rating was taken on 8th November

§Fisher’s protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Table 21. Mean percent live cover for thirty-nine bermudagrass entries in 2014 and 2015 at Stillwater, OK.

	Percent Live Cover†					
	2014			2015		
Cultivar	Spring‡	Summer	Fall	Spring	Summer	Fall
Tifway	41.7k-n§	81.7b-h	99.0a	99.0a	99.0a	99.0a
Latitude 36	19.3o-r	36.7i	99.0a	99.0a	99.0a	99.0a
Patriot	36.7l-o	68.3h	99.0a	99.0a	99.0a	99.0a
Celebration	55.0e-l	93.0a-c	99.0a	99.0a	99.0a	99.0a
NuMex Sahara	4.3r	20.0j	99.0a	99.0a	99.0a	99.0a
Princess 77	13.3p-r	71.7gh	99.0a	99.0a	99.0a	99.0a
MBG 002	51.7g-l	87.0a-e	99.0a	99.0a	99.0a	99.0a
OKS 2009-3	41.7k-n	80.7b-h	99.0a	99.0a	99.0a	99.0a
OKS 2011-1	71.7b-f	88.3a-e	99.0a	99.0a	99.0a	99.0a
OKS 2011-4	53.3f-l	85.0a-g	99.0a	99.0a	99.0a	99.0a
JSC 2-21-1	83.3a-c	95.0a-c	99.0a	99.0a	99.0a	99.0a
JSC 2-21-18	75.0a-d	90.0a-e	99.0a	99.0a	99.0a	99.0a
JSC 2007-8	81.7a-c	92.3a-c	99.0a	99.0a	99.0a	99.0a
JSC 2007-13	81.7a-c	88.3a-e	99.0a	99.0a	99.0a	99.0a
JSC 2009-2	83.3a-c	91.7a-d	99.0a	99.0a	99.0a	99.0a
JSC 2009-6	86.7ab	91.0a-d	99.0a	99.0a	99.0a	99.0a
Riviera	68.3b-h	93.3a-c	99.0a	99.0a	99.0a	99.0a
Yukon	42.0k-n	47.3i	99.0a	99.0a	99.0a	99.0a
North Shore SLT	18.3o-r	68.3h	99.0a	99.0a	99.0a	99.0a
12-TSB-1	11.0rq	51.7i	99.0a	99.0a	99.0a	99.0a
11-T-251	65.0c-i	88.3a-e	99.0a	99.0a	99.0a	99.0a
11-T-510	58.3d-k	94.7a-c	99.0a	99.0a	99.0a	99.0a
TifTuf	76.7a-d	95.3ab	99.0a	99.0a	99.0a	99.0a
FAES 1325	45.0j-m	90.7a-d	99.0a	99.0a	99.0a	99.0a
FAES 1326	41.7k-n	81.7b-h	99.0a	99.0a	99.0a	99.0a
FAES 1327	46.7i-m	80.0c-h	99.0a	99.0a	99.0a	99.0a
PST-R6PO	60.0d-k	80.0c-h	99.0a	99.0a	99.0a	99.0a
PST-R6T9S	68.3b-h	76.7d-h	99.0a	99.0a	99.0a	99.0a
PST-R6CT	46.7i-m	70.0gh	99.0a	99.0a	99.0a	99.0a
BAR C291	30.0m-p	81.7b-h	99.0a	99.0a	99.0a	99.0a
OKC 1131	91.7a	95.0a-c	99.0a	99.0a	99.0a	99.0a
OKC 1163	70.0b-g	93.0a-c	99.0a	99.0a	99.0a	99.0a
OKC 1302	70.0b-g	88.3a-e	99.0a	99.0a	99.0a	99.0a
Astro	76.7a-d	97.0a	99.0a	99.0a	99.0a	99.0a
U-3-SIU	50.0h—l	75.0e-h	99.0a	99.0a	99.0a	99.0a
U-3-NC	68.3b-h	91.7a-d	99.0a	99.0a	99.0a	99.0a
U-3-TGS	73.3a-e	90.0a-e	99.0a	99.0a	99.0a	99.0a
TifGrand	23.3n-q	45.0i	99.0a	99.0a	99.0a	99.0a
Quickstand	61.7d-j	86.3a-f	99.0a	99.0a	99.0a	99.0a
LSD value (0.05)	18.7	15.2	1.8	1.8	1.8	1.8

† Percent living cover during turf establishment was evaluated visually on a 0 to 100 scale.
‡ In 2014, ratings were taken on 15th May, summer rating was taken on 24th July and fall rating was taken on 24th September. In 2015, ratings were taken on 4th May, summer rating was taken on 15th July and fall rating was taken on 4th October
§Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level

Figure 1. The 2003 version of Oklahoma State University's sod tensile strength testing device.

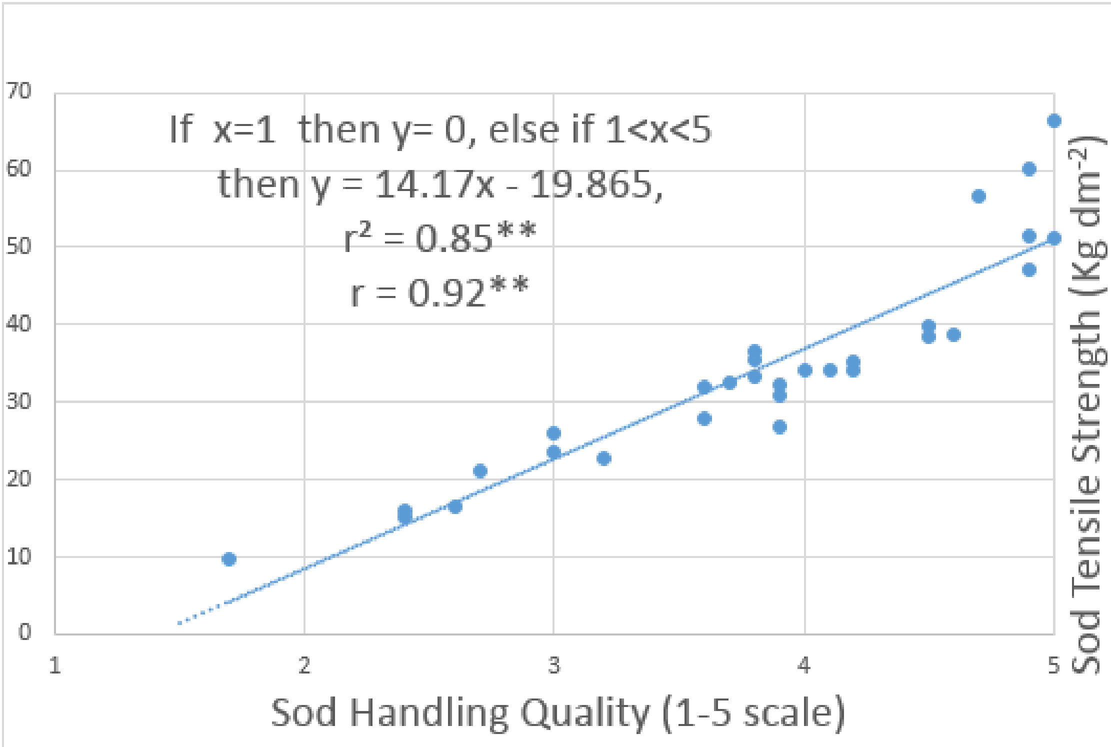

Figure 2. Relationship between sod handling quality and sod tensile strength using the mean sod tensile strength and handling quality of thirty-nine bermudagrass entries pooled over three assessment dates.
*, **, *** indicates significance at P = 0.05, 0.01, and 0.001 respectively .

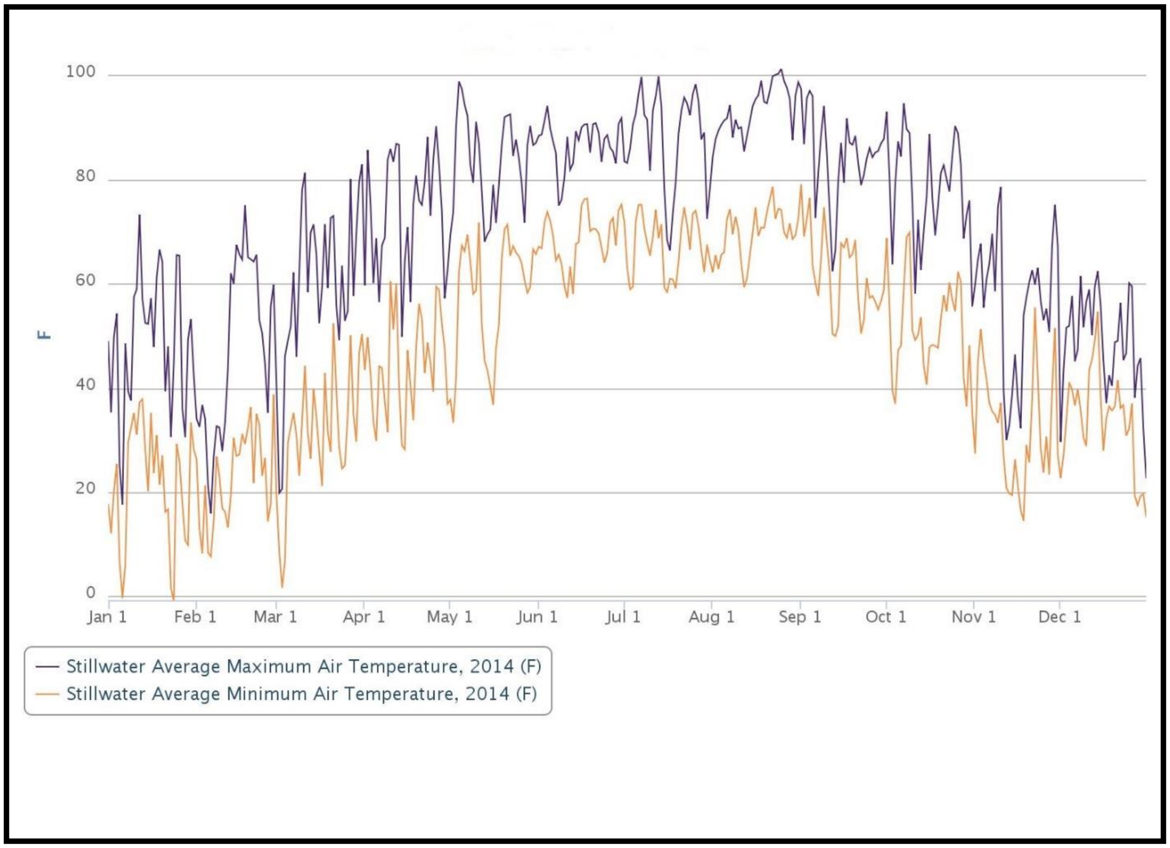

Figure 3. Average maximum and minimum air temperatures (°F) for 2014.

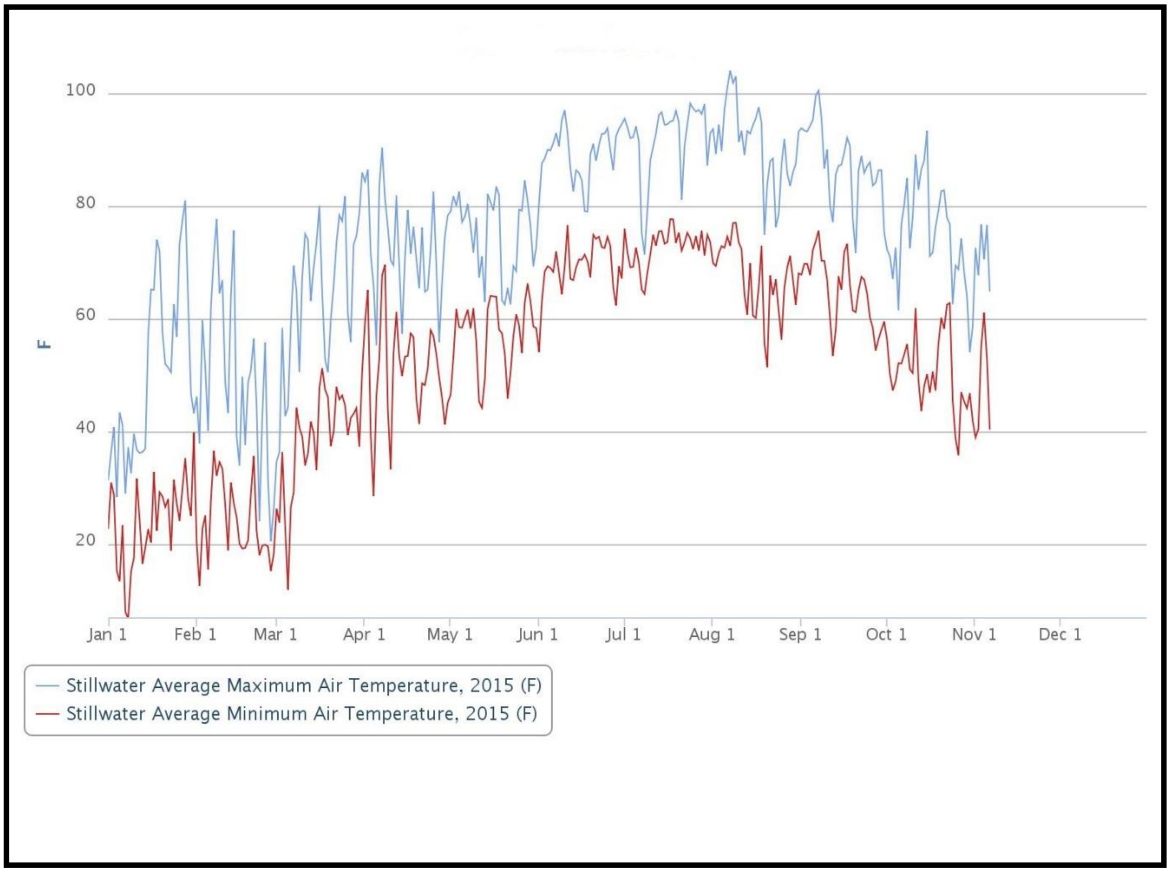

Figure 4. Average maximum and minimum air temperatures (°F) for 2015.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Goals

The goals of this study were to evaluate 34 official entries of the 2013 NTEP bermudagrass trial plus five local vegetative entries for sod tensile strength (STS), sod handling quality (SHQ), visual quality, genetic color, texture, density, green-up and living cover during 2014 and 2015 at Stillwater, OK. The goals also included the development of a first ever predictive relationship between STS and SHQ for bermudagrass sod.

Summary

Entry, harvest date and their interaction strongly influenced SHQ. The ranking of overall SHQ as a function of the sods age at harvest time was 24 months (4.3 rating) > 14 months (4.1 rating), > 22 months (3.8 rating), respectively. Thirty-nine percent (%) of the cultivars tested were in the top statistical group for SHQ on all three harvest dates. The vegetative cultivars Tifway, Latitude 36, Patriot, OKC 1163, OKC 1302, Astro, Quickstand, TifTuf, and FAES 1326 as well as seeded cultivars Princess 77, 12-TSB-1, scored a 5 on all harvest dates. Forty-nine % of the cultivars tested scored the suggested commercial minimum mean SHQ value of 4 in all three harvest dates.

The overall mean bermudagrass STS ratings by harvest date (age in months) exhibited the same trend seen with SHQ in that 24 months (43.9 kg dm^{-2}) > 14 months (39.6 kg dm^{-2}) > 22 months (34.1 kg dm^{-2}), respectively. Latitude 36 was consistently in the top statistical group and this is consistent with the findings of Han (2009). The seeded cultivars PST-R6T9S and PST-R6PO were in the lowest statistical group for STS at all harvest dates. This is in accordance with the findings of McCalla et al. (2004) where seeded cultivars were found to have lower sod strength, requiring netting to obtain satisfactory harvestability in sod production. The experimental cultivars OKC 1302, FAES 1325, FAES 1326, FAES 1327, and 12-TSB-1 provided STS not statistically different from the industry standards, Tifway and Patriot.

A strong positive correlation (r=0.92***) between STS and SHQ was found and a highly significant linear relationship (r^2 = 0.85***) was developed between overall STS and SHQ. Predicted mean STS values as a function of SHQ were 8.5, 22.6, 36.8 kg dm^{-2}, respectively for SHQ 2, 3 and 4 under the particular management regime followed in this trial.

Entries varied substantially with respect to their percent live cover, quality, color, shoot density, texture, spring green-up and fall color retention. Following an initial establishment period of approximately 13 months, by fall of 2014 all entries maintained live cover of 99% for the remainder of the study. This suggests that the cultivars were well adapted to the site and the management regime utilized. All cultivars maintained acceptable ($\geq$ 6) turfgrass quality in the months June, July and August of 2014 and 2015.

A lower TQ was reported in late season ratings taken in November of 2014 and 2015. Entries providing the highest TQ in 2014 were JSC 2-21-18, 11-T-251, 11-T-510, and TifGrand. In 2015, the top performers with respect to TQ were JSC 2-211, JSC 2-21-18, TifTuf, and Latitude 36. The cultivars were found to have a better mean color in summer of 2014 and 2015 than in spring and fall of both years. This could be explained by the more ideal air temperatures for bermudagrass growth during these periods. The experimental cultivars OKC 1131 and 11-T-510 were not statistically different from Tifway for turfgrass color. All bermudagrass entries were found to have a better shoot density rating in 2014 than in 2015. The cultivars with a lower mean shoot density rating in both years were seeded entries. Seeded cultivars present in the trial were found to be coarser textured than vegetative entries. This is in accordance with the fact that seeded cultivars are generally coarser textured than modern vegetatively propagated cultivars. The standards Tifway, TifGrand, and Princess 77 and the experimental cultivars 12-TSB-1, 11-T-251, FAES 1327, PST-R6CT were slowest to green up in 2014 and 2015. The experimental cultivar OKC 1131 was in the top statistical group for all of the rating dates conducted for spring green-up. TifGrand and TifTuf ranked highest in fall color retention in 2014 and 2015, respectively. The cultivars with a lower fall color retention in 2014 and 2015 were Patriot, NuMex Sahara, Yukon, PST-R6T9S, U-3-NC and Quickstand. The bermudagrass entries generally retained their color better in 2015 than in 2014 although this factor was not statistically tested.

Conclusions

The significance of this research is multi-fold. First, the information gained from this research when paired with additional findings from other trials will help turfgrass developers formulate a decision as to whether the experimental bermudagrass lines tested should be further pursued for possible commercial release. Fertile seed-propagated lines having superior performance traits might also serve in future breeding and development of additional germplasm for testing and/or commercial release. Sod handling quality (SHQ) and sod tensile strength (STS) were the major sod performance traits evaluated in this study. A value of SHQ ranging from 3 to 5 on a scale of 1 to 5 (5=excellent and best) was considered to be acceptable for industry handling. Hence from a sod producer's perspective, a cultivar with a minimum acceptable SHQ and yet having excellent visual character would still be of interest irrespective of its mere satisfactory level of sod tensile strength.

Entries that were able to provide SHQ ranging from the minimum acceptable to the best SHQ by the time of the first harvest at 14 months of age are of great importance since they did not require additional length of cropping cycle. Such cultivars might be more profitable than cultivars requiring a longer cropping cycle to achieve satisfactory handling quality provided all other factors amongst entries are consistent. These cultivars would also be of interest to producers because these cultivars require lesser inputs to produce high quality sods. However, such cultivars also need to be consistent in their performance in future harvests.

This study has been the first ever to develop a predictive linear regression relationship between STS and SHQ. However, the predictive linear equation derived needs to be tested on an independent dataset to determine its broad application or if its use is limited to trials and conditions identical to that of this study.

Visual characteristics of bermudagrass cultivars are of immense importance. All of the cultivars evaluated in the trial had satisfactory ratings which would be considered suitable for use in the commercial market, especially during the peak of the growing seasons. The clonally propagated commercial cultivars released from OSU as well as the experimental OSU entries OKC 1163 and OKC 1302 possessed excellent color, quality, leaf texture and shoot density along with good STS and SHQ. These attributes help to support pursuit of further testing and possible commercialization of these experimental lines. Clonally propagated cultivars are known to have a better STS and SHQ and are popular in sod production.

The results of this study revealed that the seeded experimental cultivar 12-TSB-1 had an STS value similar to Tifway. However, the slow establishment rate of this cultivar relative to vegetative bermudagrass options might be of a concern to sod producers. The use of seeded cultivars would be beneficial for sod production owing to high production volume due to the ease with which a larger land area can be seeded than sprigging or plugging of vegetative cultivars. From a plant breeder's perspective, seeded cultivars with a high mean STS are a unique find and might be exploited for further improvement in this trait when developing future seeded cultivars. Cultivars of such kind could be considered for further testing so that these could be commercialized and also serve as potential parents in breeding programs.

CHAPTER V

LITERATURE CITED

Aylward, L. 2003. Real life solutions: ‘Princess’ Royal. Reprinted from Golfdom. 2003 January 59(1):64-66.

Alderson, J., and W.C. Sharp. 1994. Grass varieties in the United States. USDA. Agriculture Handbook No. 170. p. 54.

Baltensperger, A. A., B. Dossey, L. Taylor, and J. Klingenberg. 1993. Bermudagrass, *Cynodon dactylon* (L.) Pers., seed production and variety development. International Turfgrass Soc. Res. J. 7:829-838.

Barton, L., G.G.Y. Wan, and T.D. Colmer. 2006. Turfgrass (*Cynodon dactylon* L.) sod production on sandy soils: I. Effects of irrigation and fertilizer regimes on growth and quality. Plant and Soil 284:129-145.

Beard, J. B., Rieke, P. E., and King, J. W. 1969. Sod production of Kentucky bluegrass. Int. Turfgrass Soc. Res. J. 1:509-513.

Beard, J.B. 1973. Turfgrass science and culture. Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Beard, J.B. 2001. Turfgrass Root Basics. TURFAX 9. 4-7.

Belcher J.L, R.H. Walker, E. Van Santen, G.R.Wehtje. 2002. Non-tuberous sedge and kyllinga species' response to herbicides. Weed Technol. 16:575–579.

Brosnan, J.T., G. K. Breeden, A. W. Thoms, and J. C. Sorochan. 2014. Effects of pre-emergence herbicides on the establishment rate and tensile strength of hybrid bermudagrass sod. Weed Technol. 28:206-212.

Burns, R.E., and J.G. Futral. 1980. Measuring sod strength with an Instron Universal Testing Instrument. Agron. J. 72:571-573.

Burton G.W. 1951. The adaptability and breeding of suitable grasses for the Southeastern States. Adv Agron. 3:197–2.

Burton, G.W. and R.H. Hart. 1967. Use of self-incompatibility to produce commercial seed-propagated F1 bermudagrass hybrids. Crop Sci. 7:524-527.

Burton, G.W. 1991. A history of turf research at Tifton. U.S. Golf Assoc. Green Sec. Rec. 29(3):12-1441.

Casler, M.D and R.R. Duncan. 2003. Turfgrass biology, genetics, and breeding. 1 Ed. John Wiley & Sons, Inc. Hoboken, N.J. p. 236.

Cattani, D. J., Miller, P. R., and Smith, S. R., Jr. 1996. Relationship of shoot morphology between seedlings and established turf in creeping bentgrass. Canadian J. Plant Sci. 76:283-289.

Christians, N. 2004. Fundamentals of turfgrass management. 2nd Ed. Iowa State Univ. John Wiley & Sons, Inc. Hoboken, N.J.

Christians, Nick. 2011. Fundamentals of turfgrass management. 4th Ed. John Wiley & Sons, Inc. Hoboken, N.J.

Croce, P., A. De Luca, M. Mocioni, M. Volterrani, and J.B. Beard. 1999. Seeded and vegetatively propagated cultivar comparisons within both *Cynodon* and *Zoysia* species. 4th International Herbage Seed Conference. Perugia-Italy.

Darrah, C.H. and A.J. Powell, Jr. 1977. Post-harvest heating and survival of sod as influenced by pre harvest and harvest management Agron. J. 69:283-287.

Dipaola, J. M. and J. B. Beard. 1992. Physiological effects of temperature stress. In D. V. Waddington, R. N. Carrow, and R. C.Shearman (eds.). Turfgrass. ASA, CSSA, and SSSA, Madison, WI.

Fagerness, M.J., Yelverton, F.H., and Cooper, R. J. 2002. Bermudagrass [*Cynodon dactylon* (L.) Pers.] and zoysiagrass (Zoysia japonica) establishment after preemergence herbicide application. Weed Technol. 16:597-602.

Forbes, I. and G.W. Burton. 1963. Chromosome numbers and meiosis in some *Cynodon* species and hybrids. Crop Sci. 3:75–79.

Gannon T.W., F.H. Yelverton, and L.P. Tredway. 2012. Purple nutsedge (*Cyperus rotundus*) and false-green kyllinga (*Kyllinga gracillima*) control in bermudagrass turfgrass. Weed Technol. 26:61.

Gardner, D. 2008. Pre and post emergence crabgrass control. SportsTurf. 24(6):14-20.

Giese, M.S., R.E. Gaussoin, R.C. Shearman, and T.P. Riordan. 1997. Sod production characteristics of turf-type *Buchloë dactyloides*. Int. Turf. Soc. Res. J. 8:455-465.

Giolo, M., S. Macolino, E. Barolo, F. Rimi. 2013. Stolons reserves and spring green-up of seeded bermudagrass cultivars in a transition zone environment. Hortscience 48: 780–784.

Goatley, J.M., Jr., D.M. Smith, P.D. Gerard and G.E. Coats. 1997. Comparing sod strength parameters of warm-season turfgrasses using a hydraulically driven sod strength machine. HortTech 7(4):421-426.

Hall, J.R. III. 1980. Effect of cultural factors on tall fescue - Kentucky bluegrass sod quality and botanical composition. Proc. Third Int. Turf. Res. Conf. 3:367-377.

Hanna, W.W. 1986. A bermudagrass primer and the Tifton bermudagrass. U.S. Golf Assn. Green Sec. Rec 24:11-13.

Hanna, W.W., G.W. Burton, and A.W. Johnson. 1990. Registration of ‘Tifton 10’ turf bermudagrass. Crop Sci. 30:1355–1356

Han, H.R. 2009. Development of improved turf-type bermudagrasses. M.S. thesis. Oklahoma State University. Stillwater.

Harlan, J.R., J.M.J. de Wet, W.L. Richardson, W.W. Huffine, J. Deakin, S.P. Sen Gupta and A. Carpena. 1966. Biosystematics of the genus *Cynodon* (Gramineae). Oklahoma Agricultural Experiment Station Proceedings Series P-537.

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

Harlan, J.R., J.M.J. de Wet, W.W. Huffine, and J.R. Deakin. 1970a.A guide to the species of *Cynodon* (Gramineae). OK. Agric. Exp. Stn. Bul. B-673.

Harlan JR, de Wet JMJ, Rawal KM, Felder MR, Richardson WL(1970b) Cytogenetic studies in *Cynodon* L.C. Rich. (Gramineae).Crop Sci. 10:288–291.

Heckman, N.L., G.L. Horst, R.E. Gaussoin, and K.W. Frank. 2001b. Storage and handling characteristics of trinexapac-ethyl treated Kentucky bluegrass sod. Hort. Sci. 36(6):1127-113.

Heckman, N. L., T. E Elthon, G. L. Horst and R. E Gaussoin. 2002. Influence of trinexapac-ethyl on respiration of isolated wheat mitochondria. Crop Sci. 42(2):423-427.

Hensler, K.L., M.D. Richardson, and J.R. Bailey. 1999. Implications of seeded bermudagrass planting date and morphology on cold tolerance. p. 69–71.In J.R. Clark and M.D. Richardson (ed.) Horticultural studies 1998. Res. Series 466. Arkansas Agric. Exp. Stn., Univ. of Arkansas, Fayetteville, AR

Higgins, J. 1998. Bermudagrass Lawns. Alabama Coop. Ext. Sys. ANR-29. Alabama A&M Univ. and Auburn Univ.

Hurcombe, R.E. 1948. Experiments with *Cynodon dactylon* and other species at the South African Turf Research Station. African Explosives and Chemical Industries, Ltd., and South African Turf Research Fund, Frankenwald, South Africa. 90 pp.

Johnson. B.J. 1977. Differences in tolerance of bermudagrass and zoysiagrass cultivars to herbicides. 217– 225. Beard, J.B. Proc. 3rd Int. Turfgrass Res. Conf. Munich, West Germany 11–13 July ASA Madison, WI.

Juska, F.V. and A.A. Hanson. 1964. Evaluation of bermudagrass varieties for general purpose turf. USDA Agricultural Handbook. 270:1-54.

King, K.W., J.B. Beard, and P.E. Rieke. 1982b. Effects of carbon dioxide, oxygen, and ethylene levels of Kentucky bluegrass sod. J. Amer. Soc. Hort. Sci. 107:638–640.

Kneebone, W.R. 1966. Bermudagrass -- worldly, wily, wonderful weed. Economic Botany 20:94-97.

Koske, T.J. 1994. Sod Production for Louisiana. Baton Rouge, LA: LSU Ag Center. Available at:http://www.lsuagcenter.com/NR/rdonlyres/32B8AFC3-3508-4F99-AA33-60B6AF03E664/44947/pub2904SodProductionHIGHRES.pdf.

Krans, J.V., H.W. Philley, J.M. Goatley, Jr., and M. Tomaso-Peterson. 1992. The relationships of rhizome density, sod strength, and spring green-up in bermudagrass. Agron. Abs. 84:172.

Lima, C. P. D., C. Backes, V. Bôas, R. Lyra, M.R.D Oliveira, T. A. M. Kiihl and E. E. Freitag. 2010. Bermuda grass sod production as related to nitrogen rates. Revista Brasileira de Ciência do Solo 34(2):371-378.McCalla, J.H., M.D. Richardson, J.W. Boyd, D.E. Karcher, and J.W. Landreth. 2004. Sod production using seeded bermudagrass. 2004 Annual Meeting Abstracts [ASA/CSSA/SSSA].

McCalla, J., M. Richardson, J. Boyd, and A. Patton. 2009. Effect of mesotrione on sod quality of Tifway bermudagrass. Arkansas Turfgrass Report 2008, Ark. Ag. Exp. Stn. Res. Ser.568:50-53.

McCullough, P. E., de Barreda, D. G., Reed, T. V., Yu, J., & Waltz, F. C. 2014. Sod harvesting intervals of four warm-season turfgrasses for halosulfuron and sulfentrazone. Weed Technology 28(1):47-57.

Mehlich, A. 1984. Mehlich-3 soil test extractant: a modification of Mehlich-2 extractant. Commun. Soil Sci. Plant Anal. 15(12):1409-1416.

Mitchell, C.H., and R. Dickens. 1979. Nitrogen fertilization and mowing height effects on tensile strength of bermudagrass sod. Agron. J. 71(6):1061-1062.

Moore, K.J., K.J. Boote, and M.A. Sanderson. 2004a. Physiology and developmental morphology. In: Warm-Season Grasses. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI, pp. 1–37.

Morris, K.N., and R.C. Shearman. 2000. NTEP Turfgrass Evaluation Guidelines. [Online]. Available at http://www.ntep.org/pdf/ratings.pdf (accessed 2 November 2015). National Turfgrass Evaluation Program. Beltsville, MD.

Pair, J.C., R.A. Keen, C.M. Taliaferro, D.L. Martin, J.F. Barber, and R.N. Carrow. 1994a. Registration of Midfield turf bermudagrass. Crop Sci. 34(1)307.

Pair, J.C., R.A. Keen, C.M. Taliaferro, D.L. Martin, J.F. Barber, and R.N. Carrow. 1994b. Registration of Midlawn turf bermudagrass. Crop Sci. 34(1)306-307.

Parish, R. L. 1995. A simple device to measure sod strength. HortTech, *5*(4):308-309.

Rieke, P.E., J.B. Beard, and C.M. Hansen. 1968. A technique to measure sod strength for use in sod production studies. Agron. Abs. 60:60.

Rogers, R. A., J. H. Dunn, and C. J. Nelson. 1975. Cold hardening and carbohydrate composition of Meyer zoysia. Agron. J. 67:836-838.

Schiavon, M., S. Macolino, B. Leinauer, and U. Ziliotto. 2015. Seasonal changes in carbohydrate and protein content of seeded bermudagrasses and their effect on spring green-up. Journal of Agronomy and Crop Science. doi:10.1111/jac.12135

Schmidt R.E., R.H. White, S.W. Bingham. 1986. Technique to measure rooting of sod grown in small containers. Agronomy Journal 78:212–216.

Sharpe, S.S., R. Dickens, and D.L. Turner. 1989. Herbicide effects on tensile strength and rooting of bermudagrass (Cynodon dactylon) sod. Weed Technology 3(2):353-357.

Shildrick, J. P. 1982. Mixtures and seed rates for sod production. J. Sports Turf Res. Inst. 58:76 95.

Skerman, P.J. and E. Riveros. 1990. Tropical grasses. FAO Plant Production and Protection Ser., no 23. FAO, Rome.

Segars, C. 2013. Identification of improved traffic tolerance in experimental and commercially available bermudagrass varieties. M.S. thesis.Oklahoma State University. Stillwater

Taliaferro, C.M. 2003. Bermudagrass (Cynodon (L.) Rich). p. 235-256. In Casler, M.D. and R. Duncan (eds.) Turfgrass Biology, Genetics, and Cytotaxonomy. Sleeping Bear Press.

Taliaferro, C.M., D.L. Martin, J.A. Anderson, M.P. Anderson, G.E. Bell, and A.C. Guenzi. 2003. Registration of 'Yukon' bermudagrass. Crop Sci. 43:1131-1132.

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

Taliaferro, C.M., F.M. Rouquette, Jr., and P. Mislevy. 2004. Bermudagrass and stargrass. p. 417–475. In L.E. Moser et al. (ed.) Warm-season (C4) grasses. ASA, CSSA, and SSSA, Madison, WI.

Taliaferro, C.M., D.L. Martin, J.A. Anderson, and M.P. Anderson. 2006. Patriot turf bermudagrass. U.S. Plant Patent PP16,801. Date issued: 11 July.

Turgeon, A.J. 2006. Instructional modules: Introduction to turfgrass management. Educational resources for turfgrass science, University Park, PA. [Online]. Available at http://turfgrass.cas.psu.edu/ (accessed 13 May 2015; verified 14 May 2015).

USDA. 2002. Census of agriculture. United States Department of Agriculture. Washington. DC.

USDA. 2007. Census of agriculture. United States Department of Agriculture. Washington. DC.

USDA-NRCS. 2015. WebSoil Survey. Payne County, Oklahoma. USDA-NRCS. Available at: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx.

Wharton, S.M. 1999. Overseeded bermudagrass fairway performance and post dormancy transition as influenced by winter overseeding practices and trinexapac-ethyl. M.S. Thesis. VA Poly I&S University.

Wu, Y.Q., C.M. Taliaferro, G.H. Bai, D.L.Martin, J.A. Anderson, M.P. Anderson, and R.M.Edwards. 2006. Genetic analyses of Chinese *Cynodon* accessions by flow cytometry and AFLP markers. Crop Sci. 46:917-926.

Wu, Y., D.L. Martin, J.A. Anderson, G.E. Bell, M.P. Anderson, N.R. Walker, and J.Q. Moss. 2009. Recent progress in turf bermudagrass breeding research at Oklahoma State University. USGA TERO 8(16):1-11.Wu, Y., D.L. Martin, Z. Wang, C. Tan, and T. Samuels. 2011. Microsatellite molecular markers accurately identify clonal turf bermudagrass. USGA TERO 10(10):1-7.

Wu, Y.Q., D.L. Martin, C.M. Taliaferro, J.A. Anderson and J.Q. Moss. 2013. Northbridge bermudagrass. U.S. Plant Patent 20120304350 P1. Date issued: 29 November

Wu, Y.Q., D.L. Martin, C.M. Taliaferro, J.A. Anderson and J.Q. Moss. 2014. Latitude 36 bermudagrass. U.S. Plant Patent PP24271 P3. Date issued: 25 February.

Wu, Y., and D.L. Martin. 2015. Development of seeded and vegetatively propagated bermudagrass varieties improved in turf quality and stress tolerance. USGA TERO 14(3):21-22.

VITA

Lakshmy Gopinath

Candidate for the Degree of

Master of Science

Thesis: AN ASSESSMENT OF THE SOD HANDLING QUALITY AND TENSILE STRENGTH OF THIRTY-NINE TURF BERMUDAGRASSES

Major Field: Horticulture

Biographical:

Education:
-Completed the requirements for the Master of Science in Horticulture at Oklahoma State University, Stillwater, Oklahoma in December, 2015.

-Completed the requirements for the Bachelor of Science in Horticulture at Tamil Nadu Agricultural University, Coimbatore, India in 2012.

Experience:
Graduate Research Assistant in the Turfgrass Science Program in Horticulture and Landscape Architecture Dept., A, Turfgrass Oklahoma State University, Stillwater, OK.

Professional Memberships:
-American Society of Agronomy
-Crop Science Society of America
-Pi Alpha Xi Honor Society

.