ASSESSING SOD PRODUCTION CHARACTERISTICS: SOD HANDLING QUALITY AND SOD TENSILE STRENGTH OF WARM SEASON TURFGRASSES

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Title of Study: ASSESSING SOD PRODUCTION CHARACTERISTICS: SOD HANDLING QUALITY AND SOD TENSILE STRENGTH OF WARM SEASON TURFGRASSES

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Abstract: Study I: The objective of this study was to assess the sod handling quality (SHQ) and sod tensile strength (STS) of entries grown at two heights (2.5 cm and 7.6 cm) in the 2016 NTEP Seashore Paspalum Trial at Stillwater, OK. Sod was harvested in July and September of 2017 at 12 and 14 months after planting, respectively. To assess SHQ and STS, two sod pads, each measuring 38 cm x 30.5 cm x 1.5 cm (length x width x depth), were cut from each replicate within each mowing height. The SHQ of each entry was assessed on a 1 to 5 visual scale where 1= very poor SHQ and 5=excellent SHQ. The STS was measured as the peak force required to cause sod pad tearing using a hand winch and force transducer/recorder system. Date of harvest had a significant effect upon the SHQ as well as STS. The main entry effect and date were found to have a significant effect upon the SHQ at p = 0.001. Significant date (p=0.001) and entry x date (p=0.001) were present with respect to STS. Mowing heights of 2.5 vs 7.6 cm did not produce a difference in small pad SHQ and STS. Average SHQ of the seashore paspalum entries ranged from 2.6 to 4.3. All entries except 'UGA Sr 14-1E' had an average SHQ greater than 3.0 which was considered the minimum acceptable quality for commercial sod production. The overall average SHQ and STS of entries was lower at 14 vs 12 MAP. However, 'UGP 73' had numerically greater STS at 14 than at 12 MAP. Additional research is needed to separate the effect of sod maturity versus possible negative impacts of harvesting sod late in the growing season after cool nights and short day lengths may have impacted seashore paspalum STS and SHQ.

Study II: The objective of this study was to assess the sod tensile strength (STS) and sod handling quality (SHQ) of experimental bermudagrass lines over time. Sod was harvested at 14 and 72 months after planting (MAP) with STS and SHQ assessed as discussed under Study I. There were highly significant (p=0.001) entry, date and entry x date effects for SHQ and STS. The SHQ and STS was unstable over time as average SHQ and STS fell from 70.1 kg dm^{-2} at 14 MAP to 16.7 kg dm^{-2} at 72 MAP. A strong positive correlation was found between sod handling quality and sod tensile strength (r=0.73 at p = 0.0001 at 14 MAP and r=0.92 at p = 0.0001 at 72 MAP.) at both harvest dates suggesting that sod handling quality as defined in prior published studies remains a broadly useful and reliable indicator of sod tensile strength for bermudagrass.

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CHAPTER I
REVIEW OF LITERATURE

Introduction

Turfgrasses are low growing grasses that form a uniform ground cover and can tolerate constant mowing (Emmons and Rossi, 2015). Turfgrass provides many functional, recreational, and aesthetic benefits contributing to the quality of human life (Beard and Green, 1994). The benefits of turfgrass to the local environment include : protection of soil resources from wind and water erosion by binding the underlying soil with vigorous root systems; improving soil quality by adding organic matter resulting from the decay of roots and other plant tissues; improving groundwater recharge as turfgrass reduced runoff resulting in increased infiltration of water through the soil-turfgrass ecosystem; dissipation of heat in urban areas through the cooling process of transpiration; providing an inexpensive and safe recreational surface; and improving human physical and mental health (Beard and Green, 1994).

The United States is delineated into two major turfgrass adaptation zones; the warm-season zone, located primarily around the Gulf Coast states, and the cool-season zone, located primarily north of the 37th parallel (Emmons and Rossi, 2015). The optimum growing temperature range for warm season grasses is around 25 to 35°C (Turgeon, 1996). Bermudagrass (*Cynodon* spp.), zoysiagrass (*Zoysia* spp.), St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze], centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.], bahiagrass (*Paspalum notatum* Flugge.), buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.) or [*Bouteloua dactyloides* (Nutt.) J.T. Columbus], and carpetgrass (*Axonopus affinis* Chase) are the primary warm season turfgrasses used in the U.S. (Christians, 2007). There are four simplified climatic zones of turfgrass adaptation in the United States. They are the cool humid zone, the warm humid zone, warm arid zone and the cool arid. Apart from these four climatic zones there is one more region known as the transition zone extending through the central part of the country (Christians et al., 2016). In the transition zone, warm-season turfgrasses can be injured or killed due to extreme temperatures and enter a winter dormancy whereas hot summer temperatures are not favorable for the cool season turfgrass stands (Christians et al., 2016).

Sod Production Characteristics: Sod Tensile Strength (STS) and Sod Handling Quality (SHQ)

Blocks, plugs, squares, or strips of turfgrasses along with their adhering soil are collectively represented by the term sod (Beard and Rieke, 1969). The desired characteristics for a high quality sod include 1) uniformity, 2) high shoot density, 3) adequate strength for harvesting and handling, 4) free from serious weeds, weed seeds, insects, diseases, and nematodes, 5) acceptable color, 6) sufficient maturity in terms of carbohydrate reserves to permit effective rooting and 7) a minimum thatch layer (Beard, 1973).

Commercial sod production was initiated during the 1920's (Beard and Rieke, 1969) in the United States. Growth within the sod industry increased significantly due in part to advancements in mechanized sod cutters, release of improved varieties of turfgrass for sod farming, and availability of broadleaf herbicides such as 2, 4-D during the 1950's (Beard and Rieke, 1969). Ability to provide an instant stand of turfgrass, and less post-planting care has surpassed the relatively higher costs of installing sod, making sod a popular method for establishment of turfgrass (Emmons and Rossi, 2015).

According to the 2012 United States Department of Agriculture Census, 321,309 acres of sod were harvested in the United States of America (USDA- NASS, 2018). In Oklahoma the total sod acres harvested in 2012 was 14,078 (USDA- NASS, 2018). Bermudagrass is the most common warm season grass used for sod production in the U.S. Other warm season turfgrass species used in sod production are zoysiagrass, St. Augustine grass, centipedegrass, buffalograss, and carpetgrass. Kentucky bluegrass (*Poa pratensis* L.) is the cool-season species produced in the greatest quantity in sod production due to its vigorous rhizomes and excellent sod forming characteristics (Christians, 2007).

Adapted turfgrass cultivars, soil conditions, climate, and cultural factors influence the success of sod crop production. Depending upon these factors a sod crop is produced in a time of six months to two years. The time from seeding/sprigging to sod production harvest for Kentucky blue and bermudagrass are shorter than for zoysiagrass, St. Augustinegrass and red fescue (*Festuca rubra* L.) (Beard, 1973). Kentucky bluegrass sod can be harvested as early as six months after seeding if the climate is favorable. Under less favorable climate it may take up to two years for the harvest (Beard and Rieke, 1969). In the transition zone, tall fescue (*Festuca arundinacea* Schreb) and the mixtures of Kentucky bluegrass with tall fescue are also used in sod production. The sod forming characteristics of tall fescue are weaker than that of Kentucky bluegrass, thus it requires longer production time when Kentucky bluegrass/tall fescue mixtures are used for sodding (Beard and Rieke, 1969).

High quality sod is of great importance in commercial sod production. Uniform stands of sod which has good appearance, rapid establishment, can be handled easily during harvest and installation, and is free of weeds are highly desired by sod producers and consumers alike (Beard, 1973). Adequate sod strength for handling is one of the characteristics of high quality turf (Beard and Rieke, 1969). Sod is required to have enough strength to hold together when handled if harvested without using any supplemental technique such as nylon netting to enhance the sod strength. Turfgrass with weak sod strength is at risk of breaking during the handling, transportation, and installation process, possibly resulting in economic losses to the sod producer and additional costs to the consumer. Suitable profit margins, production cycles, and good handling characteristics are the important parameters when deciding commercial viability of cultivars. Newly developed turfgrass cultivars are not considered sustainable for sod production until the cultivars provide these qualities.

The first definition of sod strength was described as the weight (measured in kilograms) required to tear apart a sod piece into two parts (Rieke et al., 1968). Over time researchers have used a variety of names and terms such as sod strength, sod tearing strength, sod tensile strength and defined them in different ways (Ross et al., 1991). The terms sod strength and sod tensile strength are often used interchangeably. Shearman et al. (2001) defined sod strength as the capacity of sod to resist a longitudinal stress, measured as the force needed to rip the sod. Later on, the term sod tensile strength was used and defined as the ability of sod to withstand longitudinal stress and measured it as the minimum amount of longitudinal stress needed to tear the sod (Heckman et al., 2001). Sod tensile strength (STS) varies among the various turfgrass species and between cultivars (Giese et al., 1997; Han, 2009; Shearman et al., 2001). Currently, the interspecific hybrid bermudagrass cultivar 'Tifway' (*C. dactylon* (L.) Pers. *x C. transvaalensis* Burtt-Davy) is considered the industry standard for satisfactory STS, whereas the *C. dactylon* cultivar 'Midlawn' [*C.dactylon* (L.) Pers. *x C. transvaalensis* Burtt-Davy) is considered the industry standard for poor STS in research conducted at Oklahoma State University (Han, 2009 and Gopinath, 2015).

Sod handling quality is a relatively new method to assess the handling quality of sod pads. Han (2009) is believed to be the first researcher to assess sod handling quality (SHQ) using a qualitative, numeric, discontinuous rating scale. The SHQ, as characterized by Han (2009), was assessed using a unit less scale with values from one to five, 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 (this was the suggested minimum acceptable value for industry handling), 4 = very mild cracking (this was the desired minimum rating for cultivar commercialization) and 5 = no cracking. This is a very simple and quick method for assessing sod pads. It does not involve use of any additional equipment for the testing, hence, sod producers and scientists can be easily trained on the implementation of this technique (Han, 2009).

Han (2009) conducted a study to assess the sod production characteristics: SHQ and STS of four hybrid bermudagrass cultivars: Patriot, OKC 70-18, Tifway and Midlawn at Oklahoma State University, Stillwater OK. Tifway and Midlawn bermudagrasses were included as the standard for good, and poor sod production characteristics respectively. Results showed that Tifway exhibited greater sod tensile strength than Midlawn at four out of five harvest events. Patriot provided either equal or greater SHQ and STS than Tifway. OKC 70-18 exhibited lower SHQ and STS than Tifway during all five harvests. Additionally, OKC-7018 did not provide better SHQ and STS than Midlawn on any harvest date. The study also reported a strong correlation ($r= 0.89$, $p= 0.001$) between the two sod handling characteristics (SHQ and STS). Han (2009) concluded that Tifway and Patriot provided suitable SHQ and STS while OKC70-18 and Midlawn were grouped as poor performers for both parameters of sod handling. Due to the poor SHQ and STS of OKC70-18, the Oklahoma State University (OSU) Turfgrass Development Program choose not to commercially release OKC70-18 (D.L. Martin, personal communication, 2018).

Gopinath (2015) conducted a study at Oklahoma State University (OSU), Stillwater, OK to assess the STS and SHQ of thirty-nine cultivars of bermudagrass. The experiment included commercially available cultivars Tifway, Latitude 36, ‘Celebration’, ‘Quickstand’, ‘Astro’, Patriot, and ‘Tifgrand’ as standards. Three harvests were conducted at 14, 22, and 24 months after planting (MAP). Entry and harvest date were found to have significant effect upon SHQ and STS. Results showed that experimental varieties OKC-1302 and 12-TSB-1 had higher STS than the commercially available standard Patriot. Experimental lines OKC 1302, FAES 1325, FAES 1326, FAES 1327, and 12-TSB-1 were not statistically different than the standards, Tifway and Patriot. Excellent sod handling quality (SHQ =5) was observed for the vegetative entries Tifway, Latitude 36, Patriot, Astro, Quickstand, Tiftuf, OKC 1163, OKC 1302 and FAES 1326, and the seeded entries Princess 77 and 12-TSB-1. The seeded variety PST-R6T9S exhibited the lowest SHQ and STS in the trial. Overall, vegetative varieties performed better than seeded entries. Latitude 36 performed consistently well throughout all harvests. Both SHQ and STS exhibited similar trends, the overall SHQ and STS averages of the bermudagrass entries at second harvest (22 MAP) were less than the first harvest (14 MAP). Overall average handling quality of the bermudagrass entries were 4.3 at 24 MAP, followed by 4.1 at 14 MAP and 3.8 at 14 MAP. The average sod tensile strength was 43.9 at 24 MAP followed by 39.6 at 14 MAP and 34.1 at 22 MAP. A strong correlation between SHQ and STS (r=0.92, $P < 0.001$) and a highly significant linear relationship was found between the two parameters in the bermudagrasses evaluated ($r^2 = 0.85$***) in the 2013 NTEP bermudagrass trial at Stillwater, OK.

Effects of Turfgrass Management Practices on Sod Tensile Strength

Fertilization, mowing, application of pesticides, growth promoters are among the regular turfgrass management practices for a beautiful, functional and healthy sod. These management practices may impart positive and/or negative effects on the sod formation process. The root system of turfgrass is believed to become shallower with a decreasing mowing heights (Guertal and Evans, 2006). Mowing puts the turfgrass plant into stress due to removal of the green tissues responsible for photosynthesis. This reduces the plant's ability to produce carbohydrates needed for growth and development. The plant compensates this loss by directing the carbohydrates to the shoots to acquire greater leaf area and shoot density thereby decreasing rooting depth. In this scenario, roots do not receive adequate energy and structural building material leading to less root mass and shallower roots (Christians et al., 2016). Several studies have reported on the effects of management practices on the root zone, quality, and production characteristics of sod (Brosnan et al., 2014; Hall III and Bingham, 1993; Hall, 1980; Mitchell and Dickens, 1979).

Fertilization and Mowing

Mitchell and Dickens (1979) assessed the effects of mowing height, and the rate and frequency of nitrogen fertilization on STS of two hybrid bermudagrasses: Tifway and 'Tifgreen'. Nitrogen was applied at an interval of two and four weeks at the rate of 0.6 kg N ha^{-1}, 1.2 kg N ha^{-1} and 2.5 kg N ha^{-1} and mowed at three heights of cut: 0.0125m, 0.02m and 0.025 m. Results showed that nitrogen application at four week intervals produced higher sod strength. Additionally, nitrogen fertilization at the lower rate (0.25 kg N ha^{-1}) produced higher STS. Mowing heights did not produce any effect upon the STS of both bermudagrass cultivars. Hall (1980) reported decrease in sod strength at higher rates of nitrogen application on tall fescue-Kentucky bluegrass sod and no mowing heights (0.025, 0.05, and 0.07 m) effected sod strength.

Guertal and Evans, (2006) conducted a study to evaluate the effects of different nitrogen rates and mowing heights on 'TifEagle' bermudagrass putting green at Auburn University Turfgrass Research Unit, at Auburn, Al. The study was conducted for three years in 2002, 2003 and 2004. Nitrogen was applied weekly at the rates of 3, 6, 12, 24 and 48 kg ha^{-1}. Mowing heights applied were 0.0032, 0.0039 and 0.0048 m. At lowest heights of cut turfgrass color, and rhizome and stolon mass were reduced than higher heights of cut (0.0039 and 0.0048 m). Additionally, increased nitrogen rates (0.0039 and 0.0048 kg ha^{-1}) favored the ground cover and shoot density.

Herbicides

Herbicide application is a very common and important practice in commercial sod production. Sod producers and consumers require high quality sod that is why uniform, weed free sod is crucial in commercial sod production. Weeds are problematic as they degrade the quality as well as the aesthetics of the sod. Both pre-emergent and post-emergent herbicides are used to keep the turfgrass stands free of weeds to achieve the desired quality. Annual grasses and some annual broadleaf weeds are controlled by the use of dinitroaniline herbicides (Bhowmik and Bingham, 1990; Murphy, 1999), BAS 514 and fenoxaprop ethyl were found effective in controlling large crabgrass (Chism and Bingham, 1991), indaziflam at all rates (35, 52.5, and 70 g ai ha^{-1}) and prodiamine at the rate of 840 kg ai ha^{-1} were effective in controlling smooth crabgrass (Brosnan et al., 2011). Annual bluegrass and annual broadleaf weeds control were achieved by using triazine herbicides such as simazine in most of the warm season grasses except bahiagrass (Murphy, 1999). In the cool season grasses, benefin at 2.2 to 3.4 kg ai ha^{-1}, pendimethalin at 1.7 to 3.4 kg ai ha^{-1}, prodianilne at 0.6 to 1.7 kg ai ha^{-1}, and benefin plus trifluralin at 1.1 plus 0.6 to 2.3 plus 1.1 kg ai ha^{-1} were found to control a number of annual grass weeds such as annual bluegrass, smooth crabgrass, goosegrass, yellow and green foxtail, barnyardgrass and fall panicum (Bhowmik and Bingham, 1990).

Herbicide application is of particular concern to the producers and users who require high quality, fast recovering, and weed-free sod. Weeds may interfere with turfgrass physiologically, functionally and asthetically, affecting the visual quality, rooting, sod tensile strength, and regrowth of the turfgrass (Bingham, 1974; Brosnan et al., 2014; Jagschitz, 1980; Mitchell and Dickens, 1979; Troutman and Jagschitz, 1971). These are the important factors of turfgrass that determines the overall appearance, ability to harvest and install sod, and rate of establishment. Dickens et al. (1989) evaluated the effects of atrazine, bensulide, DCPA, DPX-6316, imazapyr, imazaquin, napropamide, oxadizaon, pendimethalin, sethoxydium, simazine, sulfometuron and tridiphane on the rooting and sod tensile strength of immature ‘Emerald’ zoysiagrass sod. Immature turf was the sod with 100% ground cover but inadequate tensile strength for harvesting and handling whereas the mature turf had 100% ground cover with suitable tensile strength. Sod tensile strength was measured at 2, 4 and 8 weeks after treatment (WAT). In the year 1986, sod tensile strength was not affected by any herbicide at 2 WAT and 8 WAT. At 4 WAT tensile strength was found to be less than the untreated control. In the year 1987 also no significant reduction in STS was reported at 2, 4 and 8WAT. Application of imazapyr and oxadiazon showed no difference in STS as compared to the untreated control. However, Bensulide, napropamide and sulfometuron were found to restrict rooting of harvested sod for two to four weeks. Atrazine, simazine and oxadiazon at higher rates were found to be associated with rooting damages but only during year one of the study. At 8 WAT the zoysiagrass turf was able to recover from the detrimental effects of all herbicides except imazapayr.

Brosnan et al. (2014) conducted a field research from 2010 to 2013 at East Tennessee Research and Education Center-Plant Sciences Unit (Knoxville, TN) to study the effects of application of several pre-emergent herbicides on the establishment rate and STS of Tifway bermudagrass. Herbicides and application rates used in the 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}), dimethenamid-P (1.6 kg ai ha^{-1}), prodiamine + sulfentrazone (0.84+0.41 kg ai ha^{-1}) and Indaziflam (0.03 and 0.05 kg ai ha^{-1}). Results showed that all herbicide treatments caused delay in growth as compared to the non-treated control. Indaziflam applied at both rates reduced the STS of Tifway bermudagrass during the first year's harvest only which was conducted at 377 days after sprigging of the bermudagrass. Indaziflam reduced the STS during the first year's harvest only. No other herbicides were found to reduce the STS at any time. The herbicides pendimethalin, dithiopyr, prodiamine, oxadiazon, prodiamine+sulfentrazone, and dimethenamid slowed down the rate of establishment of hybrid bermudagrass but did not reduce the STS.

McCullogh et al. (2014) conducted field research on four warm season turfgrasses at University of Georgia in Griffin to evaluate the effects of two post emergent herbicides: halosulfuron and sulfentrazone. The study was performed on Tifway bermudagrass, 'Tifblair' centipedegrass, 'Palmetto' St. Augustine grass and 'Zeon' zoysiagrass. Halosulfron was applied at a rate of 0.07 kg ai ha^{-1} and sulfentrazone was applied at three rates: 0.21, 0.42 and 0.84 kg ai ha^{-1} which was 0.5, 1 and 2 times than the labeled rates respectively. Request of herbicide was done at one, two, four and eight weeks before harvesting (WBH). Results were compared with the non-treated controls. The study found that neither of the herbicides reduced the STS of Tifway bermudagrass and Tifblair' centipede grass. However, STS of St. Augustine grass was reduced by 15 % by the application of herbicides one week before harvest (WBH). Application of the herbicides 1 week before harvest (WBH) reduced the STS of Palmetto St. Augustine grass and Zeon zoysiagrass by 15 and 22% respectively. Moreover, only sulfentrazone applied at double rates (than the labeled rate) reduced the STS of zoysia grass by 20% but no other treatments were found to have less STS than the non-treated controls and application of halosulfron does not showed any effect on the STS of the four turfgrasses .

Begitschke et al. (2018) conducted a field study to evaluate the effects of various pre-emergent herbicides on STS of 'Latitude 36' hybrid bermudagrass at Mississippi State University over a two-year period. The study was initiated in 2016 and was repeated in the following year. Herbicides applied were atrazine (1.12 kg ha^{-1}), atrazine (1.12 kg ha^{-1}) + S-metolachlor (0.86 kg ha^{-1}), dithiopyr (0.56 kg ha^{-1}), flumioxazin (0.286 kg ha-1), indaziflam (0.033 kg ha-1), liquid and granular applied oxadiazon (2.24 kg ha-^{1}), S-metolachlor (2.78 kg ha^{-1}), pendimethalin (1.66 kg ha^{-1}), prodiamine (0.594 kg ha^{-1}), and simazine (2.24 kg ha^{-1}). The study reported that sod tensile strength of the Latitude 36 bermudagrass was not reduced by the any of the preemergence herbicide treatment. Conversely, prodiamine, pendimethalin, dithiopyr, flumioxazin, and S-metolachlor were found to increase the STS of the hybrid bermudagrass in the later year 2017.

Sod Netting

Netting is both a noun, referring to a netting product, and it is also a verb, referring to the process of applying the netting product to the sod. Netting collectively is one of the techniques used in the turfgrass sod production industry to improve sod forming ability (Christians et al., 2016). Three methods of applying netting involve incorporating nylon netting 1) below the soil surface or 2) on the surface of the seeded sod field. As the turfgrass plants mature, the vegetative growth intermingles with the net forming a sturdy and uniform sod. Netting is a useful tool in sod production for the species that have inadequate sod tensile strength for handling due to the growth habit (Christians et al., 2016). An additional method of using netting is its 3) incorporation mechanically on to the under surface of the big rolls of sod during harvest to provide additional strength and stability to the heavy pieces of sod. Plastic mesh (Burns, 1980), nylon netting (Carrow and Sills, 1980; McCalla et al., 2008) and recently biodegradable netting (Nedia Enterprises, 2018) have been in use in sod netting. One method of manufacture of biodegradable netting is to make it out of all natural jute fibers which are completely degradable without being exposed to UV; however, the effectiveness of this new method in sod production is not known and requires research.

Sod netting improves the sod handling characteristics of the turfgrass and shortens the time required for harvesting (Christians et al., 2016). Shorter growing cycle reduces the need of irrigation, chemical applications and maintenance per crop is reduced and sod crop could be harvested more often. Consequently, reduces the need of water a valuable resource and cut off the potential adverse environmental impacts from the use of chemicals (herbicides, pesticides), fertilizers, and diesel exhaust (Reisetter, 2001). However, netting is a highly specialized and expensive procedure and is difficult to use (Decker, 1991). Tall fescue plots with netting exhibited five to six-fold increase in sod strength as compared to the control (non-netted) plot and handling of the sod established with netting was much easier than sod established without netting (Carrow et al., 1981). McCalla et al. (2008) reported that sod netting had a significant effect on the percentage harvestable sod and STS of seeded 'Riviera' bermudagrass sod and it can be used when establishing seeded bermudagrass types to produce reliable sod in less time (McCalla et al., 2008). A study was conducted to test the effectiveness of different types of sod reinforcement methods including plastic mesh and strings. The experiment consisted of four treatments: a monofilament nylon fishline, stranded plastic string, strips of plastic mesh and the control with no reinforcement on the sod of centipedegrass. Results showed that plastic mesh was a good method of sod reinforcement for the rhizomatous and stoloniferous warm season grasses. The plastic mesh anchored well with the sod consequently increasing the sod tensile strength of the centipede grass. The other treatments did not significantly increase the STS (Parish et al., 1991).

Sod Tensile Strength Measuring Devices

Researchers have used several custom designed devices to measure the sod tensile strength. Rieke et al. (1968) developed one of the first devices to measure STS. This device had two platforms: one static, one mobile. Design of the device was such that first half of the sod was clamped to the static platform and second half to the mobile platform. Mobile platform was attached to a metal container through a cable. Sand was added constantly to the metal container to generate uniformly increasing stress and sod strength was measured as the weight (in kg) required to tear apart the sod piece (40 cm wide). After its invention, modification of the initial design to measure the sod tensile strength have occurred. A device was used to measure the sod strength and called it a 'sod stretching device'. The device consisted of a immobile frame affixed with a mobile track driven by an electric-powered gear activator. A push/pull gauge scale attached to the mobile unit was set in motion and sod strength was measured as the force (in kg) required to break the sod (Goatley and Schmidt, 1991). Another device developed to measure the sod tensile strength was a simple and low-cost design by Parish (1995). This device was made of available components and could be operated by one person. It was constructed using a steel framework with expanded steel-mesh top, two clamp units, and a force measuring device. The mobile clamp unit at the front was used to stretch the sod and the stationary clamp unit at the back side was used to hold the other end of the sod piece. Horizontal displacement produced by the movable clamp caused the sod to stretch and a common torque wrench measured the force (Parish, 1995). Sorochan et al., (1999) built a device to measure sod strength at the Hancock Turfgrass Center, Michigan State University which consisted of hydraulic pulling mechanism to stretch the piece of sod and a digital load cell to measure the point at which the sod piece broke (Sorochan et al., 1999). Han (2009) developed a device to measure sod tensile strength at Oklahoma State University. The device was based upon design principles used by Rieke et al. (1968) and Sorochan et al. (1999); with modification in the position of the table. The table was mounted vertically instead of in the horizontal in order to align the force vectors exerted by the linear actuator on sod shearing and the force of gravity. Dimensions of the STS device were 147cm x 53cm x 97cm (height x width x depth) and weighed 65 kg (excluding the battery). The device had two plates: one upper and one lower. The upper plate was stationary while the lower plate was mobile. The sod pad was clamped in such a way that it was in contact with both of the plates. Upward pulling of the upper plate caused the sod pad to break. The peak force required to tear the sod pad was measured by a digital force meter (Chatillon brand, digital force instrument, Model DFIS, John Chatillon & Sons, Inc., Greensboro, NC) and the values obtained were converted into peak force per cross sectional area (kg dm^{-2}) using the width and depth measurements of the sod pads. This study has been conducted using this device.

Problem Statement

High quality sod is of great importance in commercial sod production. A high quality sod has the characteristics such as good appearance, quick establishment and ability to handle easily during installing and harvesting. Rhizomes, stolons, and knitting of roots together with soil results in sod strength (Emmons, 2015). Turfgrasses with weak sod strength has tendency of falling apart during handling and/or transporting resulting in poor quality sod. Adequate sod strength for handling is one of the characteristics of high quality turf (Beard and Rieke, 1969). The bermudagrass cultivar Midlawn was discontinued from the sod farms due to its poor handling quality and sod strength. Midlawn a hybrid bermudagrass was tested in the in the 1986 National Turf Bermudagrass Evaluation test (Pair et al., 1994) and it performed very well and was consistently in the top ranking for its dark green color, texture and density of sod, overall turf quality compared to other turf bermudagrass cultivars, cold hardiness and resistance to spring dead spot disease. However, this cultivar did not perform well in the sod production industry following its commercialization. Sod producers discontinued this hybrid bermudagrass due to its poor handling quality. Several producers reported that Midlawn sod was not able to stay intact during rolling and/or transporting (D.L. Martin, personal communication, 2017). One sod production operation that did find success in Midlawn sod production limited their harvest method/stacking method to that of small slab, non-folded sod pads that were flat-stacked on pallets (D.L. Martin, personal communications, 2017). Turfgrasses with inadequate STS resulting damage to the sod during handling, transporting and planting can decrease the profitability of sod producers. Hence, good handling quality and STS play a very important role in commercial sod production. As mentioned above assessing sod handling quality on the basis of a numbered scale is very new method, only few researches have been conducted by using this method, any further research by using this method would be beneficial for the credibility of the method itself. Moreover, research on the sod production characteristics on the basis of the two traits, STS and SHQ, will serve as useful information to make decisions on the suitability of the lines under test for commercialization as well as to allow comparisons of the parameters STS and SHQ for further decision making of the breeders and end users in the future.

Objectives

Objectives of this research work were to assess the sod production characteristics of sod handling quality and sod tensile strength on i) ten cultivar entries at two harvest dates when grown under two mowing heights in the 2016 NTEP Seashore Paspalum Trial; ii) Twenty-nine entries at two harvest dates in the 2010 OSU Vegetative Bermudagrass Trial.

CHAPTER II

ASSESSING SOD PRODUCTION CHARACTERISTICS OF TEN SEASHORE PASPALUM LINES

Abstract: Seashore paspalum (*Paspalum vaginatum* Swartz) is a warm-season turfgrass with potential to be used on high saline/sodic soil areas of Oklahoma. Objectives of this research were to assess the sod handling quality (SHQ) and sod tensile strength (STS) of entries grown at two heights (2.5 cm and 7.6 cm) in the 2016 NTEP seashore paspalum Trial at Stillwater, OK. The trial was planted using plugs in July of 2016. The experimental field design was randomized complete block with split block arrangement of mowing heights. The trial was watered as needed to prevent drought stress, fertilized with 171 and 195 kg N ha^{-1} in 2016 and 2017, respectively. Sod was harvested on July and September of 2017 at 12 and 14 months after planting, respectively. To assess SHQ and STS two sod pads, each measuring 38 cm x 30.5 cm x 1.5 cm (length x width x depth), were cut from each replicate within each mowing height. SHQ of each entry was assessed on a 1 to 5 visual scale where 1= very poor SHQ and 5=excellent SHQ. STS was measured as the peak force required to cause sod pad tearing using a hand winch and force transducer/recorder system.

Date of harvest had a significant effect upon the SHQ as well as STS. The main entry effect was found to have a significant effect upon the SHQ but not on the STS although a significant entry x date effect was present. Mowing heights of 2.5 vs 7.6 cm did not produce a difference in small pad SHQ and STS. Average SHQ of the seashore paspalum entries ranged from 2.6 to 4.3. All entries except UGA Sr 14-1E could be harvested to produce transportable small sod pads suitable for commercial install at 12 and 14 months of age and at both mowing heights. At 12 MAP, the seashore paspalum entries exhibited mean STS values from a minimum of 55.3 kg dm^{-2} to a maximum of 137.3 kg dm^{-2}. All three commercial cultivars, 'Salam', 'Sea Isle 1' and 'Seastar', demonstrated an average SHQ rating equal to or greater than 4, the desired handling quality for commercialization of a cultivar. With respect to STS, all three commercial cultivars exhibited STS equal to or greater than values previously reported for 'Tifway' bermudagrass. The average SHQ and STS of entries were lower at 14 vs 12 MAP except for entry 'UGP 73' that had numerically greater STS at 14 MAP. Over all entries, the average SHQ at 12 MAP was greater than that at 14 MAP, 4.3 vs 3.5, respectively. Similar to SHQ, the overall average STS fell from 95.6 kg dm^{-2} at 12 MAP to 66.4 kg dm^{-2} at 14 MAP (T value = 9.1, $p = 0.05$). Additional research is needed to separate the effect of sod maturity versus possible negative impacts of harvesting sod late in the growing season after cool nights and short daylengths may have impacted seashore paspalum STS and SHQ.

Introduction

Seashore paspalum (*Paspalum vaginatum* Swartz.), also known as siltgrass, sand knotgrass, and saltwater couch (Christians et al., 2016), is a warm season perennial turfgrass found between 30-35 N-S latitudes in tropical to sub-tropical and warm temperate regions (Skerman and Riveros, 1990). Where adapted, it is popular with turfgrass producers and end-users because of its tolerance to a wide range of environments such as aquatic, semi-aquatic, moist and salt affected areas of coastal regions (Duncan and Carrow, 2000a; Skerman and Riveros, 1990). Seashore paspalum is commonly used on golf courses and athletic fields for its shade tolerance; however, in Florida and other coastal areas it is widely used in home lawns (Trenholm and Unruh, 2003).

Seashore paspalum is a dark green, rhizomatous and stoloniferous grass. The texture of individual genotypes ranges from coarse to fine with a pointed leaf tip (Christians et al., 2016). It has good density, can tolerate low mowing heights and requires less fertilization than bermudagrass (Duncan and Carrow, 2000a). It develops higher shoot densities at lower height of cuts and produces its finest turf at height of cuts below one inch (Duble, 2001). Seating, signage or other obstacles may shade areas of sports fields for extended periods of time. In these areas, bermudagrass frequently has poor density, lower recuperative potential and is less uniform, leading sports field managers to utilize seashore paspalum due to its improved shade tolerance. Seashore paspalum can tolerate multiple stresses such as salinity (Bingham, 1974; Dudeck and Peacock, 1985; Lee et al., 2004; Marcum and Murdoch, 1994; Raymer et al., 2008; Uddin et al., 2011), drought (Huang et al., 1997), low light or shade (Jiang et al., 2005; Jiang et al., 2004), and low soil aeration (Duncan and Carrow, 2000a).

Ecotypes of seashore paspalum have been found growing on coastal areas exposed to seawater containing total salinity of 54 dS m^{-1} or 34,400 mg L^{-1} (Duncan, 1997; Duncan and Carrow, 2000b). Two genotypes, ‘Sea Isle Supreme’ and ‘S99’ were reported to be the most salt tolerant turfgrasses among 15 entries (14 seashore paspalum and one ultra-dwarf bermudagrass) screened for salt tolerance at the University of Georgia. For performance traits of turf quality and total biomass, these two genotypes ranked in the top statistical group when a salt concentration of 40 dS m^{-1} (Raymer, 2006) was utilized for irrigation. SI 94-1 and SI 92 (ecotypes of Seashore paspalum) exhibited higher salinity tolerance than bermudagrass (Carrow and Duncan, 2004). Salinity tolerance varies among seashore paspalum cultivars, ecotypes and genotypes (Dudeck and Peacock, 1985; Lee et al., 2004; Raymer, 2006). 'Aloha' and 'Sea Dwarf' seashore paspalum were watered with three salinity levels (15,000, 30,000 and 45,000 mg NaCl L^{-1}) using hydroponics techniques. These cultivars did not produce differences in shoot or root lengths, fresh clipping weight, or dry matter weight at the lower salinity level of 15,000 mg NaCl L^{-1}. At 30,000 mg NaCl L^{-1} the traits examined declined considerably and at 45,000 mg NaCl L^{-1} the growth of grass was halted (Pessarakli and McMillan, 2014). Lee (2004), evaluated the relative salinity tolerance of 28 seashore paspalum and four hybrid bermudagrass cultivars by using a sea-salt solution (salinity ranging from 1.1 to 41.1 dS m^{-1}) in sand growing media conducted in a green house. Salinity tolerance was assessed on the basis of seven shoot growth parameters. Lee (2004) found most of the seashore paspalum cultivars were more salt tolerant than hybrid bermudagrass cultivars. Marcum and Murdoch (1994) found reduction in shoot growth and turf quality with increased salinity of six C_4 turfgrasses by using a solution culture containing five concentrations of NaCl: 1, 100, 200, 300 and 400 mM. Results showed seashore paspalum had higher shoot growth and turfgrass quality at all salinity levels compared to other turfgrasses.

When grown under conditions of 70 and 90% low light conditions, the seashore paspalum entries performed better than the hybrid bermudagrasses and, the seashore paspalum cultivar 'Sea Isle' was ranked as the top performer (Jiang et al., 2004). Under low light, relative higher levels of chlorophyll, total soluble protein content (SPC), water soluble carbohydrate content (WSC), and antioxidant enzyme activities of the grass species were the parameters contributing better tolerance (Jiang et al., 2005).

High quality sod is of great importance in commercial sod production. Adequate sod strength for handling is one of the characteristics of high quality turf (Beard and Rieke, 1969). Sod tensile strength (STS) is defined as the tensile strength allowing the sod to stay unbroken throughout the harvest, handling, transport, and installation practices (Giese et al., 1997). Turfgrass with poor STS generally will not hold together during sod harvesting, transporting, and planting procedures, consequently posing a risk of losses to sod producers and end users. The bermudagrass cultivar ‘Midlawn’ was reportedly discontinued from sod production by four of seven total licensed producers within 5 years of its initial licensure due to its poor handling quality and sod strength (D.L. Martin, personal communication, 2017). One of the first devices to measure the STS was developed at Michigan State University (Rieke et al., 1968). Since that time, many devices have been based upon the basic principles of the device developed by Rieke et al. (1968) with modified designs (Burns and Futral, 1980; Han, 2009; Jagschitz, 1980; John et al., 2008; Parish, 1995; Sorochan et al., 1999). Sod handling quality (SHQ) is the qualitative score that measures the ability of cut sod to remain intact during lifting and transporting to the site of use. Assessing SHQ on a numbered (from one to five) scale is a relatively new method, where a value of 1 represents unacceptable quality due to complete breakage and a value of 5 is excellent quality with no cracking of the sod pad being tested (Han, 2009). This method was used at Oklahoma State University in the screening and selection of hybrid bermudagrasses commercialized as ‘Patriot’ (Taliaferro et al., 2006), ‘Northbridge’ (Wu et al., 2013) and ‘Latitude 36’ (Wu et al., 2014).

Raymer et al. (2008) indicated that seashore paspalum was experiencing continued popularity globally as more people became aware of its adaptation and performance traits beneficial to end-users. In the United States, plantings of seashore paspalum has increased rapidly in areas with elevated soil salinity that exceeds the optimal growth environment for bermudagrass and other warm season turf grasses (Christians, 2007). Researchers have reported on the salinity tolerance (Lee et al., 2004a; Marcum and Murdoch, 1994; Pessarakli and McMillan, 2014; Raymer, 2006), drought tolerance (Huang et al., 1997), and disease resistance (Lv, et al., 2010; Raymer et al., 2008) but a thorough literature review revealed no peer review reports on the sod production characteristics of this turfgrass although anecdotal recommendations were provided by Duncan and Carrow (2000) for production procedures. Little to no research has been conducted on the sod production characteristics of sod handling quality (SHQ) and sod tensile strength (STS) of seashore paspalum (P. Raymer, personal communication, 2016). Improved varieties with excellent STS and SHQ are imperative for the development and possible commercialization of future turfgrass varieties. The objectives of this study were to assess sod production characteristics of ten entries in the 2016 NTEP Seashore Paspalum Trial grown at Stillwater, OK on the basis of sod handling quality and sod tensile strength at mowing heights of 2.5 cm and 7.6 cm.

Materials and Methods

Description of Research Site and Entries

This research was conducted at the Turfgrass Research Center at Oklahoma State University, Stillwater, OK. This work was conducted upon entries in the 2016 NTEP Seashore Paspalum Trial located in research block 22 West (Lat. 36.118838 N, Long. -97.103322 W). The trial had ten entries (Table 2.1) including seven experimental lines and three commercially available cultivars which were 'Salam', 'Sea Isle 1' and 'Seastar'. The soil type present was an Easpur loam (fine-loamy, mixed, thermic Fluventic Haplustolls) (USDA-NRCS, 2018).

Establishment

The field plot design was a randomized complete block design (RCBD) with three replications. The trial was planted using plugs measuring 3 cm in diameter in plots with dimensions 1.7 m by 2 m (width x length). The first replicate was planted on 6 July, with the second and third replicates planted 7 July 2016. Plots were closely monitored during establishment and hand-watered by hose as needed to promote establishment.

Cultural Management

The trial was maintained under conditions conducive to sod production. Following establishment, the study area was watered as needed to optimize growth and prevent wilting or drought stress. After the whole plots attained full cover, mowing strips were applied such that each plot was divided into sub-plots for simulating sod production conditions at two height of cut. The initial mowing height was 6 cm using a reel mower three times per week. In August 2016, sub plots were mowed using a reel mower at 2.5 cm and 6.4 cm, respectively, three times per week until growth slowed in fall when mowing was reduced to two and finally one time per week until frost after which mowing ceased. In 2017, mowing was performed using a walk behind mower at 2.5 cm and 7.6 cm up to three times per week in summer. The higher height of cut was raised from 6.4 cm in 2016 to 7.6 cm in 2017 due to the scalping of seashore paspalum entries.

The fertilization regime utilized was 171 kg N ha^{-1} and 195 kg N ha^{-1} in the years 2016 (July to September) and 2017 (April to September), respectively (Table 2.2). Soil available phosphorus and potassium indices exceeded our chosen sufficiency indices of 65 and 250 respectively using the Mehlich III method (Mehlich, 1984) so no additional applications of phosphorous and potassium were made following establishment. The trial was irrigated three times a week (10 minute each time) using overhead irrigation. In the year 2016, Oxadiazon (Ronstar® G, Bayer Environmental Science, NJ) was applied at a rate of 2.24 kg ha^{-1} in July and again in September for pre-emergent control of annual grasses and annual broadleaf weeds. Lambda-cyhalothrin (Scimitar® GC, Syngenta Crop Protection, Inc., NC) was applied at a rate of 0.14 kg ha^{-1} in the fall of 2016 to prevent infestation of fall army worms [*Spodoptera frugiperda* (J.E. Smith.)] and cut worms (*Agrotis ipsilon* Hufnagel). In the year 2017, Oxadiazon (Ronstar® G, Bayer Environmental Science, NJ) was applied at a rate of 2.24 kg ha^{-1} in April and again in September for pre-emergent control of annual grasses and annual broadleaf weeds. A tank mix of 2,4-D, mecoprop, dicamba (Strike 3 herbicide, Winfield Solutions, MN) was applied at the rate of 3.4 kg of formulated product ha^{-1} (1.07 kg 2,4-D; 0.29 kg mecoprop; 0.09 kg dicamba ha^{-1}) to attain control over winter annual broadleaf weeds. Lambda-cyhalothrin (Scimitar® GC, Syngenta Crop Protection, Inc., NC) was applied at a rate of 0.14 kg ha^{-1}in in the fall to prevent infestation of fall army worms and cut worms. Borders between and outside of the plots were sprayed with a glyphosate solution (Tomahawk 4 herbicide, United suppliers, Inc., IA) as needed to prevent contamination from adjacent plots during the whole study period.

Sod Harvest Methodology

To ensure optimum soil moisture, the plots were uniformly irrigated with supplemental hand-held hose irrigation one to three days prior to harvesting the sod. Irrigation with the in-ground sprinklers was discontinued during the harvest event. Sod pads were cut with a Ryan Junior sod cutter (Model 544844C, Textron, Racine, WI) affixed with a 30.5 cm wide blade. Two sod pads from each sub plots were assessed for SHQ and STS. Average values of the sub samples were calculated prior to being subject to analysis. Sod harvests were conducted at 12 and 14 months after planting (MAP) to assess the effects of degree of maturity on SHQ and STS. These two harvest dates were chosen because it was expected that the SHQ and STS would be suitable for harvest and that they would represent the expected amount of time to first harvest in a seashore paspalum sod production scenario. Two sod pads with dimensions 38 cm x 30.5 cm x 1.5 cm (length x width x depth) were harvested from each sub plot to assess SHQ and STS. For the 12 MAP harvest, the first and second replications were cut and tested for SHQ and STS on 21 July and the third replication was harvested and tested on 22 July 2017. For the 14 MAP harvest, the first and second replications were conducted on 22 Sept and the third replication was harvested on 23 Sept 2017.

Evaluating Sod Handling Quality (SHQ) and Sod Tensile Strength (STS)

Following cutting of the sod, the sod pads were lifted using two hands. The sod was suspended vertically by hand holding only one end of the sod pad and by rotating the wrists inward towards the body of the evaluator, given a rhythmic, gentle shake for three cycles. Sod Handling Quality (SHQ) was the assessed on each pad using the method of Han (2009) at Oklahoma State University. The scale used was 1 to 5, using whole number increments of 1 unit. The method of Han (2009) was chosen as it had been utilized successfully in the sod handling quality assessment for the OSU commercialized bermudagrass cultivars ‘Patriot’ (Taliaferro et al. 2006), ‘Latitude 36’ (Wu et al. 2014), and ‘Northbridge’ (Wu et al. 2013). The SHQ visual scale consisted of values ranging from 1 to 5, where:

1=completely breakage, inability to transport to sod tearing device (unacceptable quality), 2= substantial cracking, but still transportable to sod tearing device, 3= moderate cracking (the suggested minimum acceptable value for industry handling), 4= very mild cracking (the desired minimum rating for cultivar commercialization), and 5=no cracking or defect of product (excellent handling quality).

Sod tensile strength (STS) was measured using a device developed at Oklahoma State University in 2003 and described by Han (2009) with vertical mounted table. It was similar to the method of Rieke et al. (1968) and Sorochan et al. (1999) with modification in the position of table. The device measured 147 cm x 53 cm x 97 cm (height x width x depth) and weighed about 65 kg (excluding the battery). The device originally consisted of an electric powered actuator but due to some technical problem in the actuator, it was replaced with a manually operated hand winch. The actuator and the rotating hand winch caused upward pulling of the upper plate and this exerted a shearing force on the sod pad. The peak force required to tear the sod pad into two pieces was measured by a digital force meter (Chatillon brand, Digital Force Instrument, Model DFIS, John Chatillon & Sons, Inc., Greensboro, NC). Sod pads were loaded to the device and clamped between the vertical table and the upper and lower plates in such a way that one end of the sod pad is attached to the lower immobile plate and the other end to the mobile upper plate. After securing the plates the hand winch was rotated which caused the upward pulling of the upper plate causing the tearing of the sod pad. The peak force required to tear the sod pad into two pieces as measured by the digital force meter was recorded. For the assessment of next sod pad, the upper plate was lowered to it starting positions, the sod pad of the next sample was secured in place and the digital force meter was tared to zero before assessing STS. The peak force value obtained was then converted into peak force per cross sectional area (kg dm^{-2}) using the specific width and depth of the sod pads. This value reflected the force per cross sectional area and was recorded as the sod tensile strength of the entry using the method of Han (2009).

Post-Harvest Procedures

As the testing procedure for SHQ and STS proceeded through the study, sod pads were immediately returned to their respective plot and precise site of harvest. The harvested area was hand watered and monitored for stress within 2 hours of replacement of the sod pads. The 14 MAP harvest was conducted using the same methodology on a different part of the sub plots such that prior harvested pads were never harvested again and the post-harvest procedures were repeated.

Statistical Analysis

The analytical design for this experiment was a split block, split in time. Seashore paspalum entries were whole plots with mowing heights as subplots and sod harvest dates within entry x mowing height as the sub-sub plots. All statistical analysis was performed using SAS (v9.4, SAS Institute, Cary, NC). The General linear models procedure (PROC GLM) was used to conduct the analysis of variance (ANOVA) on SHQ and STS. The effects of entry, mowing height, and sampling date were treated as fixed effects with blocks as a random effect. Sampling date was treated as a relatively fixed effect since age of sod at harvest was expected to have a large effect on STS and SHQ based on trials conducted with bermudagrass in the past (Gopinath, 2015). Whenever, the main effects or interactive effects were found statistically significant at $p \leq 0.05$, mean separation tests were conducted on each factor using Fisher's Protected LSD test at $p=0.05$.

Results and Discussion

Sod Handling Quality (SHQ)

With respect to SHQ, the main effects of entry, block, and date were statistically significant but height had no influence on the sod handling quality of the seashore paspalum entries (Table 2.3). None of the interaction effects were significant for SHQ. For each main effect that was significant, a mean separation test was performed by using Fisher's LSD.

The average SHQ of the ten seashore paspalum entries (pooled over two harvest date) ranged from 2.6 to 4.3 (Table 2.4). The commercial standard Sea Isle 1 and the experimental line line UGA 1743 had the highest mean handling quality value of 4.3. The experimental line UGA Sr 14-1E had the lowest average SHQ with a value of 2.6 and it was statistically different than all other entries. A total of six entries including the three commercial standards Sea Isle 1, Salam and Sea Star and three experimental lines (UGA 1743, UGP 73 and UGA Sr-15-14) met the desired minimum rating for new cultivars targeted for commercialization (SHQ $\geq$ 4) as suggested by Han (2009). The commercial cultivars Sea Isle 1, Salam and Sea Star and the experimental lines UGA 1743, UGP 73, UGA Sr 15-14 and UGA Sr 15-15 were not significantly different from one another (Table 2.4). The experimental line UGA Sr 14-1E that provided the lowest SHQ (μ = 2.6), was statistically different from all other seashore paspalum entries. Its mean SHQ was also lower than the suggested minimum acceptable value for use in the commercial industry (SHQ $\geq$ 3) as suggested by Han (2009). All entries, except UGA Sr 14-1E, achieved the suggested minimum acceptable handling quality (SHQ $\geq$ 3) for use in industry. All three commercialized cultivars were statistically great in SHQ than the experimental lines UGA Hyb2 and UGA Sr 14-1E.

A highly significant date effect was present with respect to SHQ even though the date by entry interaction was not significant at the p= 0.05 level (Table 2.3). The overall average sod handling quality was reduced at 14 MAP. The overall average SHQ at 12 MAP and 14 MAP were 4.3 and 3.5, respectively (T value = 0.25, p=0.05).

Sod Tensile Strength (STS)

For STS, the main effect of date and the interactive effect of date by entry were statistically significant (Table 2.3). As with SHQ, mowing height did not produce any effect upon the STS of the entries. This result is consistent with the findings of Mitchell and Dickens (1979) and Hall (1980) in which mowing height did not produce any effects upon the bermudagrass cultivars ‘Tifway’ and ‘Tifgreen’ and tall fescue-Kentucky bluegrass sod.

At 12 MAP, the seashore paspalum entries exhibited mean STS values from a minimum of 55.3 kg dm^{-2} to a maximum of 137.3 kg dm^{-2} (Table 2.5). Experimental lines UGA 1743, and UGA Sr 14-1E had the highest and the lowest STS mean values, respectively. The three commercial standards, Salam, Sea Isle 1, and Sea Star did not differ in their STS at 12 MAP. The experimental line UGA 1743 had the highest numeric STS at 12 MAP and did not statistically differ from the Salam and Sea Isle 1 but had statistically higher STS than that of Sea Star. The entry UGA Sr 14-1E with the lowest mean STS value was in the lowest statistical group and was significantly different than all other entries in the trial. At 12 MAP all entries except UGA Sr 14-1E had greater numeric STS values than those reported for ‘Tifway’ bermudagrass (STS μ = 57.5 kg dm^{-2}) by Gopinath (2015) in the 2013 NTEP bermudagrass trial at Stillwater, OK. Han (2009) and Gopinath (2015) utilized Tifway as a commercial standard entry for suitable sod production characteristics in their bermudagrass sod production and testing trials.

Similar to the trend observed for SHQ of the seashore paspalum entries, the STS values of all entries except UGP 73 were reduced at 14 MAP as compared to 12 MAP. The overall average STS values fell from 95.6 kg dm^{-2} at 12 MAP to 66.4 kg dm^{-2} at 14 MAP (T value = 9.1. p=0.05). At 14 MAP, the seashore paspalum entries exhibited mean STS values from a minimum of 36.1 kg dm^{-2} to a maximum of 105.1 kg dm^{-2} (Table 2.5). Experimental lines UGA Sr 14-1E and UGP 73 had the lowest and the highest STS mean values respectively. At 14 MAP, UGP 73 was the only entry to have numerically higher STS as compared to its STS at 12 MAP (Table 2.5). UGP 73 had significantly greater STS at 14 MAP than all other entries in the trial. At 14 MAP, seven of 10 seashore paspalum entries provided numerically greater average STS than that reported for Tifway bermudagrass (STS μ = 57.5 kg dm^{-2}) by Gopinath (2015) in the 2013 NTEP bermudagrass trial at Stillwater, OK. The reason behind reduced sod tensile strength of the entries at 14 MAP compared to 12 MAP is not known. As per the author’s observation, the turfgrass canopy appeared to have more grain and was less compact and firm at 14 MAP. This could be the possible reason behind the reduction in the SHQ and STS values at 14 MAP harvest. However, the observation is entirely based on author's view and further investigation is needed.

Predictive Linear Relationship

A predictive linear relationship was developed between the overall mean sod handling quality and sod tensile strength data pooled over two harvest dates. The Pearson's correlation coefficient, r=0.94 at $p < 0.0001$, revealed a strong positive correlation between sod handling quality and sod tensile strength. The r^2 of this equation was found to be 0.89. This relatively high r^2 result is consistent with the findings of Gopinath (2015) that found an r^2 of 0.85 between these two parameters. In both of the studies a strong correlation was reported between sod handling quality and sod tensile strength. However, both of the studies were conducted upon bermudagrass. Sod handling quality (SHQ) was plotted on the x-axis and sod tensile strength (STS) was plotted on the y-axis. The predicted mean STS for SHQ =1 is not calculated, as the SHQ value of 1 represents complete breakage of the sod pad and inability to transport to sod tearing device, reflecting that a SHQ of 1 represents an STS of zero. Also, no entries under test in this experiment offered a SHQ value of 5, so the value was not included in the data set. However, the graph (Figure 2.1) includes the SHQ values from 1 to 5 for the visual display of the predicted equation line. The predicted mean STS as a function of SHQ for the values 2, 3, 4, and 5 are 23.6, 54.3, 84.0 and 115.7 respectively. It is noteworthy that the regression line does not pass through the origin (y=0, x=1). This is probably due to no observations for the handling quality value of 1 which corresponds to the STS value of zero. The data set contained a large number of higher SHQ and STS mean values. This should not be surprising since commercial entries in the trial which serve as standards are successful in commerce while experimental lines sponsored in the trial are believed to be advanced lines holding high probability of being commercialized contingent upon suitable performance for various traits monitored in the NTEP seashore paspalum trial.

Conclusions

There are currently no known seashore paspalum sod production enterprises in Oklahoma as of the close of the 2018 growing season (D.L. Martin, personal communication, 2018). However, seashore paspalum has potential to be used as a turfgrass in the high saline/sodic soil areas of Oklahoma if it displays suitable winter-hardiness and if the vegetative lines can be successfully produced as sod or sprigs within the region (D.L. Martin, personal communication, 2018). High overall sod quality is highly desired by the sod producers. High quality sod includes aesthetic qualities such as dark green color, high shoot density, purity, and low weed occurrence but also sod handling qualities, which allows for easier harvest and installation as well as decreasing the risk of economic losses. No work has thus far been published concerning investigations into the sod production characteristics of tensile strength and handling quality of seashore paspalum. Although outcomes are not available at this time, an effort is underway to test advanced experimental lines of seashore paspalum, developed at the University of Georgia, at two of five institutions cooperating in a USDA – SCRI funded multi-state warm-season turfgrass development effort (D.L. Martin, personal communication, 2018). This thesis report resulting from screening of SHQ and STS on entries in the 2016 NTEP Seashore Paspalum Trial is believed to be the first ever published report comparing these parameters among seashore paspalum at 12 and 14 months after planting. Based on finding of this research, suitable sod handling quality and sod tensile strength should be able to be obtained in Oklahoma at approximately 12 months after planting if suitable irrigation, fertilization, mowing and pest control are practiced using these or similar cultivars and at mowing heights of 2.5 cm to 7.6 cm.

The SHQ and STS methods used by Han (2009) and Gopinath (2015) appeared suitable for discerning SHQ and STS for commercial production and differentiating performance differences for these parameters among 10 entries in the 2016 NTEP Seashore Paspalum Trial at Stillwater, OK. The findings of this trial should help seashore paspalum breeders and developers make informed decisions concerning further trialing of these entries and perhaps commercialization decisions when coupled with knowledge of other performance parameters that were beyond the scope of this research.

With exception of UGA Sr 14-1E which had consistently lower SHQ and STS all entries in the 2016 NTEP Seashore Paspalum trial demonstrated overall good sod production characteristics. Apart from UGA Sr 14-1E, all entries had the suitable handling quality for industrial use, SHQ =3, and three experimental lines had the desired handling quality for cultivar commercialization, SHQ =4, as suggested by Han (2009). Results on the handling quality of the lines under test in this study would be useful for the breeders and developers for making informed decision on either further testing or considering for commercialization of the lines that demonstrated satisfactory handling qualities. With respect to STS all entries except UGA Sr 14-1E at both harvest events (12 MAP and 14 MAP) and UGA Hyb2 at the second harvest event at 14 MAP demonstrated mean STS values either comparable to or greater than Tifway bermudagrass, a standard cultivar for good sod production characteristics in the 2013 NTEP bermudagrass trial (STS μ = 57.4 kg dm^{-2}), in the study conducted by Gopinath, (2015). It is anticipated that the turfgrass stand is more matured at 14 MAP than 12 MAP and provide stronger sod with better handling quality. However, both SHQ and STS of the seashore paspalum entries were reduced at the later harvest (14 MAP). The reason for the reduced handling quality and tensile strength of the older product is not known and requires further investigation.

Very little work has been performed relating SHQ to STS. This trial found a strong positive correlation (Pearson's correlation coefficient, $r = 0.94$ at $p < 0.0001$) between the two traits of sod handling quality and sod tensile strength. This strong positive correlation is similar to that found by Han (2009) [r=0.89 and r= 0.73] and Gopinath (2015) [r=0.92].

Quality of sod is considered as one of the most important trait related to commercialization of a new cultivar; however, until Han (2009) there was no quantifiable means of determining sod handling quality. This study has shown that sod handling quality as defined by Han (2009) can be used as a reliable indicator of sod tensile strength. This can help sod producers and researchers quickly and reliably determine the ability of a cultivar to be used in the sod production industry without the need of cumbersome equipment used to measure sod tensile strength. However, as peer reviewers of journal manuscripts generally favor quantitative continuous measure of parameters, the author advises that the sod tensile strength parameter measured by repeatable mechanical means continue to be used in conjunction with the qualitative discontinuous scaled parameter of 1 to 5 as used by Han (2009), Gopinath (2015) and as in this work. The results of this research are based on only one year of data on sod harvest. Additional research is needed to determine the sod tensile strength and handling quality of these and other cultivars of seashore paspalum over time. This would allow for discover of the minimum amount of time needed for production of suitable handling quality as well as the time period for which handling quality remains in suitable condition. Additionally, more studies are required testing other lines soil conditions, environmental effects, and different management practices to determine reliability of these findings.

Table 2.1. Ten seashore paspalum entries in the 2016 NTEP Seashore Paspalum Trial tested for sod handling quality and sod tensile strength.

Entry Number	**Entry**	**Type of Entry**
1	Salam	Commercial cultivar
2	Sea Isle 1	Commercial cultivar
3	Sea Star	Commercial cultivar
4	UGA Hyb2	Experimental line
5	UGA 1743	Experimental line
6	UGA Sr 15-14	Experimental line
7	UGA Sr 14-1E	Experimental line
8	UGP 73	Experimental line
9	UGP 94	Experimental line
10	UGA Sr 15-15	Experimental line

Table 2.2. Fertilization schedule for the year 2016 and 2017.

Year	**Date**	**Fertilizer**	**Rate (Kg N ha^{-1})**
2016	7.07.2016	17-17-17	24.4
	7.22.2016	25-0-10	48.8
	8.16.2016	46-0-0	48.8
	9.16.2016	17-17-17	48.8
	4.18.2017	25-0-10	48.8
2017	5.16.2017	46-0-0	24.4
	6.01.2017	46-0-0	24.4
	6.20.2017	46-0-0	24.4
	8.18.2017	46-0-0	24.4
	9.01.2017	46-0-0	24.4

Table 2.3. Analysis of variance for sod handling quality (SHQ) and sod tensile strength (STS) of ten entries of seashore paspalum over two harvest dates.

Source	**DF**	**Mean Square**			
		SHQ	**P > F**	**STS**	**P > F**
Entry(E)	9	3.4	0.001	3613.7	0.08
Block(B)	2	4.4	0.01	3988.2	0.1
Error a	18				
Height(H)	1	0.5	0.5	37.7	0.1
Error b	2				
E*H	9	0.1	0.9	575.3	0.5
Error c	18				
Date(D)	1	19.2	0.001	25500.4	0.001
D*E	9	0.4	0.5	1423.9	0.02
D*H	1	0.8	0.2	474.1	0.3
D*E*H	9	0.3	0.7	415.6	0.6
Error d	40				

‡ Entry (E) represents the 10 seashore paspalum tested in this trial.
Block (B) represents the replications.
Height (H) represents the mowing heights (2.5 cm and 7.6 cm).
Date (D) represents the harvest dates (12 MAP and 14 MAP) of the sod.

Table 2.4. Mean sod handling quality (SHQ) of ten entries of seashore paspalum over two harvest dates.

Entry	**Sod Handling Quality † (SHQ) ‡ (1-5 scale)**
Sea Isle 1	4.3 a
UGA 1743	4.3 a
Salam	4.2 a
Sea Star	4.2 ab
UGP 73	4.2 a
UGA Sr 15-14	4.0 abc
UGA Sr 15-15	3.8 abc
UGP 94	3.6 bc
UGA Hyb2	3.5 c
UGA Sr 14-1E	2.6 d
LSD ¶ (p = 0.05)	0.56

† Sod was harvested in July 2017 and September 2107 by using a walk behind sod cutter (Model 544844C, Textron, Racine, WI) with 30.5 cm wide blade in three replications. Two sub samples from each of the two sub plots were taken per replicate. Sod pads had 30.5 cm width and 1.5 cm depth.
‡ Sod handling quality was assessed on a 1 to 5 visual scale where 1 = unacceptable quality, complete breakage of sod pad during handling; 2= fair, substantial cracking of sod during handling, not commercially recommended; 3 = good, moderate cracking, suggested minimum acceptable value for industry handling; 4 = minimal cracking, desired minimum rating for cultivar commercialization;5 = excellent, no cracking.
¶ Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at p = 0.05. Means were labeled using letters to designate statistical grouping before rounding to the tenths position.

Table 2.5. Mean sod tensile strength (STS) of ten seashore paspalum entries at 12 and 14 months after planting(MAP).

Entry	**Sod Tensile Strength (STS) † (kg dm^{-2}) ‡**	
	12 MAP	14 MAP
UGA 1743	137.3 a §	73.1 bc
Salam	115.9 ab	70.9 b
Sea Isle 1	106.6 abc	68.4 b
Sea Star	104.3 bc	69.9 b
UGA Sr 15-14	99.1 bc	66.1 b
UGA Sr 15-15	92.3 bc	51.8 bc
UGP 73	89.6 bc	105.1 a
UGP 94	78.6 cd	70.1 b
UGA Hyb2	77.1 cd	53.1 bc
UGA Sr 14-1E	55.3 d	36.1 c
LSD§ (p = 0.05)	31.9	27.9

† Sod was harvested in July 2017 and September 2107 by using a walk behind sod cutter (Model 544844C, Textron, Racine, WI) with 30.5 cm wide blade in three replications. Two sub samples from each of the two sub plots were taken per observation. Sod pads have 30.5 cm width and 1.5 cm depth.
‡Sod tensile strength reported in in kg dm^{-2} recorded as the peak force required to cause sod pad tearing using a hand winch and force transducer/recorder system (Model DFIS, John Chatillon & Sons, Inc., Greensboro, NC).
§ Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at p = 0.05. Means were labeled using letters to designate statistical grouping before rounding to the tenths position.

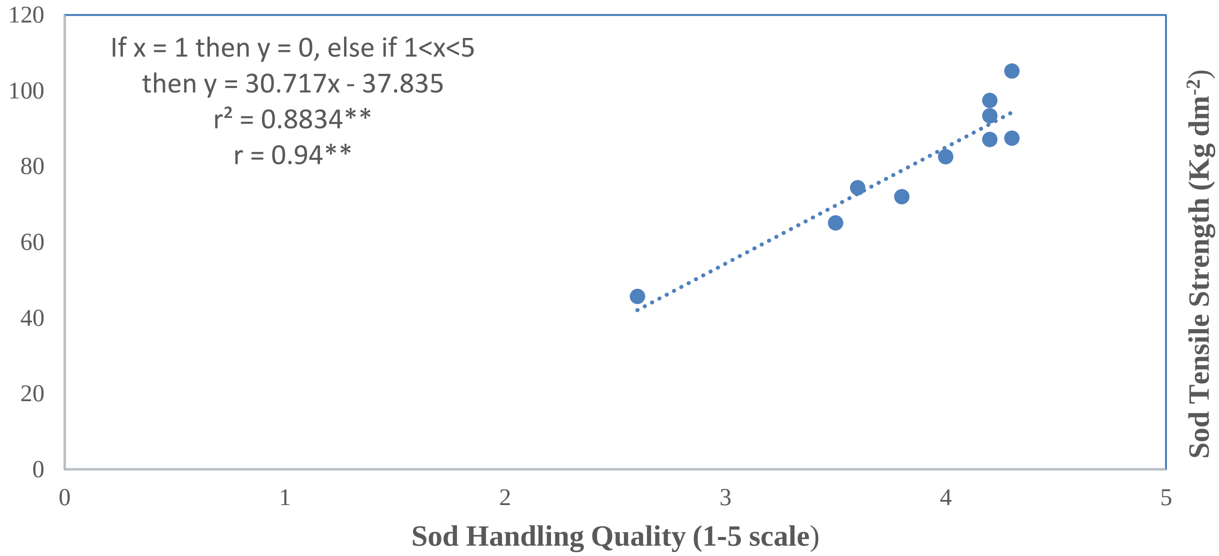

Figure 2.1: Predictive linear relationship between mean sod handling quality (SHQ) and mean sod tensile strength (STS) of ten entries of seashore paspalum pooled over two harvest dates. ** indicates significance at p = 0.01.

CHAPTER III

ASSESSING SOD PRODUCTION CHARACTERISTICS OF THE 2010 OSU VEGETATIVE BERMUDAGRASS TRIAL IN 2011 AND 2016

Abstract: Determining stability of sod production characteristics over time is important for the breeder and turfgrass development team to make decisions concerning advancement of experimental lines towards release and commercialization. The objectives of this research were to assess the sod tensile strength (STS) and handling quality (SHQ) of experimental bermudagrass lines at 14 and 72 months after planting. The entries consisted of 25 experimental lines plus four commercially available cultivars ‘Tifway’, ‘Patriot’, ‘Tifsport’, and ‘Midlawn’. The trial was planted at Stillwater on an Easpur loam using vegetative plugs in August 2010. The STS and SHQ were determined under simulated sod production conditions in the field. The trial was arranged in a randomized complete block design with three replications. The trial was watered as needed to prevent drought stress, fertilized with 195 kg N ha^{-1} yr^{-1} in 2016 and mowed at a height of 2.5 cm by a rotary type mower. Sod was harvested at 14 and 72 months after planting. To assess SHQ and STS two sod pads, each measuring 38 cm x 30.5 cm x 1.5 cm (length x width x depth), were cut from each replicate. The SHQ of each entry was assessed on a 1 to 5 visual scale where 1= very poor SHQ and 5=excellent SHQ. The STS was measured as the peak force per cross sectional area required to cause sod pad tearing. Analysis of variance (ANOVA) was performed on the dependent variables SHQ and STS with dates, overall entries and entry performance means within dates separated by LSD test. There were significant differences among entries in handling quality and tensile strength of the entries under test. The average SHQ and STS of the entries fell considerably by at 72 MAP suggesting that handling quality of the bermudagrass entries were not stable over the study period. The Pearson’s correlation coefficient for STSs and SHQs at 14 MAP and 72 MAP were calculated as r = 0.36 at $p = 0.0516$, and r= 0.48 at $p = 0.0077$ respectively. Sod handling quality of 22 bermudagrass entries at 14 MAP were either greater or equal to the desired handling quality for cultivar commercialization (SHQ = 4) whereas at 72 MAP, no entry had the acceptable handling quality for commercialization. At 14 MAP, 22 entries had STS values greater than ‘Tifway’, the standard for good sod production characteristics. At 72 MAP no entries had STS equal to the value of the standard Tifway. Additionally, a strong positive correlation was found between sod handling quality and sod tensile strength (r=0.73 at $p = 0.0001$ at 14 MAP and r=0.92 at $p = 0.0001$ at 72 MAP.) suggesting that sod handling quality as defined in prior published studies remains a broadly useful and reliable indicator of sod tensile strength for bermudagrass.

Introduction

Bermudagrass (*Cynodon* spp. [L.] Pers.) is a warm season, perennial turfgrass distributed globally between latitudes 45° N to 45° S. It is primarily adapted to tropical and sub-tropical climates (Duble, 2001; Taliaferro, 1995). The ability of bermudagrass to withstand extended periods of drought and survive under low maintenance conditions have made it a popular turfgrass choice (Christians et al., 2016). Bermudagrass can be grown across a wide area of the United States from the Gulf Coast region west to Oklahoma and as far North as Maryland along the Atlantic Coast. According to the 2012 Census of Agriculture conducted by the National Agricultural Statistical Service of the US Department of Agriculture, 386,504 acres were planted for use in sod production in the United States in 2012 (NASS, 2012).

Bermudagrass is theorized to be native to Africa and was introduced into the United States during the middle of the eighteenth century (Hanson, 1972). Bermudagrass was introduced to the western hemisphere as a forage grass but is currently used as a ground cover for home lawns, golf courses, sports fields, and soil stabilization along erosion sites such as roadsides and water ways (Dunn and Diesburg, 2004). Bermudagrass can be found on six continents and is known by the names of couch grass in Australia, kweekgrass in South Africa, gramilia in Argentina, devil's grass in India, and bermudagrass in the USA and other parts of the world (Duble, 2001). It is one of the most widely used turfgrass species in the transition zone and southern region of United States (Emmons and Rossi, 2015).

Cynodon spp. are a genus of grasses that are rhizomatous and stoloniferous with coarse to fine textured leaves and a fringe of hairs across the ligule, It grows in a prostrate growth habit via stolons to spread across the soil surface (Christians et al., 2016). The root system is fibrous with vigorous and deep rhizomes (Duble, 2001). The intergradation of stolons and rhizomes allows bermudagrass to form a tight sod when properly managed (Beard, 1973). Additionally, the production of rhizomes allows bermudagrass to grow back clonally after a sod harvest has been conducted without the need to re-establish with new sprigs or seed (Christians et al., 2016; Cockerham, 1988).

The genus *Cynodon* contains nine species and ten botanical varieties (Harlan et al., 1970). Among these, common bermudagrass [*Cynodon dactylon* (L.) Pers. var. *dactylon*], African bermudagrass (*Cynodon transvalensis* Burtt- Davy) and the interspecific hybrids of these two grasses are widely cultivated for turfgrass use (Emmons and Rossi, 2015; Taliaferro et al., 2004b). *Cynodon dactylon* has a lighter green color, increased internode length, coarse texture, a more vertical growth habit, and forms a less dense turf stand than interspecific hybrids of *C. dactylon* and *C. transvaalensis* (Emmons and Rossi, 2015; Taliaferro et al., 2004b).

Recommended mowing heights for bermudagrass can range from 0.5 inches to two inches with 0.5 to one inch considered most favorable for interspecific hybrids (Beard, 1973). For home lawn conditions, a mowing height of two inches under low maintenance programs is common (Beard, 1973; Emmons and Rossi, 2015). The prostrate growth habit and location of meristematic tissue allows bermudagrass to withstand a lower mowing height. As mowing heights decrease the root system becomes shallower (Guertal and Evans, 2006). Mowing puts the turfgrass plant into stress due to removal of the green tissues responsible for the photosynthesis. This reduces the plant's ability to produce carbohydrates needed for growth and development. The plant compensates for this loss by directing the carbohydrates to the shoots to acquire greater shoot density thereby decreasing rooting depth. In this course, roots are ignored causing less root mass and shallow roots (Christians et al., 2016). Rhizomes, stolons and roots along with the soil they are knitted together and are a functional component of sod strength. Only few studies have examined the effect of mowing height on sod strength. Mowing height had little to no effect on sod strength of 'Tifway' and 'Tifgreen' hybrid bermudagrass (Mitchell and Dickens, 1979) and Tall fescue-Kentucky bluegrass sod (Hall, 1980).

High temperatures, moderate to low rainfall and mild winters favor growth of bermudagrass. Daytime temperature between 95°F-100°F are optimal for rapid growth of bermudagrass. Soil temperatures greater than 65°F with an optimal temperature of 80°F are optimal for root development (Duble, 2001). Growth stops at 60°F and the plant begins to enter winter dormancy as temperatures approach 45°F to 50°F (7 °C – 10 °C); however, tolerance to lower temperatures differs significantly among cultivars (Emmons and Rossi, 2015).

Cynodon dactylon does not require high maintenance and can function well with frequent mowing, adequate moisture and moderate fertilization (Christians et al., 2016; Emmons and Rossi, 2015) and are well suited for the low to medium maintenance condition lawns. They also serve as a low growing ground cover for stabilizing the soil in low maintenance areas such as road sides, ditch banks, river sides, and dam sites. (Duble, 2001; Emmons and Rossi, 2015). *Cynodon dactylon* requires less nitrogen than hybrid varieties. Fertilization requirement depends upon the use of the turf. For example, tennis courts, bowling greens, and golf greens require higher nitrogen than sports field, lawns and golf course fairways while roadsides and other low maintenance areas can have very little to no fertilizer requirements (Duble, 2001). Higher use sites, such as tennis courts, require a higher nitrogen rate due to recovery requirements and high expectations of aesthetics by spectators and television viewership. Improved hybrid varieties serve in more specific areas such as golf greens, sports fields, tennis courts, and lawns where a higher quality product is desired and requires high maintenance (Duble, 2001; Emmons and Rossi, 2015). High maintenance lawn care requires vigorous cultural management; frequent mowing, vigorous fertilization regime, and other chemical applications to control the weeds, pests and disease are characteristics of a high maintenance turfgrass stand. Aggressive growth from stolons and rhizomes of bermudagrass can be problematic for flower beds and adjacent landscapes as it can invade them rapidly. Rapid growth can result in rapid thatch build up. Thatch is a layer of living plant materials intermingled with the dead and decaying plant materials such as leaves, roots, and stems that is formed in between the turfgrass plant and soil surface (Dunn and Diesburg, 2004). Thatch accumulates when the growth rate of newer tissue is faster than the decomposition rate of organic matter (Christians et al., 2016). This imbalance can be magnified when excessive nitrogen applications promotes tissue development and low pH limits microbial activity that aides in tissue decomposition Thatch is beneficial to the turfgrass stand as it provides cushioning to the surface, nutrients, and insulation to the turfgrass plants from extreme weather conditions; however, excessive thatch may be detrimental to the turfgrass plants as they may restrict nutrients, reduces water infiltration (Duble, 2001), creates a poor rooting medium for turfgrass plant and is favorable habitat for pathogens and insects harmful to turfgrass. (Christians et al., 2016).

Cynodon dactylon has superior drought resistance (Carrow, 1996; Kim et al., 1988; Poudel, 2010; Richardson et al., 2010; Severmutlu et al., 2011; Thapa, 2011; Yu, 2017). They have deep roots and are capable of surviving the extended periods of drought by going into dormancy (Beard, 1973). Unlike the superior drought resistance trait, it has poor tolerance to shade and cold (Beard, 1973; Emmons and Rossi, 2015). However, the drought resistance is not consistent for all bermudagrasses and is cultivar dependent.

Turfgrass maintenance depends upon the intended use requirements, the level of desired turf quality, and budget. Turfgrass sites such as bowling green, tennis courts, and putting greens can be considered high maintenance sites. These turfgrass sites require extensive care and a higher budget to exhibit the outstandingly well quality of turfgrass (Beard, 1973). There is always increased need of irrigation, fertilization, other chemical treatment (pesticides, fungicides and herbicides) along with regular cultivation practices of vertical mowing, aeration and top dressing (Emmons and Rossi, 2015). A high maintenance turfgrass site can require up to half pound of nitrogen per 1000 square feet weekly whereas the same amount of fertilizer is sufficient annually for low maintenance turfgrass site (Duble, 2001). Conversely, a low maintenance turf area can be defined as the one that can thrive under little to no care, cultural management practices, and are relatively inexpensive to maintain. Turfgrass sites along the sides of the roads, dam sites, ditch banks, airfields and other areas where the primary purpose of the turf is to provide low growing ground cover to stabilize the soil are grouped under the low maintenance turfgrass sites. These turfgrass sites can function well with adequate rainfall and infrequent mowing: two to three times annually (Duble, 2001; Emmons and Rossi, 2015). Most turfgrass maintenance programs fall under a moderate level of maintenance, requiring a medium to high intensity of common cultural practices to achieve the desired turfgrass quality. Golf course fairways, athletic fields, playgrounds, lawns, parks, and play grounds often receive moderate level maintenance program. A moderate maintenance program includes moderate fertilization, adequate moisture that prevent drought stress, and frequent mowing can keep bermudagrasses in this category in good shape (Duble, 2001; Emmons and Rossi, 2015).

Bermudagrass can survive under low maintenance conditions (Christians, 2011). Under a low maintenance regime, an open canopy, lower density, yet high quality turf-type bermudagrass would be more suitable for moderate maintenance lawns than high density materials that have found favor on sports fields, fairways and tee boxes would be in favor of the home lawn owners. Oklahoma State University's (OSU) bermudagrass breeding program has focused on golf course, fairways, tee boxes, and sports fields but not home lawns. Improved, fine-textured, hybrid bermudagrasses are commonly used in high maintenance turfgrass systems and less frequently as home lawns. Consequently, there is a continued need for consumer friendly bermudagrasses that functions well at a higher height of cut.

High quality turf is desired by the sod producers and end users. Adequate sod strength for handling is a characteristics of high quality turf (Beard and Rieke, 1969). Sod strength is defined as the adequate tensile strength allowing the sod to stay unbroken throughout the harvest handling, transport, and installation practices (Giese et al., 1997). Turfgrass with weak sod strength is not desired for commercial sod production as the sod has a higher risk of breaking during the process of cutting, transportation, and installation, which could result in losses to the turf producers or end users.

The strength of the sod must be high enough to facilitate the transportation, planting, and use of harvested sod pads without damage. Damage due to weak sod pads have the potential to cause significant economic harm to producers and consumers. Potential damage due to poor sod strength can even include degradation of sports field integrity under high traffic conditions. Factors found to have a significant influence on tensile strength include sugar content, stolon and rhizome thickness, and architecture (Lulli et al., 2011). Assessing SHQ on the basis of a numbered scale is a new method developed by Han (2009) to assess the handling quality of bermudagrass sod on the basis of a scale with values ranging from one to five, where: 1=completely breakage, inability to transport to sod tearing device (unacceptable quality), 2= substantial cracking, but still transportable to sod tearing device, 3= moderate cracking (this was the suggested minimum acceptable value for industry handling), 4= very mild cracking (this was the desired minimum rating for cultivar commercialization), and 5=no cracking or defect of product. Evaluation of germplasm for SHQ and STS is necessary to determine the ease of production for each bermudagrass entries. The objective of this research was to assess the sod production characteristics of the 2010 OSU vegetative bermudagrass sod tensile strength study entries on the basis of two traits: sod tensile strength and sod handling quality at two sampling dates (2011 and 2016).

Materials and Methods

Description of Research Site and Entries

The study was conducted at the Turfgrass Research Center at Oklahoma State University. The trial included bermudagrass entries from the 2010 OSU Vegetative Bermudagrass Sod Tensile Strength Trial located in South Block 25 West (Lat. 36.118366 N, Long. -97.103351W). The soil type present was an Easpur loam (Fine-loamy, mixed, superactive, thermic Fluventic Haplustolls) (USDA-NRCS, 2018).

The trial consisted of 29 entries arranged in a randomized complete block design with three replications. Twenty-five experimental lines were evaluated against each other and against the commercially available cultivars ‘Tifway’, ‘Patriot’, ‘Tifsport’, and ‘Midlawn’ that served as industry standards. In this trial Midlawn was used as a standard for poor sod tensile strength (STS) and poor sod handling quality (SHQ). This was based on observations in commercial sod production in Oklahoma plus prior sod production performance assessment by Han (2009). Tifway, Tifsport and Patriot were considered standards for suitable and high SHQ and STS. The trial was planted using plugs of the entries in August 2010 in plots that measured 1.98 m by 2.28 m (width x length). Two rows of two inch plugs, 0.6 m apart were planted at a distance of 0.3 m.

Cultural Management

The trial, planted in August 2010, received 146 kg N ha^{-1} yr^{-1} in 2010, 195 kg N ha^{-1} yr^{-1} in 2011 and 2012, 170 kg N ha^{-1} yr^{-1} in 2013 and 244 kg N ha^{-1} yr^{-1} in the years 2014 and 2015. Prior to 2016, the trial was mowed at 3.8 cm with a John Deere 2653 reel-type mower (John Deere & Company, Moline, IL) and irrigated four times a week in an amount to maximize growth and avoid bermudagrass wilting. In the year 2016, the trial received 195 kg N ha^{-1} yr^{-1} and was mowed three times a week at a height of 2.5

cm by a rotary type mower. The trial was irrigated three times a week to avoid drought stress and provide optimum conditions for growth. A tank mix of 2,4-D, MCPP and dicamba (Strike 3, Winfield Solutions, MN) and glyphosate (Tomahawk 4, Winfield Solutions, MN) was applied at 3.5 kg ha^{-1} and 1.7 kg ha^{-1}, respectively, in January 2016 to attain post emergence control of emerged winter grasses and broad leaves. Oxadiazon (Ronstar G, Bayer Environmental Science, NJ) was applied pre-emergence at 2.24 kg ha^{-1} in January and in May while pendimethalin was applied at 7 kg ha^{-1} in September of 2016 to acquire pre-emergence control of annual grasses and broadleaf weeds. In addition, insecticide Lambda-cyhalothrin (Scimitar GC, Syngenta Crop Protection, Inc., North Carolina) was applied at 0.14 kg ha^{-1} in fall to prevent an infestation of fall army worms [*Spodoptera frugiperda* (J.E. Smith.)] and black cutworms (*Agrotis ipsilon* Hufnagel). Borders were periodically sprayed with glyphosate solution to prevent bermudagrass intrusion from the adjacent plots.

Sod Harvest Methodology

Two sod harvests were conducted to evaluate the SHQ and STS of the bermudagrass entries in the trial. The first harvest was conducted in October 2011, 14 months after planting (MAP). The first replication was harvested on 25 October, 2011 and the second and third replications were harvested on 26 October, 2011. The second sod harvest was conducted in August 2016 at 72 MAP. One to three days prior to harvesting sod, plots were uniformly irrigated to ensure optimum soil moisture condition. Irrigation was halted throughout a single harvest event. For the second harvest event at 72 MAP, the first and second replications were harvested 16 Aug and the third replication was harvested 17 Aug 2016. Three sod pads from each plot were used in the 14 MAP assessment while two sod pads per plot were used in the 72 MAP assessment. All pads measured 38 cm x 30.5cm x 1.5 cm (length x width x depth) on both assessment dates. Sod pads were cut with a walk-behind sod cutter (Ryan Junior Model 544844C, Textron, Racine, WI) fitted with a 30.5 cm wide blade. Recorded values were averaged prior to data analysis.

Evaluating Sod Handling Quality (SHQ) and Sod Tensile Strength (STS)

Sod Handling Quality was assessed on the basis of a scale developed by Han (2009). The scale consisted of values ranging from one to five, where:

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

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

3= moderate cracking (the suggested minimum acceptable value for industry handling),

4= very mild cracking (the targeted minimum value for new cultivar commercialization) and

5=no cracking or defect of product (best handling quality and targeted desirable level of performance).

Sod tensile strength (STS) was measured using a device described by Han (2009). The device was based upon design principles used by Rieke et al. (1968) and Sorochan et al. (1999); with modification in the position of the table. The table was mounted vertically instead of in the horizontal in order to align the force vectors exerted by the linear actuator on sod shearing and the force of gravity. Dimensions of the STS device were 147cm x 53cm x 97cm (height x width x depth) and weighed 65 kg (excluding the battery). The device had two plates: one upper and one lower. The upper plate was stationary while the lower plate was mobile. The sod pad was clamped in such a way that it was in contact with both of the plates. The device originally consisted of an electric powered actuator; however, due to technical problems with the actuator, it was replaced with a manually operated hand winch. The rotation of the hand winch caused the upward pulling of upper plate up to cleave the sod pad into two pieces. The peak force required to tear the sod pad was measured by a digital force meter (Chatillon brand, digital force instrument, Model DFIS, John Chatillon & Sons, Inc., Greensboro, NC). Before each reading, the digital force meter was tared to zero. The value force necessary to shear the sod was next obtained and the values obtained were converted into peak force per cross sectional area (kg dm^{-2}) using the width and depth measurements of the sod pads. This value is the force per cross sectional area and recorded as the sod tensile strength of the entry (Han, 2009).

Post-Harvest Procedures

After testing for SHQ and STS in 2011, sod pads were carefully placed back into their respective original position following the harvest of 2011. This is because additional parameters were being monitored in this trial during the period 2011 – 2015. Those parameters are beyond the research scope of the focus of this study. Any loose sprigs were removed from the plots to avoid cross contamination in the trial. The harvested area was hand watered with the help of a hose. Plots were closely monitored for any signs of drought stress until the harvested sod pads completely rooted back.

Statistical Analysis

Analysis of variance (ANOVA) was conducted for the dependent variables SHQ and STS. The entry and harvest date were considered fixed effects. The main effects of block, cultivar, harvest date and their interactions were analyzed using PROC GLM. As entry, date and their interactive effect were all significant at $p \leq 0.05$, the overall means of the two dates and the cultivar performance means within dates were separated using Fisher's Protected LSD test at $p = 0.05$. Pearson's correlation coefficient was used to calculate the relationship between the variables, SHQ and STS, and between SHQ at 14 MAP and SHQ at 72 MAP and between STS at 14 MAP and STS at 72 MAP using PROC CORR in SAS (version 9.4, SAS Institute, Cary, NC).

Results and Discussion

This study examined the long term stability of two traits, SHQ and STS, of bermudagrass grown a fertility and irrigation regime commonly used for sod production, sports fields and intensively managed home lawns. Two sod harvests were performed on bermudagrass entries to determine their SHQ and STS. The first harvest was conducted in October 2011, 14 months after planting (MAP), and represents the timing of a typical first harvest from a production field planted the prior year. The second harvest was conducted in August 2016, 72 MAP, and was conducted to examine if the SHQ and STS of the entries were stable over an extended amount of time after planting. Results from this experiment in conjunction with the quantitative and qualitative visual parameters can be used for decision making concerning choices made in advancement of germplasm for further testing and/or possible release/commercialization.

For SHQ, the main effects of entry, date, and the interaction of entry and date were significant (Table 3.1). For STS, the main effects of entry, date, and interaction of entry x date and block x date were significant (Table 3.1).

Sod Handling Quality (SHQ)

As a significant entry by date interaction was present with respect to SHQ, entry means were separated within date by LSD test (Table 3.2). At 14 (MAP), the average sod handling quality values were between 1.1 to 5.0 (Table 3.2). Bermudagrass entries 7100E, 3200W-2006SN-8-6, 3200W-2006SN-57-7, 2008-1, 2008-3, 2008-4, 2008-5, 2008-7, 2008-9 and 7100E had excellent mean handling quality value of SHQ=5 as suggested by Han (2009). These 10 entries as well as the experimental entries 3200W-2006SN 42-11, 2008-2, 2008-6, 3200W-2006SN 15-11, 2008-8, 3200W-2006SN 56-1 and the standard cultivars Tifsport, Tifway and Patriot did not significantly differ in their SHQ at 14 MAP (Table 3.2).

Entry 3200W-2006SN 57-3 had the lowest handling quality (SHQ=1.1) and was not different from Midlawn (μ = 1.8) or 2008-10 (μ = 1.8) at 14 MAP. At 14 MAP a total of six entries including 3200W-2006SN 12-11, 3200W-2006SN 59-5 and 3200W-2006SN 49-12 and three standards did not met or exceed the suggested minimum rating of sod handling quality desired for industry use (SHQ = 3) as suggested by Han (2009). Three entries 2008-10, Midlawn and 3200W-2006SN 57-3 had unacceptable handling quality (SHQ < 2). The poor handling quality ratings demonstrated by the cultivar Midlawn in this trial was consistent with the finding of Han (2009). The standard entries Tifway and Patriot had excellent handling quality and this result was consistent with the findings of Gopinath (2015) in testing of the 2013 NTEP Bermudagrass Trial at Stillwater, OK.

The overall average handling quality drastically dropped from the first harvest to the second harvest. The overall mean SHQ of the bermudagrass entries during the first harvest event (at 14 MAP) in the year 2011 and at the second harvest event (at 72 MAP) in the year 2016 was 4.1 and 2.1 (T value = 2.0, p=0.05), respectively. A correlation analysis performed on the SHQ at 14 MAP and 72 MAP showed a weak positive correlation. The Pearson's correlation coefficient was calculated as r = 0.48 at $p = 0.0077$.

The mean handling quality of bermudagrass in this trial at 72 MAP was reduced relative to that at 14 MAP. The mean SHQ of the entries was between 1 and 3.7 (Table 3.2). At 72 MAP, no entries had a suitable SHQ score of 4.0 which has been suggested for new cultivar commercialization. Entry 2008-3 (μ = 3.7) had the highest mean handling quality which was lower than the desired minimum rating for cultivar commercialization as suggested by Han (2009). Five entries; 7100E, 2008-1, 2008-3, 2008-9 and Tifway had the suggested minimum acceptable value for industry handling of prior released cultivars (SHQ=3). Twelve entries had an SHQ value that was acceptable (SHQ $\geq$ 2.0) but not recommended for commercial use and the remaining twelve entries had handling quality below the recommended minimum score for commercial use (SHQ=1; Table 3.2). The drastic decline in SHQ from 14 to 72 MAP suggests that handling quality of the bermudagrass entries was not stable over the study period. Long-term evaluation of sod handling quality using sod harvesting intervals more consistent with industry practices is required in order to better understand the effect of SHQ over time. Not only is an understanding of when sod handling quality and tensile strength declines an important factor to understand from a sod production stand point, it is also useful in projection of the feasibility of movement of sod from one venue to another when cultivar replacement activities are undertaken, such as in a municipal park district when old cultivars are removed from one venue and transferred to another in order to accommodate new cultivars on the higher visibility venue.

Sod Tensile Strength (STS)

As ANOVA revealed a significant entry by date effect with respect to STS, entry means werer separated by Fisher's LSD method at $p = 0.05$ with means displayed in Table 3.1. At 14 MAP, mean STS of the bermudagrass entries ranged from 20.9 kg dm^{-2} to 113.9 kg dm^{-2} (Table 3.3). The highest mean STS was observed for the entry 3200W-2006SN 42-11 (μ = 113.9). Entries 7100 E, 2008-2, 2008-9 and the industrial standard Tifway were not different than the entry 3200W-2006SN 42-11. The lowest mean STS average was observed for the entry 3200W-2006SN 57-3 (μ = 20.9). The entries 3200W-2006SN 49-12, 3200W-2006SN 59-5, 3200W-2006SN 12-11, 2008-10 and Midlawn were not different than 3200W-2006SN 57-3.

In this trial, at 14 MAP, Tifway had a mean STS value of 88.3 kgdm^{-2}, which was higher than the overall STS value exhibited by Tifway (μ = 57.5) in the 2013 NTEP trial as reported by Gopinath (2015). Patriot (μ = 75.3) and Tifsport (μ = 70.3) showed a similar trend. The low ranking of sod tensile strength by Midlawn (μ = 32.4) in this trial was consistent with that found by Han (2009). Han (2009) suggested that an entry with a sod tensile strength similar to or less than Midlawn is not suitable for commercial sod production. Eight entries; 7100E, 3200W-2006SN 8-6, 3200W-2006SN 42-11, 2008-1, 2008-2, 2008-3, 2008-9 and Tifway, had a STS greater than 80 kg dm^{-2}. Eleven entries, 2008-5, 3200W-2006SN 33-6, 3200W-2006SN 15-11, Patriot, 2008-4, 2008-6, 2008-8, 2008-7, 3200W-2006SN 56-1, LCB 2007-4, and Tifsport provided STS values greater than 70 kg dm^{-2} at 14 MAP (Table 3.3). At 14 MAP in this trial, 23 out of 29 entries had STS values either close to or greater than Tifway in the 2013 NTEP bermudagrass trial. Gopinath (2015) considered Tifway as a standard for good sod production characteristics. Five entries 3200W-2006SN 49-12, 3200W-2006SN 59-5, 3200W-2006SN 12-11, 2008-10 and 3200W-2006SN 57-3 had STS lower than 40 kg dm^{-2} or close to the tensile strength provided by the cultivar Midlawn. The bermudagrass cultivar Midlawn was considered as the standard for poor sod production characteristics by Han (2009). Any bermudagrass turf that has STS equal to or less than Midlawn may not be suitable for traditional sod production methods that do not use supplemental techniques such as nylon netting to enhance the handling characteristics.

The mean STS dropped considerably from 14 MAP to 72 MAP. At 14 MAP, the average tensile strength of bermudagrass entries was 70.1 kg dm^{-2}. At 72 MAP, the overall mean STS decreased to 16.7 kg dm^{-2}. A correlation analysis performed on the STSs at 14 MAP and 72 MAP showed a weak positive correlation. The Pearson's correlation coefficient was calculated as r = 0.36 at p = 0.0516.

At 72 MAP the mean STS values ranged from 0 kg dm^{-2} to 51.2 kg dm^{-2}. Four entries (3200W-2006SN 33-6, 3200W-2006SN 56-1, 2008-6, and Midlawn) broke while loading to the STS device thus, not allowing testing of the sod pad for the STS. The highest average tensile strength was observed for the entry 2008-3. The entries 7100E, 3200W-2006SN 49-12 and Tifway were not different than 2008-3. At 72 MAP, no entries had mean STS value equal to the tensile strength of Tifway, which is considered an industry standard for good sod production characteristics as suggested by Gopinath (2015) and Han (2009). For most of the entries, lower STS that were either close to or less than Midlawn, were observed. Six years after planting, no entries provided sod strength close to that of the included industry standard Tifway as compared to the findings at 14 MAP. This was also demonstrated by the weak correlation coefficient (r = 0.36 at $p = 0.0516$) between the STSs at 14 MAP and 72 MAP.

Pearson's correlation coefficient was calculated for both of the harvest dates to determine the relationship between SHQ and STS within each harvest date. A strong positive correlation was found between SHQ and STS within each harvest date. At 14 MAP, Pearson's correlation coefficient was r=0.73 at $p = <0.0001$ and at 72 MAP the coefficient between SHQ and STS was r=0.92 at $p = < 0.0001$. These results were consistent with the findings of the studies conducted by Han (2009) (r=0.89 and r= 0.73) and Gopinath (2015) (r=0.92) in trials conducted upon bermudagrass.

Conclusions

High sod quality is desired by the sod production industry. High quality sod includes aesthetic qualities such as color, density, purity, and weed infestation but also sod handling qualities, which makes harvest and installation easier and decreases the risk of economic losses due to inferior product quality. The effects of numerous herbicides, nitrogen, and mowing (Brosnan et al., 2014; Dickens et al., 1989; Hall, 1980; McCullough et al., 2014; Mitchell and Dickens, 1979) on sod tensile strength have been evaluated; however, the quality of sod as a function of age in sod production stands had yet to be evaluated for bermudagrass tensile strength prior to this work.

At the first harvest at 14 MAP, which is similar to the common sod production practice the overall average handling quality of the bermudagrass entries was 4.1. Mean SHQ of the entries ranged from 1.1 to 5, with a substantial number of entries (22 out of 29) demonstrating handling quality either better or equal to the target rating for commercialization of the cultivar as suggested by Han (2009). Conversely, at the 72 MAP harvest the sod handling quality of the bermudagrass entries under test were greatly reduced. The overall average handling quality of the entries was 2.1 and at this point in in time, no entries had suitable handling quality for commercialization as suggested by Han (2009). The SHQ of bermudagrass entries ranged between 1 and 3.7.

Similar to the trend demonstrated by the bermudagrass entries with respect to SHQ, the STS of bermudagrass reduced considerably from 14 MAP to 72 MAP (STS = 70.1 kg dm^{-2} at 14 MAP and16.7 kg dm^{-2} at 72 MAP). At 14 MAP, most of the bermudagrass entries (22 out of 29) under test in this trial STS had good STS value. Their STS values were either equal to or better than Tifway bermudagrass, which is considered an industry standard for good sod production characteristics used in the studies by Gopinath (2015) and Han (2009). Conversely, at 72 MAP, no bermudagrass entries had such good average STS. Almost all entries (except 2008-3) had STS values that were near or less than the STS of Midlawn, which is considered an industry standard for poor sod production characteristics as suggested by Han (2009).

For the bermudagrass entries under test in this trial both SHQ and STS were not found to be stable over the extended period. Six years after planting, no entries provided sod strength close to that of the included industry standard Tifway as compared to the findings at 14 MAP. The SHQ and STS of entries were reduced considerably by the later harvest date of 72 MAP. As sod harvests were conducted only at 14 and 72 MAP in this study, additional research that more closely aligns with industry harvesting routines of annual sod harvesting are needed to determine the stability of SHQ and STS of the bermudagrass entries and the findings of this study. There are times when business over produce sod and it is believed that sod quality and harvestablity declines after certain amounts of time. Elucidation of the function of sod harvest suitability as a function of time may be helpful in estimating the likelihood of successful harvest if sod is left intact in the field past its generally expected suitability date for harvest.

Very little work has been performed relating SHQ to STS other than Han (2009) and Gopinath (2015). This study reported a strong positive correlation between sod handling quality and sod tensile strength (r=0.73 at *p*=<0.0001 at 14 MAP, and r=0.92 at *p*=<0.0001 at 72 MAP). The quality of sod is considered one of the most important features related to commercialization of a new cultivar; however, until Han (2009) there was no quantifiable means of determining sod handling quality. This study has shown that sod handling quality as defined by Han (2009) can be used as a reliable indicator of sod tensile strength for bermudagrass. This can help sod producers and researchers quickly and reliably determine the ability of a cultivar to be used in the sod production industry without the need of cumbersome equipment used to measure sod tensile strength. However, as peer reviewers of journal manuscripts generally favor quantitative continuous measure of parameters, the author advises that the sod tensile strength parameter measured by repeatable mechanical means continue to be used in conjunction with the qualitative discontinuous scaled parameter of 1 to 5 as used by Han (2009), Gopinath (2015) and as in this work. Finally, while an overall decline was found with STS and SHQ from 14 to 72 MAP, the author did not attempt to find the mechanism behind this decline and further research is needed to explain the decline in harvest performance traits.

Table 3.1. Analysis of variance for sod handling quality (SHQ) and sod tensile strength (STS) of twenty-nine entries of bermudagrass over two harvest dates.

Source	**DF**	**Mean Square**			
		SHQ	**P > F**	**STS**	**P > F**
Entry(E)	28	4.4	0.001	1386.3	0.001
Block(B)	2	1.3	0.08	248.1	0.4
Error a	46				
Date(D)	1	180.7	0.001	123973.4	0.001
E*D	28	1.7	0.001	740.0	0.001
Error b	28				

Table 3.2. Mean sod handling quality (SHQ) of twenty-nine entries of bermudagrass at 14 and 72 months after planting (MAP).

Entry	**Sod Handling Quality (1-5 scale) †**		**Times in top statistical group**
	14 MAP	**72 MAP**	
2008-4	5.0 a	2.0 bcdef	1
Tifsport	5.0 a	2.0 bcdef	0
3200W-2006SN 8-6	5.0 a	2.0 bcdef	0
3200W-2006SN 57-7	5.0 a	2.7 abcd	2
2008-1	5.0 a	3.2 abc	2
2008-3	5.0 a	3.7 a	2
2008-5	5.0 a	2.7 abcd	2
2008-7	5.0 a	2.0 bcdef	1
2008-9	5.0 a	3.2 abc	2
7100E	5.0 a	3.5 a	2
3200W-2006SN 42-11	4.9 ab	1.2 ef	0
2008-2	4.9 ab	2.7 abcd	2
2008-6	4.9 ab	1.0 f	1
Tifway	4.9 ab	3.3 ab	2
3200W-2006SN 15-11	4.8 abc	2 bcdef	0
2008-8	4.6 abc	2.5 abcde	2
Patriot	4.6 abc	2.8 abcd	2
3200W-2006SN 56-1	4.3 abc	1.0 f	0
LCB 2007-4	4.2 bc	1.7 def	0
3200W-2006SN 25-2	4.1 c	1.2 ef	0
3200W-2006SN 31-4	4.1 c	2.5 abcde	2
3200W-2006SN 33-6	4.0 c	1.2 ef	0
3200W-2006SN 49-11	3.2 d	1.5 def	0
3200W-2006SN 12-11	2.8 de	1.7 def	0
3200W-2006SN 59-5	2.8 de	1.8 cdef	0
3200W-2006SN 49-12	2.4 ef	2.3 abcdef	2
2008-10	1.8 fg	1.7 def	0
Midlawn	1.8 fg	1.0 f	0
3200W-2006SN 57-3	1.1 g	1.2 ef	0
LSD (p = 0.05)	0.7	1.4	

†Sod handling quality was assessed on a 1 to 5 visual scale where 1= unacceptable quality, complete breakage of sod pad during handling; 2= fair, substantial cracking of sod during handling, not commercially recommended; 3= good, moderate cracking, suggested minimum acceptable value for industry handling; 4= minimal cracking, desired minimum rating for cultivar commercialization;5= excellent, no cracking.
‡ Sod was harvested in October 2011 and August 2016 by using a walk behind sod cutter (Model 544844C, Textron, Racine, WI) with 30.5 cm wide blade in three replications. Sod pads have 30.5 cm width and 1.5 cm depth.
§ Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at $p \leq 0.05$ significance level. Means were labeled using letters to designate statistical grouping before rounding to the tenths position.

Table 3.3. Mean sod tensile strength (STS) of twenty-nine bermudagrass entries at 14 and 72 months after planting (MAP).

Entry	**Sod tensile strength† (kg dm^{-2}) ‡**		**Times in top statistical group**
	14 MAP	**72 MAP**	
3200W-2006SN 42-11	113.9 a	3.5 gh	1
7100E	109.5 ab	35.8 ab	2
2008-2	105.2 abc	27.3 bcde	1
2008-9	100.4 abcd	22.6 bcdefg	1
Tifway	88.3 abcde	34.9ab	2
2008-1	85.6 bcdef	28.5 bcd	0
3200W-2006SN 8-6	84.7 bcdef	16.3 bcdefgh	0
2008-3	84.2 bcdefg	51.2 a	1
2008-5	78.8 cdefgh	28.4 bcd	0
3200W-2006SN 33-6	78.3 defgh	0.0 h	0
3200W-2006SN 15-11	76.8 defgh	14.3 bcdefgh	0
Patriot	75.3 defgh	25.2 bcdef	0
2008-4	74.4 defgh	13.5 bcdefgh	0
2008-6	74.1 defgh	0.0 h	0
2008-8	71.7 efgh	19.4 bcdefgh	0
2008-7	71.6 efgh	18.4 bcdefgh	0
3200W-2006SN 56-1	71.3 efgh	0.0 h	0
LCB 2007-4	71.3 efgh	7.7 edefgh	0
Tifsport	70.3 efgh	17.8 bcdefgh	0
3200W-2006SN 57-7	69.0 efghi	14.9 bcdefgh	0
3200W-2006SN 31-4	60.2 fghij	19.7 bcdefgh	0
3200W-2006SN 25-2	57.8 ghijk	2.5 h	0
3200W-2006SN 49-11	56.8 hijk	6.9 defgh	0
3200W-2006SN 49-12	42.8 ijkl	29.3 abc	1
3200W-2006SN 59-5	38.5 jkl	18.5 bcdefgh	0
3200W-2006SN 12-11	38.1 jkl	10.0 cdefgh	0
Midlawn	32.4 kl	0.0 h	0
2008-10	31.2 kl	12.6 cdefgh	0
3200W-2006SN 57-3	20.9 l	6.0 efgh	0
LSD ($p = 0.05$)	26.6	22.2	

† Sod was harvested in October 2011 and August 2016 by using a walk behind sod cutter (Model 544844C, Textron, Racine, WI) with 30.5 cm wide blade in three replications.

‡Sod tensile strength reported in in kg dm^{-2} recorded as the peak force required to cause sod pad tearing using an electric powered actuator and force transducer/recorder system (Model DFIS, John Chatillon & Sons, Inc., Greensboro, NC).

§ Fisher's protected LSD test: within columns, means followed by the same letter are not significantly different at $p \leq 0.05$ significance level. Means were labeled using letters to designate statistical grouping before rounding to the tenths position.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Suitable sod handling quality and sod tensile strength are required of every turfgrass species if turfgrass varieties are to be grown for commercial sod sale. The goals of the research presented in Study I (Chapter II) of this thesis were to assess the sod production characteristics (sod handling quality [SHQ] and sod tensile strength [STS]) of experimental 'seashore paspalum' entries (*Paspalum vaginatum* Swartz.) against commercial industry standards under mowing heights of 2.5 and 7.6 cm at 12 and 14 months after planting (MAP). The goals of the research covered in Study II (Chapter III) of this thesis were to determine the sod handling quality and sod tensile strength of experimental bermudagrass lines (*C. dactylon* (L.) Pers. *x C. transvaalensis* Burtt-Davy) versus commercial standards at 14 MAP and to determine the stability of the performance parameters over an extended time period up to 72 MAP.

To assess SHQ and STS two sod pads, each measuring 38 cm x 30.5 cm x 1.5 cm (length x width x depth) were cut from each replicate. SHQ of each entry was assessed on a 1 to 5 visual scale where 1= very poor SHQ and 5=excellent SHQ. The STS was measured as the peak force required to cause sod pad tearing using a hand winch and force transducer/recorder system.

In the research presented in Chapter II of this thesis two sod pads were cut from each replicate within each mowing height (2.5 cm and 7.6 cm). For the research presented in Chapter III sod harvest was conducted as mentioned above.

The investigation discussed in Chapter II found that there were significant differences among the seashore paspalum entries in sod handling quality (SHQ). The date effect was also found to be significant. The mowing height effect was not found to exert any effect upon SHQ. All paspalum entries except 'UGA Sr 14-1E' could be harvested at 12 and 14 months of age and at both mowing heights to produce transportable small sod pads suitable for commercial install. With respect to the sod tensile strength (STS) of the ten seashore paspalum entries, the main effect of harvest date and the harvest date by entry interaction were statistically significant. The main effects of entry and mowing height did not produce any significant effect upon the STS of the seashore paspalum entries. The average SHQ and STS of seashore paspalum entries were lower at 14 than at 12 months after planting except for the entry ‘UGP 73’ that had numerically greater STS at 14 MAP. The reason for reduced handling quality and tensile strength of the older product is not known and requires further investigation. Mowing heights of 2.5 vs 7.6 cm did not produce a differences in small pad SHQ or STS, and additional sod production mowing heights should be investigated. The experiment should be repeated across both geographic locations and time to determine the stability of our findings.

The study discussed in Chapter III of this thesis examined the long term stability of SHQ and STS of bermudagrass grown at fertility and irrigation regimes commonly used for sod production, sports fields and intensively managed home lawns. Sod harvests were conducted at 14 and 72 MAP. For both SHQ and STS, the entry effect and date effect were significant. For SHQ, the main effects of entry, date, and the interaction of entry by date were significant. The average handling quality drastically dropped from first harvest to the second harvest. The overall average handling quality of the entries at 14 MAP and 72 MAP were 4.1 and 2.1 respectively on the 1 to 5 scale. With respect to STS, the main effects of entry, date, and interaction of entry by date and block by date were significant. Similar to the trend shown with respect to SHQ, the overall average STS of the bermudagrass entries was also reduced at the later harvest date at 72 MAP. The overall sod tensile strength of the bermudagrass entries at 14 MAP and 72 MAP were 70.1 kg dm^{-2} and 16.7 kg dm^{-2} respectively. For the bermudagrass entries under test in this trial (Chapter III), both SHQ and STS were not found to be stable over the extended period. Sod harvests were conducted only at 14 (typical to the common sod practice) and 72 MAP (atypical to the common sod production practice). Additional research that more closely aligns with industry harvesting routines of annual sod harvesting are needed to determine the stability of SHQ and STS of the bermudagrass entries and the findings of this study.

Both studies discussed in this thesis reported a strong positive correlation between the two sod production traits of SHQ and STS. In Chapter II covering work on seashore paspalum, a strong positive correlation ($r = 0.94$ at $p = 0.0001$) was found between STS and SHQ of the seashore paspalum entries. In the trial discussed in Chapter III, a strong positive correlation was found between sod handling quality and sod tensile strength of the hybrid bermudagrasses tested within each harvest dates ($r=0.73$ at $p=<0.0001$ at 14 MAP, and $r=0.92$ at $p=<0.0001$ at 72 MAP)

High quality sod includes aesthetic qualities such as dark green color, high shoot density, purity, and low weed occurrence but also sod handling qualities, which allows for easier harvest and installation as well as decreasing the risk of economic losses. No work has thus far been published concerning investigations into the sod production characteristics of tensile strength and handling quality of seashore paspalum. The findings of Study I (Chapter II) discussed in this thesis should help seashore paspalum breeders and developers make informed decisions concerning further trialing of these entries and perhaps commercialization decisions when coupled with knowledge of other performance parameters that were beyond the scope of this research. This study resulting from screening of SHQ and STS on entries in the 2016 NTEP Seashore Paspalum Trial is believed to be the first ever published report comparing these parameters among seashore paspalum at 12 and 14 months after planting. Based on finding of this research, suitable sod handling quality and sod tensile strength should be able to be obtained in Oklahoma at approximately 12 months after planting if suitable irrigation, fertilization, mowing and pest control are practiced using these or similar cultivars and at mowing heights of 2.5 cm to 7.6 cm. The average SHQ of the ten seashore paspalum entries (pooled over two harvest date) ranged from 2.6 to 4.3. The STS of seashore paspalum entries ranged from 55.3 kg dm^{-2} to a maximum of 137.3 kg dm^{-2} at 12 MAP whereas at 14 MAP the seashore paspalum entries had mean STS values from 36.1 kg dm^{-2} to 105.1 kg dm^{-2}.

It is anticipated that the turfgrass stand is more matured at 14 MAP than 12 MAP and this increased maturity was expected to provide stronger sod with better handling quality. However, both SHQ and STS of the seashore paspalum entries were reduced at the later harvest (14 MAP). The overall average SHQ values fell from 4.3 at 12 MAP to 3.5 at 14 MAP (T value = 0.25, *p*=0.05). The overall average STS values fell from 95.6 kg dm^{-2} at 12 MAP to 66.4 kg dm^{-2} at 14 MAP (T value = 9.1. *p*=0.05). The reason for the reduced handling quality and tensile strength of the older product is not known and requires further investigation.

Entry UGA Sr 14-1E had consistently poor SHQ and STS at both harvest dates. At 12 MAP, apart from UGA Sr 14-1E, all entries had the suitable handling quality for industrial use, SHQ =3, and three experimental lines had the desired handling quality for cultivar commercialization, SHQ =4. For STS, all entries except UGA Sr 14-1E at both harvest events (12 MAP and 14 MAP) and UGA Hyb2 at the second harvest event at 14 MAP had mean STS values either comparable to or greater than Tifway bermudagrass, a standard cultivar for good sod production characteristics.

In Trial II (Chapter III) of this thesis, a sod harvest was conducted at 14 MAP, which is similar to the harvest practice schedule in commercial sod production. The second harvest was conducted at 72 MAP, atypical to common sod production practice. However, the extended time period to the second harvest was undertaken to examine if SHQ and STS, were stable over such prolonged period in the field. For both SHQ and STS, the entry, date and the entry X date effects were significant. At 14 MAP, the overall average handling quality of the entries was 4.1. Mean SHQ of the entries ranged from 1.1 to 5, with a considerable number of entries (22 out of 29) demonstrating handling quality either better or equal to the target rating for commercialization of the cultivar (SHQ=4). Conversely, at 72 MAP the sod handling quality of the bermudagrass entries under test were greatly reduced. The overall average handling quality of the entries was 2.1 at 72 MAP. At this point in in time, no entries had suitable handling quality for commercialization.

Similar to the trend demonstrated by the bermudagrass entries with respect to SHQ, the overall average STS was reduced from 70.1 kg dm^{-2} at 14 MAP to 16.7 kg dm^{-2} at 72 MAP. At 14 MAP, STS of the entries ranged from 20.9 to 113.9 kg dm^{-2}. Most of the bermudagrass entries (22 out of 29) demonstrated STS values either equal to or better than 'Tifway' bermudagrass, which is considered an industry standard for good sod production characteristics used in previous studies. Conversely, at 72 MAP, no bermudagrass entries had average STS values even close to the STS of Tifway. All entries except 2008-3 demonstrated STS values that were near or less than the STS of 'Midlawn' at 72 MAP. Midlawn is considered a standard for poor sod handling quality and sod tensile strength. Results from this research suggested that the SHQ and STS of bermudagrass entries under test in this trial were not stable over the extended time period. The SHQ and STS of all entries were reduced considerably by the later harvest date of 72 MAP. However, as sod harvests were conducted only at 14 and 72 MAP in this study, additional research that more closely aligns with industry harvesting routines of annual sod harvesting are needed to determine the stability of SHQ and STS of the bermudagrass entries.

So far, very little work other than that previously conducted at Oklahoma State University has been performed relating SHQ to STS. Both studies in this thesis found a strong positive correlation between sod handling quality and sod tensile strength. These results were in line with the previous studies conducted at Oklahoma State University. In Study I (Chapter II) conducted on seashore paspalum, Pearson's correlation coefficient was $r = 0.94$ at $p < 0.0001$. In Study II (Chapter III) conducted on bermudagrass, Pearson's correlation coefficients were $r=0.73$ at $p=<0.0001$ at 14 months after planting (MAP) and $r=0.92$ at $p=<0.0001$ at 72 MAP.

The quality of sod is considered as one of the most important performance traits related to sod production. The methods of assessing SHQ and STS for commercial production and differentiating performance for these parameters among seashore paspalum entries and for assessing the quality of sod as a function of age in sod production for bermudagrass tensile strength has been demonstrated in this thesis.

The findings from both trials in this thesis support prior findings that assessing sod handling quality on a 1 to 5 scale (1= unacceptable, 5=excellent) is a useful and reliable method for determining relative sod tensile strength with respect to suitability for harvest. This qualitative method of assessment can help sod producers and researchers quickly and reliably determine the ability of a cultivar to be used in the sod production industry without the need of cumbersome equipment used to actually quantitatively measure sod tensile strength. However, as peer reviewers of journal manuscripts generally favor quantitative continuous measures of parameters, the author advises that the sod tensile strength parameter measured by repeatable mechanical means continue to be used in conjunction with the qualitative discontinuous scaled parameter of 1 to 5.

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