DEVELOPMENT OF IMPROVED TURF-TYPE

BERMUDAGRASSES

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CHAPTER I

INTRODUCTION TO DEVELOPMENT OF IMPROVED TURF-TYPE BERMUDAGRASSES

BERMUDAGRASS AS TURF

Worldwide, there are more than 10,000 species of grasses (Watson and Dallwitz, 1992). Grasses can be used for a number of purposes including turfgrass. By definition, "turfgrasses are plants that form a more or less continuous ground cover that persists under regular mowing and traffic" according to Turgeon (2006). Using this definition of turfgrass, there are less than 50 species of grasses which can be classified as turfgrasses. The growth habit of grasses is characterized by the method of spread. A bunch type grass is one which spreads exclusively by method of tillers and occasionally very short rhizomes. A grass can spread by lateral above ground stems called stolons or it may spread by below ground stems called rhizomes. As these horizontal stems spread, they can knit together to form a sod. Turgeon (2006) defines sod as the surface layer of turf harvested for transplanting, such that sod consists of the interconnected community of turfgrass plants, the soil adhering to their roots and the underground organs of the turf. Therefore, grasses which spread by rhizomes or stolons or both methods have at least two important advantages in the turf industry over bunch type grasses: re-growth from horizontal stems when the plants are injured, and favorable characteristics for use in the sod industry (Christians, 2004).

Selection of turfgrass species for a site is dependent upon many factors. Probably among the first criteria to consider would be the climate. Oklahoma is located within the U.S. transition zone (USDA cold-hardiness zones 6-7), a region where the temperate and subtropical climate zones converge (Cathey, 1990). The transition zone has been described as one in which it is very difficult to manage grasses. Winters in this area can have the potential to be too cold for warm-season grasses to persist as perennial stands, and summers in this region may place physiological stresses on cool-season grasses which make it difficult for them to survive (Christians, 2004).

Bermudagrasses (*Cynodon* species) are versatile and widely used as warm-season turfgrasses. Common bermudagrass (*C. dactylon* (L.) Pers. var. *dactylon*) is typically a tetraploid (2n=4x=36 chromosomes), and African bermudagrass (*C. transvaalensis* Burtt-Davy) a diploid (2n=2x=18 chromosomes) (Harlan et al., 1970). While African bermudagrass is not widely used as a turfgrass in the U.S., it and common bermudagrass can be crossed to form triploid (2n=3x=27 chromosomes) interspecific hybrid bermudagrasses. ‘Tiffine’ (Tifton 27) was among the first interspecific hybrids tested during the early 1950’s. However the releases of ‘Tifgreen’ (Tifton 328) in 1956 and ‘Tifway’ (Tifton 419) in 1960 were probably the most influential upon the turfgrass industry during early years of bermudagrass breeding and development (Burton, 1991).

Bermudagrass can be identified using a number of vegetative features. It has a narrow and continuous collar with hairs, a ligule with a fringe of hairs about one to three mm long and auricles are absent. The vernation of bermudagrass is folded, with the leaf blade being 1.5 to 4 mm wide. The growth habit of bermudagrass is stoloniferous and rhizomatous with uneven internodes (Christians, 2004).

Bermudagrass has many favorable turf characteristics which lead to its extensive use on lawns, athletic fields, and golf-courses. It is a long-lived perennial, aggressive in spreading ability, capable of forming sod, and tolerant of low mowing. Bermudagrass has the dynamic ability to withstand heat, drought, and traffic and has few damaging insect or disease problems when compared with other warm-season or cool-season grasses. It is best-adapted between 45 degrees north to 45 degrees south latitude in climates with humid to semi-arid growing conditions (Taliaferro et al., 2004).

Turf bermudagrass has recently been the subject of much attention from researchers and breeders. The United States Golf Association (USGA) (headquartered at Far Hills, NJ) has invested substantial financial resources into the improvement of bermudagrasses. Additionally, the National Turfgrass Evaluation Program (NTEP) (headquartered at Beltsville, MD), a private not-for-profit corporation, has coordinated extensive bermudagrass cultivar evaluation across the United States. For example, in the recently completed 2002-2006 NTEP bermudagrass trial, 42 entries (including 29 seeded and 13 clonally propagated bermudagrasses) were evaluated for various visual and functional characteristics. At Oklahoma State University (OSU), 7 additional local entries were included to improve the usefulness and impact of the trial. For a bermudagrass to be included in an official NTEP trial, entry fees have recently ranged from $8,000 to $10,000. The NTEP cooperators evaluate the bermudagrass entries for a series of visual characteristics which are rated throughout the growing season. More recently "ancillary" characteristics have been monitored at several test sites. These special evaluations have included performance features such as divot recovery rate, traffic tolerance, leaf firing resistance under drought, and tolerance to spring dead spot disease (Morris, 2007).

BERMUDAGRASS STUDIES AT OKLAHOMA STATE UNIVERSITY

At Oklahoma State University, the founding and formalization of the turfgrass program is generally attributed to Dr. Wayne Huffine. Dr. Huffine had initially worked with forage bermudagrasses, but he soon expanded his work to include turfgrass education and research. A report written by Dr. Huffine sheds more light on the history of the development of the turfgrass program. Turf research by Oklahoma Agricultural Experiment Station faculty began in 1948 with work conducted by Professor W.C. Elder. It was not until 1953 that Dr. Huffine began supervising the research (Huffine, 1955). Between 1963 and 1967 researchers from OSU conducted a comprehensive biosystematic study of the genus *Cynodon* (Harlan and de Wet, 1969, Harlan et al., 1970). Dr. Huffine, Dr. Jack R. Harlan, and Dr. Johannes Martenis Jacob de Wet were among the researchers who collected some 700 accessions from around the world during the 1950s and 1960s and revised the taxonomic classification of *Cynodon* based on their biosystematic study (Harlan and de Wet, 1969). After the world bermudagrass collection at OSU was established, Dr. Charles Taliaferro and Dr. Huffine continued expansion of the collection from materials throughout the southern midwestern U.S. (Brede et al., 1989). In the late 1960s and early 1970s research at OSU began to address the testing of seeded bermudagrasses for cold tolerance (Ahring and Irving, 1969; Ahring et al., 1975).

Dr. Charles Taliaferro of the Department of Plant and Soil Sciences carried on the program as his work expanded from developing forage grasses to selecting and breeding turf-type bermudagrasses. To expand the OSU collection, he made trips to China to acquire additional bermudagrass germplasm. U.S. Golf Association funding began in the mid-1980s to assist the turf bermudagrass development program at OSU (Taliaferro, et al, 2004). Emphasis on cold tolerant seeded types dominated the 1980s, then the additional goal of pursuing clonally-propagated cultivars began in the 1990s (Martin et al., 2007). Among Taliaferro's turfgrass contributions were seeded bermudagrasses such as 'Guymon' (GX59) which was a general purpose (pasture and forage) bermudagrass released in 1982 (Taliaferro et al., 1983) and issued a Plant Variety Protection (PVP) Certificate (PVP 8300171) in 1985 (Oklahoma Agriculture Experiment Station, 1985). Guymon was the first seeded bermudagrass with documented improved cold-tolerance as compared to 'Arizona Common' (Taliaferro et al., 1983). However, one of Dr. Doug Brede's accomplishments, 'Cheyenne' (CD-14) released by Jacklin Seed Company (5300 W. Riverbend Avenue, Post Falls, ID 83854) (awarded PVP 9000079 in 1996) is considered as the first turf-type seeded bermudagrass with improved cold-tolerance (J.R. Simplot Company, 1996). In 2005, PVP status was awarded to two more Oklahoma State University seeded bermudagrasses: 'Yukon' (OKS 91-11) (Taliaferro et al., 2003) granted PVP Certificate number 200100234 (Oklahoma Agriculture Experiment Station, 2005b), and 'Riviera' (OKS 95-1) released in 2001 (PVP 200300221) (Oklahoma Agriculture Experiment Station, 2005a). Yukon is frequently credited with being the first cold-tolerant seeded turf-type bermudagrass with highly improved visual characteristics. In addition, Taliaferro and researchers at OSU worked in conjunction with faculty at

Kansas State University and retired turfgrass breeder Dr. Ray Keen to jointly release 'Midlawn' (A-22) and 'Midfield' (E-29) hybrid bermudagrasses in 1991 (Pair et al., 1994a, 1994b). Midlawn (PP8,162) and Midfield (PP8,168) were each granted a U.S. Plant Patent (PP) in 1993 (Keen, 1993a, 1993b). In 2002, the OSU bermudagrass development program led by Taliaferro released 'Patriot' (OKC 18-4), a tetraploid (2n=4x=36 chromosomes) interspecific hybrid bermudagrass which was awarded U.S. Plant Patent (PP16,801) in July of 2006 (Taliaferro et al., 2006). Patriot is believed to have been the first turf-type tetraploid interspecific hybrid bermudagrass released to the trade.

Dr. Yanqi Wu first joined the OSU bermudagrass research team as a Doctoral candidate under the direction of Dr. Taliaferro in 2000. In 2006, Dr. Wu was selected for the Grass Breeding and Genetics faculty position in the Department of Plant and Soils Sciences at OSU and currently leads the bermudagrass development effort following the retirement of Dr. Taliaferro (Martin et al., 2007). Dr. Wu's contributions include describing genetic characteristics, conducting DNA fingerprinting, and testing fertility and crossability of new bermudagrass accessions he collected from China (Anderson and Wu, 2007; Wu et al., 2004, 2005, 2006a, 2006b). These new bermudagrass materials are being used for current and future breeding and development efforts at OSU.

The USGA sponsored research grants which were awarded to the OSU bermudagrass program focused on selection of grasses with improved cold tolerance, and increased Spring Dead Spot (SDS) disease resistance. Dr. Jeff A. Anderson has coordinated research testing for freeze tolerance of both forage (Anderson and Taliaferro, 1995) and turf (Anderson et al., 1988, 1993, 2002a) bermudagrass cultivars. Spring Dead

Spot (SDS) disease caused principally in Oklahoma by *Ophiosphaerella herpotricha* (Fr.:Fr.) J. C. Walker has been identified as a major concern in transition zone regions of the U.S. Researchers at OSU have been involved with various SDS studies in cooperation with other universities (Baird et al., 1998; Martin et al., 2001b, Tisserat et al., 2004). While some of the OSU plant pathology research projects have addressed attempts to control the disease, the breeding program has worked to test and select bermudagrass cultivars that are less susceptible to disease symptoms (Anderson et al., 2002b; Martin et al., 2001a). Recently, Dr. Nathan Walker has worked with the OSU bermudagrass research team to identify and test new techniques to study the behavior and process by which *O. herpotricha* infects bermudagrass. It is possible that these techniques may be able to facilitate more immediate screening of cultivars for resistance to SDS in a laboratory setting rather than relying solely upon data collected from multiple year field evaluations (Walker et al., 2008).

After the commercialization of Midlawn, which possessed improved cold hardiness and spring dead spot resistance (Pair et al., 1994b), but lacked acceptable sod tensile strength and handling quality, the latter were identified as key features in selecting a prospective commercially viable bermudagrass (D.L. Martin, Oklahoma State University, personal communication, 2004).

A recent concern among golf-course superintendents in Oklahoma is the ability of their newly renovated hybrid bermudagrass fairways to resist encroachment by previously used common bermudagrasses (D.L. Martin, Oklahoma State University, personal communication, 2005). This has opened up another new facet of turf research evaluations which underwent preliminary studies at OSU beginning in 2006 (Han et al., 2007).

SOD STRENGTH RESEARCH

Turfgrass cultivar development programs serve the turf industry through development of grasses that provide excellent visual and functional characteristics. Turfgrass performance parameters can include color, texture, density, cold-hardiness, disease and insect resistance, wear tolerance, and rapid injury recovery rate (Morris and Shearman, 2000). For a clonally-propagated bermudagrass to be successful in the market place, it must not only have the characteristics desired by the end user but also provide those valued by the sod producer. For the producer, these include suitable profit margins, production cycles, and sod handling characteristics.

Sod production is an impressive industry globally. An organization was created for the purpose "to represent and advance the turfgrass sod industry worldwide through the promotion of improved practices and the professional development of members and the enhancement of the environment" (Turfgrass Producers International, 2008). This organization was established in 1967 by 40 individuals who saw the benefits of such a network to their industry. Originally founded under the name "American Sod Producers Association," they later changed their name to "Turfgrass Producers International" in 1994. At that time, the organization had grown to include a membership of 932 companies spread over 35 countries (Turfgrass Producers International, 2008). Based on the findings of a Gallup Survey, TPI reported that more than 4 million American homes had purchased sod in the year 1996, for a sales volume of $460 million (Christians, 2004). In the 2002 U.S. Departments of Commerce and Agriculture Census of Agriculture, the sod industry had a 25% increase in production over a 5 year period. Annual sales by turfgrass sod producers are now in excess of one billion dollars (Turfgrass Producers International, 2008).

Presumably any bermudagrass can be propagated by plugs or sprigs but sod producers also need a bermudagrass to have suitable sod harvest and handling characteristics. Bermudagrasses such as ‘Midiron’ and Midlawn offer cold hardiness (Anderson et al., 1993), spring dead spot resistance (Baird et al., 1998; Morris, 1997), and respectable overall visual quality among other suitable performance characteristics. Despite this, these cultivars have nearly disappeared from the marketplace since their commercial release. In Oklahoma, Midiron was found to have poor sod strength by several sod producers (Rick Nelson; Tulsa Turf, LLC; personal communication, 1997). Telephone interviews surveying five of six (83%) licensed producers that abandoned production of Midlawn indicated that these former producers did so, at least in part, based on unsatisfactory sod handling characteristics. A specific complaint was Midlawn’s frequent tendency to break apart while being rolled, stacked and/or transported (D.L. Martin, Oklahoma State University, unpublished, 2004).

Two additional sod strength harvest methods include sod “slabbing” and the use of nylon netting. The use of nylon netting can be beneficial to reduce time from planting to harvest and strengthen sod grown from seed (Beard et al., 1980; Carrow and Sills, 1980; McCalla et al., 2008). Sod slabbing is the cutting and stacking of sod into simple squares without rolling. Slabbing eliminates the need for nylon netting to assist in maintenance of sod roll integrity. However, these methods are not preferred in some situations. Nylon netting can add additional harvest expense and is not tolerable in some landscape and sports turf applications. Slabbing alone limits the producer to a single harvest method and assures substantial hand installation labor will also be required.

A Historical Perspective on Sod Strength Research

Rieke et al. (1968) from Michigan State University provided the earliest description of sod strength testing research found in the literature. Rieke et. al. (1968) wrote an abstract summary report: “A technique to measure sod strength for use in sod production studies.” This report has been frequently cited in the literature. It is worth quoting to reveal the original terminologies and intent of this measuring device as it relates to sod production. The abstract stated:

> “In studying the effects of management practices on sod production an objective means for measuring sod strength has been needed. The extent of root and rhizome growth determines whether sod is ready to be harvested. A device was constructed to obtain an estimate of the contribution of roots and rhizomes to sod strength by determining the weight required to tear a piece of sod 40 cm wide. One-half of the sod piece is clamped on a stationary platform; the other portion on a portable platform which is attached by a cable to a metal container. Silica sand is added to the container at a constant rate to provide a uniform increase in stress. Sod strength is recorded as the weight required to tear the sod piece at the interface between the platforms. The sod must be cut at a uniform depth for consistent results. Good correlation was found between sod

strength measurements and root and rhizome weights as influenced by nitrogen treatments. In evaluation of selected species and varieties for sod production, consistent differences in sod strength were observed ranging from 15 to 40 kg. This technique provides a useful research tool for evaluating management factors in sod production."

Rieke et al. (1968) used the terms "sod strength" and "tear" to describe the process, and the observations were reported in kilograms (15 to 40) with a brief notation of the width (40 cm) and a comment stating that a uniform cutting depth should be used although the depth utilized in their work was not specified. This summary report set the precedent for future sod strength research. Since that early work from the 1960s, research methods and explanations for assessing measurements for sod strength have developed substantially over the years.

Influence of Cultural Management Factors on Sod Strength

Researchers have evaluated various turfgrass species to determine relationships between nitrogen fertility rates (Hall, 1980; Mitchell and Dickens, 1979), herbicide use (Sharpe et al., 1989; Turner et al., 1990), biostimulator use (Goatley and Schmidt, 1991), plant growth regulators (McCalla et al., 2008; Sorochan et al., 1999), root density (Rieke et al., 1968), rhizome density (Krans et al., 1992; Rieke et al., 1968), mowing height (Hall, 1980; Mitchell and Dickens, 1979), maturity of the turf stands (Sorochan, 1999), soil types (Sorochan, 1999), depth/thickness of sod cut (Heckman et al., 2001a; Rieke et al., 1968; Sorochan, 1999), species, cultivars, mixtures, and seed rates (Beard et al., 1980; Hall, 1980; Hall et al., 1985; Hurley and Skogley, 1975; Ross et al., 1991; Shildrick, 1982), netting use (Beard et al., 1980; Carrow and Sills, 1980), and spring green up (Krans et al., 1992) as they affected sod production and handling characteristics.

Designing Devices for Measuring Sod Strength

Many sod strength measuring devices patterned after the one described by Rieke et al. (1968) have been designed and utilized in research (Burns and Futral, 1980; Goatley and Schmidt, 1991; Hall, 1980; McCalla et al., 2008; Parish, 1995; Shildrick, 1982; Sorochan et al., 1999). These devices are a variation on a horizontal table, having one stationary platform to which one end of the sod is clamped, with the other end of the sod attached to a platform, actuated by some mechanical means. A horizontal force is applied to the sod at a uniform rate. Attached to the movable platform is a device which measures the peak force or weight applied to the sod.

Additional Methods for Measuring Sod Strength

Shildrick (1982) tested three methods to assess sod strength in hopes of identifying a less cumbersome method for measurement. He used the traditional method described by Rieke et al. (1968) as well as two alternatives, the penetrometer and shear vane methods. Shildrick (1982) found that neither the shear vane nor the penetrometer methods were desirable to assess sod characteristics without first performing more in depth research as to which sod features were actually being assessed. He concluded that the sod tearing devices (similar to what was traditionally used in the U.S.) were the preferred method of the three that he tested for quantitatively assessing sod strength; however, he also said the designs of the sod tearing device were bulky so it limited their portability.

Terminology Used in Sod Strength Research Methods

Discrepancies in the use of terminology defining the strength of sod pads are present within the literature. Shildrick (1982) used the term “tearing force” for defining sod strength and he referred to the device as a “tearing machine”. This description coincides with that used by researchers at Michigan State in the same decade in which they used “horizontal force applied” to “tear” a sod (Beard et al., 1980; Shildrick, 1982). The term “tearing strength” can be found even as recent as 1999 in summary reports from Michigan State (Sorochan et al., 1999). Recently, the term “sod tensile strength” (STS) has been used by sod researchers (Giese et al., 1997; Heckman et al., 2001b; McCalla et al., 2008; Mitchell and Dickens, 1979; Sharpe et al., 1989). Giese et al. (1997) and Heckman et al. (2001b) defined sod tensile strength as “resistance of sod to longitudinal stress measured by the minimum amount of longitudinal stress required to separate the sod.” However, McCalla et al. (2008) used the same term “sod tensile strength”, but they defined it differently. They stated: “The machine operates by initiating a lateral pull on an immobile pad of sod and recording the maximum shear force required to break an individual piece of sod.” These two definitions might sound somewhat similar, but in fact the phrases “resistance to a longitudinal stress” and “maximum shear force,” represents two different physical concepts. Tensile strength is “the resistance of a material to longitudinal stress, measured by the minimum amount of longitudinal stress required to rupture the material” (Dictionary.com Unabridged, 2008b). Tensile tearing resulted from positive direct stress pulling on an object [Figure 1a] such that the mode of failure was in a perpendicular plane to the direction of force (Derby et al., 1992; Smith, 1998). Shear stress was a sliding failure [Figure 1b] along the plane parallel to the applied force (Derby et al., 1992).

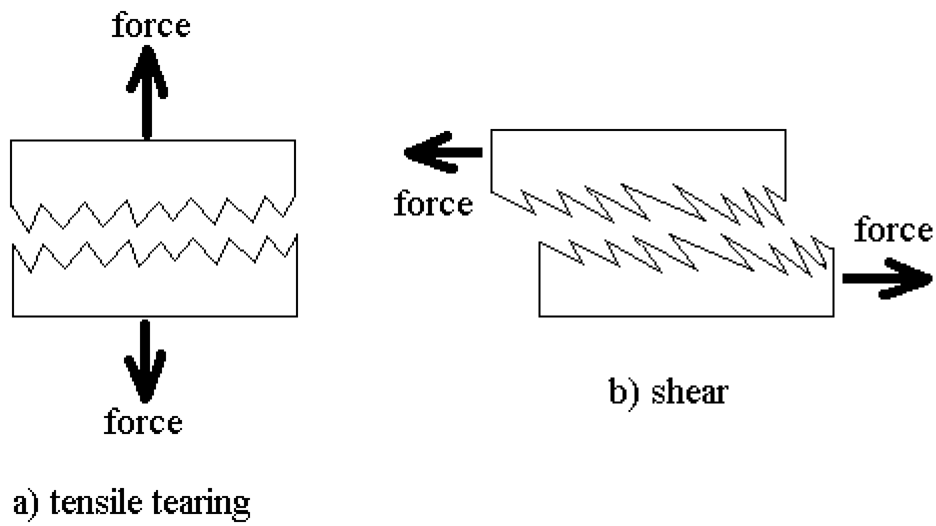

Figure 1. A visual depiction of the direction of failure of a material from a) tensile tearing and b) shear.

Also noteworthy in addressing terminology differences, McCalla et al. (2008) referred to their machine as a “sod stretching device” rather than continuing with the traditionally used term “tearing” machine. The terms “stretching” and “tearing” imply two different physical forces. Stretching is defined as “to lengthen, widen, or distend;” example “stretched the sweater out of shape” (American Heritage Dictionary of the English Language, 2004b). Stretching indicates an object is expanding in an outward direction, but does not indicate whether or not the object broke apart or just became distorted from its original shape. Tearing is defined as “to pull apart or into pieces by force” (American Heritage Dictionary of the English Language, 2004c).

In this report, “sod tensile strength testing device” or “sod tensile strength tearing machine” have been selected to specifically describe the instrument used based upon the machine and its function. This choice is consistent with the traditional terminology used for describing the methods employed within the sod research literature by Beard et al. (1980), Shildrick (1982) and Sorochan et al. (1999). Additionally, the term “sod tensile strength” will be used to describe the specific parameter which the “sod tearing device” measures. Within this research, the understanding of the definition of this term is in agreement with the wording chosen by researchers at the University of Nebraska (Giese et al., 1997; Heckman et al. 2001b). The term “sod strength” will be a more general and overall performance feature of the sod as it relates to usefulness in the sod production industry or consumer applications, rather than being assigned as the term for the specific testing method used. These definitions are consistent with the traditional expressions found in turfgrass sod research as well as the strictest physical science definitions of terms within this research discipline.

The term “breakage” will be used to describe the sod pad when it is in the “state of being broken” such that the sod pad is no longer one solid piece but has been completely torn into two separate pieces (Dictionary.com Unabridged, 2008a). The term “cracking” will be used to mean “to tear without complete separation of parts” and will describe the sod pads which experienced some degree of tension stress but did not rupture, break apart or separate completely during handling and transport (American Heritage Dictionary of the English Language, 2004a).

Defining a Standard for Commercial Acceptability of a Turfgrass Sod Pad

The literature has not reported a non-disputed, standard critical minimum value of sod tensile strength for a given turfgrass species. Minimum acceptable sod strength values were not given for bermudagrass research (McCalla et al., 2008; Mitchell and Dickens, 1979; Sharpe et al., 1989). While Giese et al. (1997) cited several examples that suggested acceptable sod strength values for Kentucky bluegrass (*Poa pratensis* L.), they did not find any suggestions for Buffalograss (*Buchloë dactyloides* (Nutt.) Englem.). Hall et al. (1985) reported that Kentucky bluegrass mean sod strength above 20 kg was commercially harvestable, while means below 20kg were only marginally harvestable. Beard et al. (1980) published findings for 45 cm wide Kentucky bluegrass sod harvested at 1.3 cm depth and suggested that values below 84 kg were unacceptable. Shildrick (1982) reported that the weakest 30.5 cm wide Kentucky bluegrass sod harvested at 1.0 cm depth with 34.3 kg of tensile strength was believed to be completely acceptable.

Units of Sod Strength Measurement

In early manuscripts, the peak weight which tore the sod was reported as the unit of measure for sod strength (Beard et al., 1980; Rieke et al., 1968; Shildrick, 1982). Previous research using a sod tearing device stated a critical minimum tensile strength in kilograms for acceptable sod and that value cannot be transferred from one experiment to another even for the same grass species. Shildrick (1982) reasoned that sod width differences accounted for the discrepancy in what was considered acceptable sod. Shildrick (1982) provided calculations of the sod strength which included the weight per width of sod pad concluding that his materials yielded a range of 1.56 to 1.12 kg cm^{-1} sod strength. When Shildrick (1982) calculated the sod strength value for the work by Beard et al. (1980), the yielded value of 1.87 kg cm^{-1} was the critical minimum standard, and sod less than that value was unacceptable as argued by Beard (1980). Shildrick (1982) still believed that his minimum sod strength was suitable, and concluded that there was still a sod depth factor to consider and that sod harvested at different widths might not be comparable on a length basis.

Heckman et al. (2001a) reported in a summary abstract that previous findings within the literature were not utilizing the defined physical science units for stress. They claimed that reports should use a measurement of force, in which values for the peak weight and the measured width and depth of the sod thickness are considered, so that data could be expressed in units that measure stress/strain such as kPa. Heckman et al. (2001a) also asserted the point which Shildrick (1982) had reasoned, that indeed a researcher must take into account the width and the depth of the sod to have a basis to compare sod tensile strengths to develop an industry standard. No published sod tensile strength research has thus far been reported in force units using kPa.

A New Method for Assessing Sod Pads

In much of the literature, it is unclear exactly how the individual researchers assigned their critical minimums for commercially acceptable sod tensile strength (Beard et al., 1980; Hall et al., 1985; Shildrick, 1982). It is reasonable that visual and/or physical handling of the sod pads in relation to an expectation may be necessary to determine this. Researchers from University of Nebraska-Lincoln made a clear statement of what sod tensile strength measurements should reflect: "Acceptable commercial sod tensile strength was defined as adequate tensile strength that allowed the sod to remain intact through harvest, handling, transport, and installation processes" (Giese et al., 1997). Sod producers are believed to rely upon a simple qualitative measurement of physical handling characteristics such as satisfactory or unsatisfactory when harvesting, transporting, and installing sod. Sod producers do not generally perform a quantitative assessment of sod strength. Consequently, there is not a minimum weight or force per unit area to use as a minimum acceptable standard. Sod producers use the appearance and feel of the sod as an assessment of usability. Based upon the quickness and ease of this type of an estimate, which requires no specialized equipment, such a ranked handling quality rating could be useful in simplifying tests for screening grass cultivars for acceptable sod strength. A critical minimum tensile force universally acceptable to the industry may not be necessary if a method of qualitative sod handling characteristics can be shown to be as or more useful than a quantitative tensile strength measurement.

THESIS OBJECTIVES

The research within this thesis includes various adaptive studies with turf selections from common bermudagrass (*Cynodon dactylon* L. Pers.) and interspecific hybrid bermudagrasses resulting from crosses of *Cynodon dactylon* (L.) Pers. x *Cynodon transvaalensis* Burtt-Davy. The objectives of this project were to i) compare the sod tensile strength and handling characteristics of four inter-specific hybrid bermudagrasses under simulated Oklahoma sod production conditions, ii) evaluate 34 clonal and 2 seed-propagated bermudagrasses for visual characteristics (establishment rate, living cover, spring green-up, shoot density, leaf texture, color, seedhead expression, scalping damage, fall color retention, and visual quality) and sod characteristics (sod tensile strength and sod handling quality) under simulated golf course fairway conditions, and iii) establish the relationship between sod tensile strength and handling quality.

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CHAPTER II

EVALUATION OF FOUR INTERSPECIFIC HYBRID TURF BERMUDAGRASSES FOR SOD HANDLING CHARACTERISTICS

ABSTRACT

To be successfully harvested as a sod crop, a turfgrass must have suitable sod handling characteristics. 'Patriot', 'OKC 70-18', 'Tifway' and 'Midlawn' hybrid bermudagrasses (*Cynodon dactylon* L. Pers. X *C. transvaalensis* Burtt-Davy) were evaluated for sod handling quality (SHQ) and sod tensile strength (STS). The SHQ was evaluated using a 1 to 5 scale with 1 = complete breakage during handling, not harvestable, 3 = moderate cracking, suggested minimum acceptable rating, and 5 = no cracking, excellent quality. Sod tensile strength was measured in kg dm^{-2} as the peak force required to tear the 30.5 cm wide by 1.5 cm thick sod pad. Five harvests (experiments) were conducted over 4 years. The SHQ strongly correlated with the STS (r=0.89, p=0.001). Patriot provided STS greater than or equal to Tifway on 4 of 5 harvests and greater SHQ on all 5 harvests. The STS and SHQ of OKC 70-18 were lower than that of Tifway in all 5 harvests. OKC 70-18 provided STS equal to Midlawn in 3 harvests and less than Midlawn in 2 harvests. The SHQ of OKC 70-18 was lower than that of Midlawn on 1 harvest, greater on 1 harvest and not different on 3 harvests. Results of this research correlate well with a telephone survey of licensed sod producers in that Patriot and Tifway have good sod handling characteristics while Midlawn has minimally acceptable to poor sod handling characteristics.

INTRODUCTION AND LITERATURE REVIEW

Even though turfgrass cultivar development programs have provided improved cultivars to the marketplace, a clonally-propagated bermudagrass will not be successful long-term in the marketplace, unless it has suitable profit margins, production cycles, and sod handling characteristics. While any bermudagrass can be propagated by plugs or sprigs, it is very common to establish bermudagrass by sod. Even when bermudagrasses such as ‘Midiron’ and ‘Midlawn’ offer improved cold hardiness (Anderson et al., 1993), spring dead spot resistance (Baird et al., 1998; Morris, 1997), and respectable overall visual quality and other suitable performance characteristics, these cultivars have nearly disappeared from the marketplace since their commercial release. Sod producers in Oklahoma found that Midiron had poor sod strength (Rick Nelson; Tulsa Turf, LLC; personal communication, 1997). When Dr. D.L. Martin surveyed licensed producers that abandoned production of Midlawn, five of six (83%) indicated that they did so at least in part based on unsatisfactory sod handling characteristics. Specifically, they complained that Midlawn frequently broke apart while being rolled, stacked, and/or transported (D.L. Martin, Oklahoma State University, unpublished, 2004). Sod can be netted or slabbed to improve its strength and handling characteristics. However, these installation methods require additional costs of materials and/or labor and they may not be desirable for some turf applications (Beard et al., 1980; Carrow and Sills, 1980; McCalla et al., 2008). Therefore, inherent favorable sod characteristics is highly desirable for a clonally propagated cultivar.

OBJECTIVES

The objectives of this research study were to i) compare the sod tensile strength and handling characteristics of ‘OKC 70-18’ and ‘Patriot’ relative to standards of Midlawn and ‘Tifway’ and to ii) establish the relationship between sod tensile strength and handling quality.

MATERIALS AND METHODS

Four Bermudagrass Cultivars to Evaluate for Sod Production

The OSU experimental line OKC 70-18 is a clonally-propagated interspecific hybrid bermudagrass (*C. dactylon* L. Pers. X *C. transvaalensis* Burtt-Davy) that demonstrated overall excellent performance in a 1997-2001 trial conducted under simulated golf course fairway conditions (D.L. Martin, Oklahoma State University, unpublished, 2001). OKC 70-18 ranked first in overall mean quality in the 2002-2006 NTEP bermudagrass trial at nine transition zone test sites (Morris, 2007). Performance of this cultivar appears to justify commercialization provided that it has suitable sod handling characteristics.

Patriot (OKC 18-4) is a 2002 release from the OSU bermudagrass development program that is now in production by six producers. Licensed producers have reported that Patriot has very good sod harvest/handling characteristics (D.L. Martin, Oklahoma State University, personal communication, 2005).

Midlawn bermudagrass has lost favor in commercial production due to its reported undesirable sod strength and handling characteristics. As such, Midlawn may prove to be a useful “standard” entry for research work testing sod strength. Any cultivar whose sod strength is not different than Midlawn can be considered undesirable for sod production using certain methods.

Tifway bermudagrass has been commercially sold and frequently used within the turf market place since its initial release by Dr. Glenn W. Burton in 1960 (Alderson and Sharp, 1994) from the USDA/ARS Georgia Coastal Plain Experiment Station (Burton, 1991). In the late 1970s, research was conducted on Tifway sod strength at Auburn University. The summary report indicated that Tifway provided satisfactory sod tensile strength and greater sod strength in all 3 years of tests than ‘Tifgreen’ (Mitchell and Dickens, 1979). Therefore Tifway should be an excellent standard entry for comparison such that any cultivar with equal or greater sod tensile strength than Tifway could be considered suitable for commercial sod production using traditional methods.

Planting Methods

Patriot, Tifway, Midlawn and OKC 70-18 bermudagrasses were sprigged on two planting sites within the Oklahoma Botanical Garden located 1.6 km west of Stillwater, OK (36° 07’ 06” N, 97° 06’ 10” W). Site 1 was sprigged on 27 August 2002 and Site 2 was sprigged on 2 June 2006. The soil was an Easpur silty clay loam (a fine-loamy, mixed, thermic Fluventic Haplustoll). Soil pH ranged from 6.9 to 7.7 during the study. Phosphorus (P) and potassium (K) soil levels were optimized at or above 73 and 281 kg ha^{-1}, respectively. One month prior to sprigging, on 30 July 2002, the Site 1 was treated with glyphosate at a rate of 5.61 kg ha^{-1} for general pre-plant post-emergent weed control. The plots were fallowed for one year prior to establishment to ensure they were free of contaminant bermudagrass. Plots were prepared to the dimensions of 1.37 x 2.44 m. On 27 Aug 2002 (Site 1) and on 2 June 2006 (Site 2) each plot was hand sprigged at a rate of 10.5 m^3 ha^{-1} (120 bu A^{-1}) using freshly harvested sprigs. The sprigs were placed in three furrows running east to west, parallel with direction of planned sod cutter pass with approximately 46 cm furrow spacing. The furrows were built up such that the final soil level in the furrow was raised approximately 2-3 cm to bury all except the top 1-2 cm of the sprigs, and the soil was closed around the plant materials. The sprigs were immediately irrigated to prevent desiccation. The four bermudagrass cultivars were replicated eight times in a randomized complete block design.

Post-Planting Trial Site Maintenance

Maintenance practices closely simulated those of sod production techniques utilized in Oklahoma. Following sprigging and harvest events, the trial area was fertilized at 73.2 kg N ha^{-1} to facilitate rapid establishment and grow-in. When fully covered, plots were maintained at 48.8 kg N ha^{-1} mo^{-1}. The plots were mowed at a 3.8 cm height of cut (clippings returned) 1 to 2 times wk^{-1} during the growing season with a reel-type mower. The trial area was irrigated as needed to maximize growth and avoid wilting of the turfgrass.

Pest Management Practices

The plots were treated with oxidiazon pre-emergent (PRE) herbicide for annual weed control, and were also managed preventative for grub control as needed throughout the course of the study. For planting Site 1, oxadiazon was applied PRE on 10 Sep 2002 to research plots at the rate of 3.36 kg ha^{-1}. On 14 Mar 2003 a combination of 2,4-D; mecoprop-p and dicamba were applied post-emergent (POST) at 0.67, 0.18, and 0.06 kg ha^{-1} for broadleaf weeds. Diquat dibromide was applied on 14 Mar 2003, 12 Mar 2004 and 8 Mar 2005 at the rate of 0.56 kg ha^{-1} for POST annual weedy grass control. On 31 Mar 2003 oxadiazon was applied at the rate of 3.36 kg ha^{-1}. A combination of 2,4-D at

0.56 kg ha^{-1}, mecoprop-p at 0.15 kg ha^{-1} and dicamba at 0.06 kg ha^{-1} were applied POST on 12 Mar 2004 to control broadleaf weeds. Triclopyr and clopyralid were applied POST for broadleaf weed control on 8 Mar 2005 at 0.63 and 0.21 kg ha^{-1} respectively. On 5 Aug 2005 imidacloprid was applied POST at 0.34 kg ha^{-1} to control grubs. Simazine was applied POST on 23 Nov 2005 at 1.12 kg ha^{-1} for annual weed control. In 2007, heavy rainfall and flooding interfered with effective use of chemical weed control methods. Subsequently, hand-weeding was practiced to remove non-bermudagrass plant species from the plots several times prior to harvest during that year. The hand-weeding was performed to ensure that all bermudagrass sod would have equal solid cover, free from weak spots that might affect the sod harvesting quality and tensile strength testing processes. On 6 Jun 2006 oxadiazon was applied PRE at time of sprigging using 2.24 kg ha^{-1} to the Site 2 trial area for annual weedy grass control.

In all years, 23 cm borders of bare soil were maintained using glyphosate as needed at 1.79 kg ha^{-1} between plots to control bermudagrass encroachment into the adjacent plots of another cultivar.

Sod Harvest Methodology and Evaluation

One to three days prior to harvest, the plots were uniformly irrigated as needed to moisten soil to facilitate harvest. Harvest date and days (d) since planting or last harvest were Site 1: 8 Aug 2003 (346), 20 July 2004 (357), 26 Sep 2006 (116) and 14 Aug 2007 (322) and at Site 2: 12 Oct 2006 (132), respectively. On each harvesting date, two passes (side by side) were conducted to cut sod in each plot using a walk behind sod cutter. The sod cutter blade was 30.5 cm wide with a 1.5 cm bench-setting for depth. At least ten randomly selected sod pads were measured at each harvest date for sod thickness and data were recorded to obtain a mean value for the sod thickness used in calculating tensile strength. The actual sod thickness (top of the soil to bottom of the soil) averaged 1.5 cm (range 1.3 cm to 1.9 cm among experiments). The sod pads were cut to a minimum length of 38 cm (range: 38 to 56 cm) with a sod knife. Three sub-samples per plot were then evaluated for SHQ and STS.

Sod Handling Quality Assessment

Sod handling quality was assessed during sod lifting and transporting to the tensile strength determination site. Sod handling quality was rated on a scale of one to five where the sod pad experienced:

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

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

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

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

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

Sod Tensile Strength Measurement

Sod tensile strength was assessed using a sod tensile strength testing device [Figure 2] built in the form of a table which operated using similar principles to the traditional model as originally described by researchers at Michigan State University (Rieke et al., 1968, Sorochan et al., 1999). Our sod strength testing device measured 147 x 53 x 97 cm (height x width x depth) and weighed 65 kg (excluding battery). The major difference between our sod testing device and that of Rieke et al. (1968) was that our table was mounted vertically instead of horizontally. This deviation facilitated speed and ease of insertion and removal of sod pads, but otherwise did not affect the operation of the device. Each time a sod pad was loaded and clamped into the device, the digital force meter (Chatillon brand, digital force instrument, Model DFIS, John Chatillon & Sons, Inc., Greensboro, NC) was tared to zero prior to sod tearing. The point at which the sod pad tore was measured in peak weight mode. Prior to analysis, raw data were converted using the sod pad width and depth information to reflect the point of sod tensile failure in peak force per unit area (kg dm^{-2}). This value, which reflects the point at which the sod broke, was referred to as the sod tensile strength.

Figure 2. Oklahoma State University 2003 version of a sod tensile strength testing device.

Post-Harvest Procedures

To prepare plots for re-growth and future harvests, additional passes with the sod cutter were made through the middle of each plot to soil grade. The turf cover from the original planted furrows was left. Re-growth occurred from the remaining plants. Immediately after harvesting the sod from each of the plots, all loose plant materials were removed from the site and the bare soil areas were inspected and stolons or loose live materials from other cultivars was removed. Additionally, re-growth of the harvested area was inspected and bermudagrasses rogued if not consistent with the parent sprig cultivar.

Data Analysis

A total of five sod harvests were conducted, each treated as a separate experiment. Four experiments were conducted on Site 1, and one experiment on planting Site 2. For all experiments, the field planting design and analytical design was a randomized complete block with four treatments (cultivar) and eight replications of cultivars with two exceptions. Due to complications, only seven replications were able to be harvested in the experiment conducted on 14 Aug 2007 on Site 1 and on 12 Oct 2006 on Site 2. Sub-sample values were pooled in the analysis to form a single observation for each plot. An analysis of variance (ANOVA) was conducted on the dependent variables sod tensile strength and sod handling quality within each harvest date (experiment) using SAS software for Windows, "PROC GLM" (SAS Institute, Cary, NC, v9.1, 2002). When cultivar effects in the ANOVA were significant at the 95% probability level, means were separated using Fishers protected LSD test. Pearson's correlation coefficient was calculated to measure the relationship between mean sod handling quality and mean sod tensile strength across experiments using SAS "PROC CORR".

RESULTS AND DISCUSSION

Because the two sprigging events took place at different times of year and turf growth varied due to different weather patterns, no pre-determined harvest date was assigned. Instead, the plots were visually monitored until all four bermudagrass cultivars had reached full cover and visibly appeared ready for sod harvest. It was felt that this would best simulate the industry scenario, where turf could be expected to have variable re-growth and maturity at cutting each year due to weather and contract demands.

Sod Tensile Strength

Highly significant cultivar effects were found for sod tensile strength in the ANOVAs for all five experiments (Table 1). Mean sod tensile strength values of cultivars in each of the experiments are reported in Table 2. Pearson's correlation coefficient for the relationship between mean sod tensile strength of a cultivar and the age of sod (d) at harvest was $r=-0.31$, $p=0.18$, $N=20$, revealing sod tensile strength was not well correlated with the age of sod. All sod harvests were conducted when plots visually appeared suitably mature, within the range of sod age tested in this study. The sod age did not seem to have significant influence upon the sod tensile strength. Overall mean sod tensile strength varied among experiments. Due to variable cropping cycle length and the differing number of replications used among experiments, we chose not to pool data among the experiments.

Tifway was included as a standard cultivar which traditionally has exhibited high sod tensile strength (Mitchell and Dickens, 1979; Sharpe et al., 1989) while Midlawn was included as a standard that has provided poor sod strength for sod producers (D.L. Martin, Oklahoma State University, personal communication, 2004). Sod tensile strength for Tifway was greater than that of Midlawn on four harvest dates and similar on one date at p=0.05 (Table 2). These findings are consistent with the opinion of four sod producers obtained by telephone survey (D.L. Martin, Oklahoma State University, unpublished, 2004) who had produced both Midlawn and Tifway and believed that Tifway had better sod strength than Midlawn.

Patriot's sod tensile strength was statistically greater than that of Tifway on three dates, similar on one date and less than that of Tifway on one harvest date. Patriot provided sod tensile strength greater than that of Midlawn and OKC 70-18 on all five harvest dates. OKC 70-18 provided tensile strength lower than that of Tifway during all five harvests, while tensile strength of OKC 70-18 was similar to that of Midlawn on three dates and was less than that of Midlawn on two harvest dates.

The transportation of the sod strength measurement device to and from the field test site, the careful preparation and assembly of the device, its loading and unloading with sod samples as well as the tensile strength test cycling of the device proved very cumbersome and time consuming. This finding correlates well with the findings of Shildrick (1982) in which he concluded that the sod strength tearing device was bulky and cumbersome. Using the OSU device built in 2003, a minimum of two people were required to safely transport and position the 64 kg sod tensile strength device as well as its 12 volt deep cycle marine-type battery power source to the vicinity of the test plots. The device and process did generate a reliable quantitative comparison of sod tensile strength in which we found a great deal of agreement in sod strength ranking among cultivars over dates.

Sod Handling Quality

Cultivar effects in the ANOVAs for sod handling quality (Table 3) were highly significant in all five experiments. Mean sod handling quality ratings for each of the experiments are reported in Table 4. Mean sod handling quality ratings of Tifway were greater than that of Midlawn on all five harvest dates. These findings were consistent with the opinion of four sod producers obtained by telephone survey (D.L. Martin, Oklahoma State University, unpublished, 2004) who had produced both Midlawn and Tifway and had stated that Tifway had better sod strength and improved handling characteristics than did Midlawn. Sod handling quality for Patriot was greater than Tifway on one harvest and similar to Tifway on four harvests. Patriot provided greater handling quality than Midlawn on all five harvests dates, a finding consistent with an opinion expressed by one producer that had worked with both Patriot and Midlawn (Gary Wilbur, Oakwood Sod Farms, Delmar, MD, personal communication, 2004) under commercial production conditions. OKC 70-18 provided mean handling quality ratings lower than that of Tifway during all five harvests. The handling quality of OKC 70-18 was greater than Midlawn on one harvest, similar to Midlawn on three harvests, and lower than that of Midlawn during one harvest.

The scaled 1 to 5 handling quality assessment of sod physical characteristics proved to be rapid and reliable in that there was good agreement in relative ranking of cultivars in handling quality among harvest dates. Pearson's correlation coefficient for the relationship between mean sod handling quality and mean sod tensile strength was r = 0.89, p=0.001, N=20, revealing a strong positive correlation between the two parameters.

CONCLUSIONS

This research is believed to be the first published account of using a 1 to 5 qualitative rating scale for evaluation of SHQ of harvested product. Shildrick (1982) used a 1 to 5 scale to characterize the maturity level of a sod field relative to its readiness for harvest, prior to its actually being harvested. A strong positive correlation (r=0.89, p=0.001) between STS and SHQ techniques was found in this research. By using the SHQ evaluation method, it may be possible for researchers to shift away from the exclusive use of STS measurements for some turfgrass research applications. Additionally, the SHQ technique may provide a valuable new tool for certain applications, whether used by itself or coupled with the STS technique. The sod handling quality technique which scored sod pads on a 1 to 5 scale can be easily taught to evaluators. Because the procedure is quick and efficient without the requirement of additional testing equipment, SHQ may prove a better suited technique than STS measures for screening large numbers of plants in a turfgrass breeding program. This SHQ technique could prove more cost effective for rapidly ruling out turfgrass sod selections which scored less than 3, the critical minimum acceptable rating. Both STS and SHQ techniques proved valuable in comparing a final stage experimental line with commercially available turfgrass cultivars. Having the additional SHQ results to compare with STS could provide the researcher with a clear interpretation of the STS values, such that a critical minimum STS value need not be pre-defined. Instead, the results from the SHQ technique may assist in defining the critical minimum STS for each given experiment or harvest date.

Tifway generally provided significantly greater SHQ and STS than Midlawn, a finding consistent with observations by commercial sod producers. These two cultivars may serve as useful standards of comparison in future turfgrass sod tensile strength or handling quality performance screenings. Tifway has been widely sold and established from sod throughout the U.S. since its release in 1960 (Alderson and Sharpe, 1994; Burton, 1991). Therefore, Tifway may serve as a good representative of suitable sod characteristics. A cultivar which performs worse than or not significantly better than Midlawn could be identified as unsuitable for use by traditional sod production methods that do not use nylon netting to supplement sod handling characteristics. Inclusion of both standards would seemingly be important so as to properly characterize the performance of previously untested cultivars in any future studies.

Patriot provided STS and SHQ which generally equaled or exceeded that of Tifway, and which was greater than OKC 70-18 and Midlawn. OKC 70-18 provided STS and SHQ which did not generally appear to be better than Midlawn, and in some instances was worse than Midlawn. With respect to sod handling characteristics the grouping of Patriot and Tifway with suitable performance versus Midlawn and OKC 70-18 with less suitable performance found in this trial is in good agreement with informal and non-published opinions of licensed sod producers. In this trial Patriot provided sod tensile strength and handling quality suitable for commercial production. Additional research is needed to i) identify possible management practices that could facilitate improved sod tensile strength and handling characteristics for Midlawn and OKC 70-18 and ii) identify genetic factors which might attribute to poor sod characteristics of these two cultivars.

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Table 1. Analysis of variance comparing sod tensile strength of four bermudagrasses during five sod harvests.

	Site 1												Site 2		
	5 - 8 Aug 2003			20 July 2004			26 Sep 2006			14 Aug 2007			12 Oct 2006		
Source	df	ms		df	ms		df	ms		Df	ms		df	ms	
cultivar	3	2157	**	3	7210	**	3	1839	**	3	11004	**	3	13800	**
block	7	516	*	7	828	*	7	22314	NS†	6	135	NS	6	290	NS
error	21	173		21	231		21	664		18	334		18	436	

* Significant at the 0.05 probability level.
** Significant at the 0.001 probability level.
† NS, nonsignificant at the 0.05 probability level.

Table 2. Mean sod tensile strength of four bermudagrasses during five sod harvests.

	Sod Tensile Strength†				
	Site 1				Site 2
Cultivar	5 - 8 Aug 2003	20 July 2004	26 Sep 2006	14 Aug 2007‡	12 Oct 2006§
	kg dm^{-2}¶				
OKC 70-18	25.2 b#	24.7 c	13.9 c	0.0 d	35.7 c
Patriot	41.4 a	65.7 a	82.9 a	54.3 a	71.3 b
Tifway	42.1 a	42.6 b	49.1 b	34.6 b	85.3 a
Midlawn	25.5 b	35.6 b	25.2 c	20.5 c	34.4 c
Experiment Means	33.6	42.1	42.8	27.4	56.7
LSD (0.05)	7.9	9.1	15.5	11.8	13.5

† Sod was harvested in eight replications per harvest date, except as noted below. Three sub-samples per plot were used in all experiments.

‡ Seven replications of data were used from the 14 Aug 2007 harvest. An eighth replication was lost due to grub damage and unlevel plots which prevented uniform sod harvest.

§ Seven replications of data were used from the 12 Oct 2006. An eighth replication was unable to be harvested.

¶ Sod tensile strength reported in kg dm^{-2} for sod harvested at 1.5 cm depth and 30.5 cm width. Peak weight was recorded at the point of sod failure with observations later converted to force based upon a calculation of mass divided by sod cross sectional area.

Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 3. Analysis of variance comparing sod handling quality of four bermudagrasses during five sod harvests.

	Site 1												Site 2		
	5 - 8 Aug 2003			20 July 2004			26 Sep 2006			14 Aug 2007			12 Oct 2006		
Source	df	ms		df	ms		df	ms		df	ms		df	ms	
cultivar	3	15.1	*	3	14.9	*	3	43.5	*	3	58.2	*	3	15.4	*
block	7	2.0	NS†	7	1.2	NS	7	1.6	NS	6	1.2	NS	6	1.3	NS
error	21	1.3		21	1.2		21	1.2		18	1.1		18	1.2	

* Significant at the 0.001 probability level.
† NS, nonsignificant at the 0.05 probability level.

Table 4. Mean sod handling quality of four bermudagrasses during five sod harvests.

	Sod Handling Quality†				
	Site 1				Site 2
Cultivar	5 - 8 Aug 2003	20 July 2004	26 Sep 2006	14 Aug 2007‡	12 Oct 2006§
OKC 70-18	2.5 b¶	3.3 b	2.0 b	1.0 d	4.0 b
Patriot	3.6 a	4.9 a	4.8 a	4.8 a	4.5 ab
Tifway	4.2 a	4.7 a	4.2 a	3.7 b	5.0 a
Midlawn	2.7 b	3.8 b	2.5 b	2.1 c	3.0 c
Experiment Means	3.3	4.2	3.4	2.9	4.1
LSD (0.05)	0.7	0.7	0.7	0.7	0.7

† Sod was harvested in eight replications per date, except as noted below, with three sub-samples per plot on all dates. Sod quality was measured on a 1 to 5 scale where 1=poor, complete breakage of sod during handling; 2=fair, not commercially recommended, substantial cracking of sod during handling; 3=good, our suggested minimum acceptable quality for industry handling, moderate cracking of the sod may occur; 4=very good, our desired minimum rating for cultivar commercialization, minimal cracking; and 5 = excellent, very tight, no cracking. Factors influencing quality were the uniformity and smoothness of sod pad edges as well as its ability to hold together under its own weight when suspended vertically.

‡ Seven replications of data were used from the 14 Aug 2007 harvest. An eighth replication was lost due to grub damage and unlevel plots which prevented uniform sod harvest.

§ Seven replications of data were used from the 12 Oct 2006. An eighth replication was unable to be harvested.

¶ Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

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CHAPTER III

EVALUATION OF THIRTY-SIX BERMUDAGRASSES FOR VISUAL CHARACTERISTICS AND SOD PRODUCTION QUALITIES

ABSTRACT

Turfgrass industry adoption of high quality, cold-hardy seeded and clonally-propagated bermudagrasses (*Cynodon* spp.) in the transition zone has been strong. Interest in bermudagrass cultivars with further performance improvements remains high. Thirty-two high quality final-stage experimental lines developed at Oklahoma State University were evaluated over 4 years for visual and functional qualities under simulated golf course fairway conditions at Stillwater, OK. A 1.3 cm mowing height was used. Clonally-propagated 'Tifway', 'TifSport', and 'Patriot' (*C. dactylon* L. Pers. X *C. transvaalensis* Burtt-Davy) **were included as standards as well as seeded 'Riviera'** (*C. dactylon* (L.) Pers.) **bermudagrass. Sod handling quality (SHQ) and sod tensile strength (STS) were also tested. Entries varied substantially in their establishment rate, color, texture, density, visual quality and sod features. Most experimental lines equaled or exceeded the visual quality of both the clonal and seeded standards. The STS was well correlated with SHQ (r=0.73, p=0.001, N=72). A 1 to 5 SHQ scale (3=acceptable, 5=best) was useful in screening entries. Twenty-four of 32 clonal lines provided 'very good' SHQ (mean rating ≥ 4 on 1 to 5 scale) on both sod harvest dates. Seeded bermudagrasses provided lower SHQ than most clonal lines. Clonal entries OKC 11-19 and OKC 11-34 provided excellent visual quality and sod handling characteristics warranting further testing for possible commercial release.**

INTRODUCTION AND LITERATURE REVIEW

Bermudagrass is an aggressively spreading, sod forming, perennial which tolerates frequent low mowing, withstands heat, drought, and traffic. When compared to other warm-season or cool season grass species, bermudagrass has few damaging disease or insect problems. These favorable turf characteristics lead to the extensive use of bermudagrasses on lawns, athletic fields, and golf courses in the U.S. transition zone as well as the southern states. Winter injury and Spring Dead Spot (SDS) disease are two major issues which affect turf bermudagrasses grown in the transition zone (USDA cold-hardiness zones 6 and 7) where turfgrasses experience colder winters than the more southern U.S. (USDA cold-hardiness zones 8-10) (Taliaferro et al., 2004; Cathey, 1990).

Traditionally, the Oklahoma State University (OSU) turf bermudagrass breeding program has strived to develop bermudagrasses with improved cold-tolerance (Anderson et al., 1988, 1993, 2002a; Martin et al., 2007) and SDS tolerance (Anderson, 2002b; Baird et al., 1998; Martin et al., 2001a, 2001b; Tisserat et al., 2004; Walker et al., 2008). The selections evaluated in this near final stage testing were developed with such criteria in mind. In addition, for a clonally-propagated bermudagrass to be successful in the marketplace, the grass must have excellent end-user performance traits, suitable sod production characteristics, and handling traits.

Thirty-one high quality clonally-propagated experimental lines of bermudagrass were selected by the OSU Bermudagrass Development Team for final stage testing under simulated golf course fairway conditions. ‘Tifway’, ‘TifSport’, and ‘Patriot’ hybrid bermudagrasses were included as commercial standards of comparison. Additionally, a seeded experimental bermudagrass entry was tested. This seeded bermudagrass was compared to ‘Riviera’ (OKS 95-1), a commercially available 2001 OSU release used as a standard. The intent of this multi-year field screening was to determine if any lines were suitable for advancement to national testing and potential commercial release for use in the sports turf or golf-course settings.

Sports turf and golf course applications have vastly different needs and resources to manage the grasses and maintain higher standards of turf excellence than what is expected of home lawns, parks, and commercial grounds. Turf for sport applications is typically more intensively managed than any other. Turfgrass on such sites is expected to have high density, deep green color, and grow quickly (Martin et al., 2007). In the sports turf and golf course arenas, the turf cover may be damaged or otherwise disrupted by the various sporting activities that take place on the turf surface. If a golf club removes a divot out of a fairway and the bermudagrass is slow to recover, then other plants (weeds) have the opportunity to invade the space.

Visual Characteristics

An extensive turfgrass industry network has developed among breeders and researchers, commercial producers consisting of sod growers and seed companies, and end users including managers of golf courses, athletic fields, parks and grounds, as well as homeowners. End users rely on information sources including commercial producers and university educators in order to make decisions for selecting turfgrasses suitable to their particular expectations and geographic locations. Breeders rely upon the results from cultivar research studies as well as feedback from commercial growers and the trends of end user purchasing to influence the criteria they use in selecting desirable plant materials and breeding for the next generation of turfgrasses.

The National Turfgrass Evaluation Program (NTEP), headquartered at Beltsville, MD, is an example of a private organization that connects cultivar breeders and researchers with the commercial and end user component of the turfgrass industry. The

NTEP facilitates the coordination of cultivar research trials which are conducted at select sites across the United States. These trials have established and regulated guidelines to protect the uniformity and integrity of the research and turfgrass maintenance methods. Breeders and researchers can enter their cultivars in the national trials which are conducted for a five year period of time. NTEP also includes several recognized cultivars as standard entries for comparison. In bermudagrass cultivar studies since 1986, the NTEP has had as many as 42 or as few as 26 official entries. The breakdown of those numbers reflected as few as 6 or as many as 21 clonal cultivars, and as few as 7 or as many as 29 seeded cultivars (Morris, 1993, 1997, 2002, 2007).

The NTEP cooperators use a visual rating system to estimate each parameter for measurement (Morris and Shearman, 2000). To take detailed measurements of turfgrass criteria such as a shoot count density or leaf blade width (leaf texture), would require intensive labor efforts and would not always be feasible. Therefore, using a well correlated visual estimate provides the desired information for each cultivar while employing a fraction of the labor hours and equipment costs. Evaluating visual characteristics of a turfgrass has a degree of subjectivity; however, the NTEP has established specific procedures, guidelines and criteria for use in visual cultivar evaluation studies (Morris and Shearman, 2000). The combined results of the visually evaluated criteria are intended to measure aesthetic value and functional use of the bermudagrass cultivars. Each criteria has specified guidelines for evaluation such that "properly trained observers can effectively discern subtle differences between turfgrasses, using the visual rating system." (Morris and Shearman, 2000). For this cultivar evaluation study, a rating system based upon the guidelines prepared by NTEP has been selected.

To provide useful comparisons among the cultivars within this research, it is necessary to select at least one cultivar which can be used as a “standard” entry for describing certain parameters. Tifway (‘Tifton 419’) has been widely used since its release by Dr. Glenn W. Burton in 1960 from the Georgia Coastal Plain Experiment Station (Alderson and Sharp, 1994). It is a triploid (2n=3x=27 chromosome) sterile interspecific hybrid with suitable characteristics for use on lawns, fairways, tees, and athletic fields including: darker green color, frost tolerance, early spring growth, dense weed-free sod, and wear tolerance (Burton, 1966 and 1991).

Patriot is a 2002 release from the OSU Bermudagrass Development Program that is now in production by six producers. It has dark green color, excellent SDS disease resistance, cold tolerance, rapid establishment, and moderately fine leaf texture (Taliaferro et al., 2006). All producers of Patriot sod have indicated that it has very good sod harvest/handling characteristics. (D.L. Martin, Oklahoma State University, personal communication, 2005). This cultivar will be used primarily as an “in-house” standard for visually comparing with characteristics of new experimental cultivars.

Sod Tensile Strength and Handling Quality

In addition to improved visual and performance characteristics desired by the end user, a clonally-propagated bermudagrass must provide suitable sod strength and handling quality. While sprigging, plugging, sod slabbing and the use of nylon netting for improving sod strength are all methods to establish bermudagrass, traditional sod production methods are very common for selling and establishing bermudagrass turf. Long-term success of a clonally-propagated cultivar in the marketplace depends, to some degree, upon the inherent sod characteristics it possesses. A sod producer takes into account the profit margins, production cycles and handling characteristics of a cultivar.

In bermudagrass sod research from the 1970s, Tifway exhibited satisfactory sod tensile strength (Mitchell and Dickens, 1979). Therefore, a cultivar such as Tifway would provide an excellent “standard” entry for comparison, such that any cultivar with equal or greater sod tensile strength than Tifway, could be considered desirable and suitable to commercial sod production using traditional methods.

OBJECTIVES

The objectives of this research were to evaluate 34 clonal and 2 seed-propagated bermudagrasses for establishment rate, living cover, spring green-up, shoot density, leaf texture, color, seedhead expression, scalping damage, fall color retention, visual quality, sod tensile strength, and sod handling quality under simulated golf course fairway conditions.

MATERIALS AND METHODS

The bermudagrass field performance evaluation was conducted at the Oklahoma Botanical Garden, 1.6 kilometers west of Stillwater, OK (36° 07’ 05” N, 97° 06’ 11” W). The soil was an Easpur silty clay loam (a fine-loamy, mixed, thermic Fluventic Haplustoll). Thirty-six entries were established on 26 May 2004. The experimental layout was a randomized complete clock with 3 replications of each entry. All clonally-propagated materials were established by planting 25 plugs (3.8 cm diameter) into a 1.5 x 1.5 m grid on 30.5 cm centers. The seeded entries 'BerPC 99-6' (entry 35) and 'Riviera' (entry 36) were planted into 1.5 x 1.5 m plots at 48.8 kg pure live seed ha^{-1} then covered with a spun-bound polyester seed cloth to reduce risk of soil erosion and aid in germination. Clonal selections were not covered. On 14 June 2004 (19 days after planting), the seed cloth was removed from seeded selections. Clonal and seeded selections were allowed to spread to final plot size of 2.5 x 2.5 m. Borders measuring 23 cm wide were maintained free of vegetation using glyphosate herbicide as needed to prevent cross contamination of cultivars.

Turf was irrigated regularly to encourage maximum growth and to minimize wilting due to soil moisture deficit. Nitrogen fertility rates were 290 kg ha^{-1} in the establishment year of 2004 and 200 kg ha^{-1} in each of the three subsequent years respectively. Soil pH ranged from 6.2 to 6.6 during the trial. Phosphorus (P) and potassium (K) were added as needed to maintain levels at or above soil test index values of 73 and 281 kg ha^{-1} respectively. The initial mowing took place on 25 June 2004 at a 3.8 cm cutting height using a rotary mower with clippings removed. Later that same day turf was mowed at 2.5 cm with a reel type mower. On 29 June 2004 mowing height was reduced to the final height of 1.3 cm with regular mowing frequency of 3 times wk^{-1} commencing on 4 July 2004. Mowing frequency remained at up to 3 times wk^{-1} during the period of active bermudagrass growth except for brief periods when seed head expression was rated and a 3 to 5 day period without mowing was implemented. Clippings were returned throughout the course of the research.

Pest Management

Oxadiazon was applied preemergence (PRE) to the newly clonally planted bermudagrass plots on 2 June 2004 (7 days after planting) at 2.24 kg ha^{-1} for summer annual weed control. On 24 July 2004 monosodium acid methanearsonate was applied at 2.52 kg ha^{-1} for annual weedy grass post-emergent (POST) control along with 2,4-D; mecoprop-p and dicamba at 0.91, 0.24, and 0.08 kg ha^{-1} respectively for POST broadleaf weed control. Glyphosate, triclopyr and clopyralid were applied at 1.10, 0.63 and 0.21 kg ha^{-1} respectively for POST winter annual weed control on 17 February 2005. On 15 April 2005 prodiamine was applied at 0.98 kg ha^{-1} PRE for control of summer annual weeds. Imidacloprid was applied on 5 August 2005 at 0.34 kg ha^{-1} for white grub (*Cyclocephala* L. and *Phyllophaga* L. spps.) control. On 23 November 2005 simazine was applied at 1.12 kg ha^{-1} for early PRE and POST winter annual grass control. A combination of 2,4-D; mecoprop-p and dicamba was applied POST at 0.68, 0.18, and 0.06 kg ha^{-1} respectively on 14 Mar 2006 for broadleaf weeds along with prodiamine PRE at 1.09 kg ha^{-1} for summer annual weeds. On 1 Sep 2007 carbaryl was applied at 2.24 kg ha^{-1} for fall armyworm (*Spodoptera frugiperda* -J.E. Smith) control. Glyphosate was applied POST to the 23 cm border areas at 1.79 kg ha^{-1} throughout each growing season as required to prevent cross contamination of the bermudagrass plots.

Evaluating Visual Characteristics

Bermudagrass entries were evaluated on a regular basis throughout the study. Immediately prior to each rating, the evaluator ensured that recent mowing, irrigation or other plot maintenance procedures would not interfere with visual observation of the cultivars, and that solar angle as well as intensity of sun versus cloud cover would be conducive to uniform observation among the plots. Most visual ratings were performed using whole numbers on a scale of 1 to 9 or 0 to 100 (for visually estimating percentages) in keeping with the rating systems of the National Turfgrass Evaluation Program (NTEP) expressed in Morris and Shearman (2000). The following ratings were conducted from 2004 to 2007 as weather and plot conditions permitted for usable data to be collected:

Percent Living Cover

Percent living cover (PLC) of the entry during turf establishment was evaluated visually using a 0 to 100 scale (50 equaled 50% cover, 100 equaled full cover) on 21 July 2004 at 8 weeks after planting to assess the rate at which entries grew over the plot. Additionally, PLC was evaluated at least three times annually (spring, summer, fall) beginning the calendar year after establishment. The PLC rating not only reflected the damage caused by biotic (disease, insects, weeds) and abiotic (heat, cold, inundation) factors but also the ability of the entries to recuperate from prior damage.

Spring Green-Up

Spring green-up (SGU) measured the transition from winter dormancy to active spring growth. The SGU was evaluated at least once annually to note the cultivars which greened up early or more completely by the rating date. Spring green-up was rated on a scale of 1 to 9 where 1 indicated the plot was still dormant (straw-brown colored turf), 6 indicated moderate green-up, and 9 indicated the turf was fully green. When evaluating SGU, there was no discrimination among cultivars which possessed darker genetic color.

The SGU was evaluated on 11 and 28 Apr 2005, 3 and 14 Apr and 1 May 2006, and 14, 20 and 26 Mar 2007.

Shoot Density

Shoot density (SD) was rated once annually (8 Oct 2004, 26 Jul 2005, 14 Aug 2006, and 6 Jun 2007) during the summertime, on a 1 to 9 scale where 9 reflected very dense turf, 6 was acceptable, and 1 equaled very low shoot density.

Leaf Texture

Leaf Texture (LTX) was rated once annually (8 Oct 2004, 26 Jul 2005, 14 Aug 2006, and 6 Jun 2007), on a 1 to 9 scale where 1 reflected very coarse texture (widest leaf blade), 6 was acceptable, and 9 was very fine leaf texture (narrowest leaf blade).

Genetic Color

Genetic color (GC) measuring the inherent color of the genotype was evaluated once annually (20 Oct 2004, 26 Jul 2005, 30 Oct 2006, and 6 Jun 2007), on a date when all plots were healthy and actively growing. The GC parameter was rated on a 1 to 9 scale where 1 was considered the lightest green, 6 was acceptable, and 9 was considered a very dark green color.

Seedhead Expression

Seedhead expression (SHE), performed several times during a growing season to characterize when and how prolifically a particular cultivar produced inflorescence. In 2005, SHE was evaluated on 16 Aug, 16 Sep, and 19 Oct. During 2006, SHE was evaluated on 1 May, 23 Jun and 17 Oct. The SHE was also evaluated on 4 and 18 Jun 2007. The SHE was rated on a 1 to 9 scale where 9 indicated no visible presence of seedheads, 6 indicated moderate coverage, and 1 equaled complete coverage in seedheads.

The SHE was evaluated visually from a position of standing and walking directly over the plot. Seedhead expression was typically rated at the end of a 3-5 day interval when mowing was not conducted.

Scalp Damage

The scalp damage (SCDM) rating was a measurement of the severity and visual disruption of the desirable uniform green cover of the turf after a mowing event. The SCDM was rated on a 1 to 9 scale where 9 indicated that no scalp damage was present, 6 was acceptable, and 1 indicated severe scalping damage. The SCDM was evaluated on 31 Aug and 19 Oct 2005, and 23 Jun and 27 Jul 2006.

Fall Color Retention

Fall color retention (FCR) was rated after 1 September of a year and assessed the ability of the entry (cultivar) to hold color during late summer and the autumn season. The FCR of bermudagrass is believed to be influenced by temperature and day length. Fall color retention was evaluated (14 Nov 2006) on a 1 to 9 scale where 9 represented no damage, the plot was fully green, and 1 represented the most severe damage, the plot was straw-brown and indicated complete dormancy. For this evaluation, no preference was given to cultivars with darker genetic color.

Turfgrass Quality

Turfgrass visual quality (TQ) was rated on a 1 to 9 scale where 9 equaled excellent quality, 6 was acceptable, and 1 was poor quality. The TQ parameter was evaluated monthly during the active growing season normally from May through September. The TQ rating took into account both the functional and the aesthetic features of the turf and reflected many criteria, including any plot details that caused visual favor or concern by a common observer. These factors include solid cover, uniformity of the plot, presence of weed species, plot color, disease presence and or visual damage, leaf texture, density, pest damage, recovery from any mechanical damage (divot study, wear tolerance), and any other factor which may encourage or deter a visual observer from desiring the turf cultivar (Morris and Shearman, 2000).

Data Analysis for Visual Assessment

The field planting design and the analytical design was a randomized complete block with thirty-six cultivars (treatments) and three replications. Because significant cultivar by rating date effects in large trials are commonplace, and because there were a variable number of rating dates within years, we performed individual analysis of variance (ANOVA) by rating dates for the dependent variables percent living cover, spring green-up, shoot density, leaf texture, genetic color, seedhead expression, scalp damage, fall color retention, and turfgrass quality using SAS software for Windows version 9.1, general linear model procedure "PROC GLM" (SAS Institute, Cary, NC, v9.1, 2002). When cultivar effects in the ANOVA were significant at the 95% certainty level, means were separated using Fisher's protected LSD test.

Sod Tensile Strength and Handling Quality Assessment

Sod Harvesting Technique

One to three days prior to harvest, plots were irrigated to optimize moisture content suitable for sod harvest. For each of the 36 entries, 3 replications were harvested with 3 sub-samples per plot. On each harvesting date, a single north to south pass was conducted to cut sod in each plot using a walk behind sod cutter. On 26-27 Oct 2004, 22 week old sod was cut from the eastern side of the plots. One replication per day was harvested on the 30 Jun, 1 Jul, 12 Jul 2005 harvest. The 57-59 week old (13-13.5 mo) sod was cut from the western half of the plot which contained the original planted material that was not previously harvested.

Sod pads were cut using a 30.5 cm blade set at a machine blade depth of 1.5 cm. At least ten randomly selected sod pads were measured at each harvest date for sod thickness (actual cutting depth measured from the top of the soil to the bottom of the soil) and data were recorded to obtain a mean for use in calculating tensile strength. The mean sod thickness in 2004 and 2005 was 1.6 cm (range 1.3 cm to 1.9 cm). Once the sod was cut, it was separated with a sod knife into individual sod pads at a minimum length of 38 cm. This critical minimum length ensured that sod pads could be easily loaded and firmly secured into the clamps on the sod strength testing device.

Sod Handling Quality Assessment

The sod pads were lifted by hand from each of the plots, and transported to the border of the block to be tested in the tearing device. Based upon the transport and handling of the sod pad prior to testing in the tearing device, the plant material was rated on a one to five scale for sod handling quality where the sod pad experienced:

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

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

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

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

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

<u>Sod Tensile Strength Measurement</u>

Following handling quality assessment, the sod pads were inserted one at a time into the vertically mounted, OSU-designed sod tensile strength testing machine. This machine was built in the form of a table that operated using similar principles to the traditional model of a sod tearing machine as originally described by researchers at Michigan State University (Rieke et al., 1968, Sorochan et al., 1999). The major difference between our tensile strength testing device and that of Rieke et al. (1968) was that our actuator was mounted vertically instead of horizontally. Vertical loading facilitated speed and ease of insertion and removal of sod pads, but otherwise did not affect the operation of the device. The point at which the sod pad tore was measured in peak mass mode using a digital force instrument (Chatillon brand, digital force instrument, Model DFIS, John Chatillon & Sons, Inc., Greensboro, NC). Prior to analysis, raw data were converted using the sod pad width and depth information to reflect the point of sod tensile failure in peak force per unit area (kg dm^{-2}). The value which reflected the point at which the sod broke was referred to as the sod tensile strength.

<u>Post-Harvest Procedures</u>

Because various additional field performance evaluations were conducted for several seasons after assessment of sod handling characteristics, each sod pad was immediately returned to the original site where it had been harvested. Sod was returned to its respective plot, pressed firmly into place and irrigated to promote re-establishment.

Data Analysis for Sod Characteristics

Two sod harvests were conducted within the same plots (26-27 Oct 2004 and 30 June, 1 and 12 July 2005). The experiment was a randomized complete block with 36 cultivars (treatments) and 3 replications with 3 sub-samples per observation. An analysis of variance (ANOVA) was conducted on sod tensile strength and sod handling quality data within each harvest date using SAS software for Windows v.9.1, procedure ”PROC GLM” (SAS Institute, 2002). When cultivar effects in the ANOVA were significant at the 95% certainty level, means were separated using Fisher’s LSD test.

Pearson’s correlation coefficient was calculated to measure the relationship between mean sod handling quality and mean sod tensile strength across harvest dates using SAS procedure “PROC CORR”.

RESULTS AND DISCUSSION

Visual Characteristics

Highly significant cultivar and cultivar by rating date effects were found for each of the visual characteristic parameters [percent living cover during turf establishment, spring green up, shoot density, leaf texture, genetic color, seedhead expression, scalp damage, fall color retention after a frost event, and turfgrass quality] on all evaluation dates (ANOVAs not shown).

Percent Living Cover

Living cover at 8 weeks after planting ranged from 50 percent for entry OKC 10-82 to 98 percent for entries 17 and 20 (Table 5). No significant differences were present among the commercially available cultivars Patriot, Tifway, Tifsport, and Riviera. There was no difference between seeded entries Riviera and BerPC 99-6 for PLC during the establishment phase. Experimental entries 5, 8, 14, 16, 17, 18, 19, 20, 21, 22, 26, 27, and 28 all had greater PLC than Tifway, TifSport and Patriot at 8 WAP. OKC 70-18 was one of the slowest but not the slowest bermudagrass to establish. The findings of 15 locations reported in the 2002-2006 NTEP bermudagrass trial showed that Tifway, TifSport, and OKC 70-18 consistently ranked among the lowest PLC during establishment. The ranking of establishment PLC for Patriot and Riviera varied somewhat among the 15 locations for the 2002-2006 NTEP bermudagrass trial, however, more often than not, Riviera ranked high for establishment PLC and Patriot ranked intermediate (Morris, 2007).

The rate of spread of a cultivar is both inherent and controlled by the environment. Environmental factors such as fertility, irrigation, mowing height and frequency, and weed management can affect the establishment rate of a turfgrass. It was not until summer 2005 that all entries achieved 100% living cover. It is worthwhile to mention that soon after the bermudagrass plots were planted in 2004, a heavy rainfall event occurred just a few hours after the application of oxadiazon granular herbicide PRE for weed control. The slow plot establishment may be attributed to severe summer annual grass and broadleaf competition in plots during 2004. Since the weed competition may have contributed to secondary issues for plot establishment, the entries in this study which exhibited low establishment PLC should not be automatically excluded from further consideration for applications such as a golf course tee-box or an athletic field which is subject to high traffic. Additionally, a cultivar which has a slow spreading rate may be advantageous, for example in the situation of a landscape. In a landscape with sidewalks and ground beds, a cultivar which does not spread rapidly or require frequent edging could be more desirable.

When taken over several years, the PLC parameter is a measure of turfgrass stand persistence and it is an indicator of entry adaptation to the maintenance regime and environment in which the trial is conducted. Seasonal PLC ratings were also evaluated during 2004 through 2007, but data are not shown as there were generally no differences among cultivars once established. All entries maintained living cover at or very near 100 percent throughout the study. Maintenance of complete cover throughout the trial at or near 100 percent suggests that all entries showed excellent adaptation to the test site and the maintenance regime.

Spring Green-Up

The standard entries Tifway, TifSport, and Patriot were not generally among the earliest entries in this study to exhibit spring green-up (Table 6). Patriot and TifSport had equal or higher SGU ratings than Tifway on all dates. Patriot had greater SGU than TifSport on two dates and TifSport had greater SGU than Patriot on one. On four of the eight dates there was no difference among Tifway, TifSport, and Patriot for SGU. The spring green-up findings of this study for Patriot and Tifway performance were consistent with the findings of the 2002-2006 NTEP bermudagrass trial. The 2002-2006 NTEP findings from 25 testing locations showed that Patriot (mean = 5.0) had higher mean spring green-up than Tifway (mean = 4.6, LSD = 0.3), the actual SGU performance of these two cultivars was not vastly different (Morris, 2007). Following a mild winter, it may be difficult to observe differences between Patriot and Tifway for spring green-up. Entry 3 had very high SGU ratings on all dates. Entry 23, OKC 10-82 and BerPC 99-6 generally had delayed SGU. Though both seeded bermudagrass entries generally ranked low, Riviera possessed greater SGU than BerPC 99-6 on 28-Apr-2005 and on 26-Mar-2007 with no significant difference between the two cultivars on the other six evaluation dates. In some instances, poor or delayed spring green-up for a cultivar may be attributed to a delay in starting growth. In other situations, episodes of winter injury to a cultivar may cause poor SGU as reflected by low percentage of green living plant material within a plot. Within this study, no cultivars with poor cold hardiness were included as standards for comparison. Additionally, episodes of severe winterkill were not observed during this study.

Shoot Density

Tifway, TifSport and Patriot generally had moderate shoot density (Table 7). Entries 6, 7, BerPC 99-6, and Riviera had lower SD than the other entries on all dates, yet the SD of these entries were always satisfactory or above ($\geq$6). The shoot density performance of Tifway, TifSport, Patriot, and Riviera appear consistent with the summer density findings of 17 locations from the 2002-2006 NTEP bermudagrass trial (Morris, 2007). There was no difference between BerPC 99-6 and Riviera in this study for SD on any annual evaluation dates (from 2004-2007). The entries 20, 27, and 28 generally had the greatest SD. No experimental entries had SD that would exclude them from the commercial market.

Leaf Texture

Tifway and TifSport had moderately fine leaf texture. The seeded bermudagrasses BerPC 99-6 and Riviera as well as the clonal entries 6, 7, and Patriot had generally lower mean LTX ratings than the other cultivars (Table 7). Entries 27 and 28 generally had the finest LTX. There was no difference between BerPC 99-6 and Riviera for LTX. The leaf texture ratings of Tifway, TifSport, Patriot, and Riviera within this study were consistent with findings from 20 locations in the 2002-2006 NTEP bermudagrass trial (Morris, 2007). No experimental or commercialized entry had a LTX lower than a value of 6, therefore all entries are commercially acceptable for LTX.

Genetic Color

Genetic color was variable among the 36 entries in the trial (Table 8). No entry had unsatisfactory color for use as a golf, sports or lawn turf (a value <6). Entry 22 had the lightest green GC with entry 8 also having notably light green GC across rating dates. Entries 13, 23, Tifway, TifSport, and Patriot generally had the darkest green GC. There was no difference between BerPC 99-6 and Riviera for GC. The performance of Tifway, TifSport, Patriot, and Riviera for genetic color in this study was consistent with findings from 22 locations of the 2002-2006 NTEP bermudagrass trial (Morris, 2007).

Seedhead Expression

Mean SHE of 8.7, 8.3 and 8.0 reflected a cultivar lightly expressing seedheads in one, two and three replications on an evaluation date (Table 9), respectively. Tifway expressed seedheads in all replications during three of the eight evaluation dates. TifSport expressed seedheads in all replications during two of the eight evaluation dates.

Patriot never expressed seedheads in all replications during the eight evaluation dates. Of all entries tested, entry 1 expressed seedheads most frequently. BerPC 99-6 had greater SHE than Riviera on 18-Jun-2007 with no difference present between the two entries on the other seven evaluation dates.

Scalp Damage

On two of the four dates, Tifway and TifSport experienced scalp damage, but on two of the dates, they had almost no damage. The performance of Tifway and TifSport in this study appeared consistent with findings in the 2002-2006 NTEP bermudagrass trial in which some degree of scalp damage was present, but means were greater than 5.0 (Morris, 2007). Patriot ranked among the most severely scalp damaged entries on three of the four evaluation dates. Very severe scalp damage ratings for Patriot (means $\leq$4.0) were reported at both of the two locations providing SCDM data during the 2002-2006 NTEP bermudagrass trial (Morris, 2007). There was no difference in SCDM (Table 10) between BerPC 99-6 and Riviera on any of the four rating dates (two during 2005 and two taken in 2006). Additionally, the seeded entries in this study were noted to have generally less than or equal SCDM as compared to the clonal cultivars. The 2002-2006 NTEP bermudagrass trial indicated that Riviera ranked among the cultivars with the least scalp damage (Morris, 2007). Very severe SCDM was observed for experimental clonal entries 9 and 15. The propensity of these two cultivars to severely scalp will greatly decrease the likelihood of their acceptability in the marketplace, particularly for golf course applications, because the cultivars do not exhibit visual or performance traits that exceed the current commercially available standards.

Fall Color Retention

Evaluations of FCR on 14 Nov 2006 had a wide range in response of the entries to frost with a range of 2.0 to 7.5. OKC 10-82 and TifSport were ranked with the highest level of FCR (Table 5) with means of 7.0 and 7.5 respectively. The next three best performers which had only a moderate degree of FCR were entries 23, 27, and Tifway. Thirty-one cultivars, including Patriot, had a mean rating of 3.0 or below. The FCR findings for performance of TifSport, Tifway, and Patriot within this study are consistent with the 18 locations which reported FCR during the months of November each year in 2002-2006 NTEP bermudagrass trial (Morris, 2007). During the 2002-2006 NTEP bermudagrass trial, TifSport and Tifway retained fall color very well compared with Patriot which had relatively poor FCR during November.

Turfgrass Quality

Turfgrass visual quality evaluations were conducted on 3 dates in 2004 (Table 11), and 5 dates each in 2005 (Table 12), 2006 (Table 13), and 2007 (Table 14) for a total of 18 rating dates. For ease of comparison of the entries' overall performance, the number of rating dates in which an entry appeared in the top ranking statistical group for visual quality is shown in Table 14. The clonally-propagated standards Tifway, Tifsport, and Patriot were in the top ranking group 12, 10, and 10 times respectively during the course of the entire trial. Experimental entries that frequently were in the top ranked group and the number of times they appeared in that position were experimental entries 22 and 25 on 17 dates; entries 4, 12, 17, 20, 21, and 29 on 16 dates; and entries 2, 16, 18, 24, and 26 on 15 dates. The experimental seeded entry BerPC 99-6 as well as the seeded standard Riviera ranked in the top group on 5 dates. BerPC 99-6 provided higher quality than Riviera on 2 dates with Riviera providing higher quality than BerPC 99-6 on 1 date; otherwise, the quality of the these two seeded entries did not differ. Between 2005 and 2007, TQ for all entries was generally very good during the summer months. The exceptions to this occurred when another factor may have attributed to a drop in quality (i.e.-scalp damage, seedhead expression). More differences among entries for turfgrass quality were generally present in early spring and late fall; however, all entries demonstrated acceptable turfgrass quality.

Table 5. Mean percent living cover during establishment of thirty-six bermudagrass entries in 2004 and fall color retention in 2006.

		Percent Living Cover†	Fall Color Retention‡
Entry	Cultivar	21-Jul-04	14-Nov-06
1	Experimental	90 a-h§	2.3 d
2	Experimental	82 g-k	2.7 cd
3	Experimental	77 k	2.7 cd
4	Experimental	89 b-i	2.3 d
5	Experimental	94 a-e	2.3 d
6	Experimental	91 a-g	2.3 d
7	Experimental	86 e-j	2.7 cd
8	Experimental	94 a-e	2.7 cd
9	Experimental	81 h-k	2.3 d
10	Experimental	88 d-j	2.3 d
11	Experimental	78 jk	2.0 d
12	Experimental	91 a-g	2.3 d
13	Experimental	87 e-j	2.3 d
14	Experimental	92 a-f	2.7 cd
15	Experimental	77 k	2.0 d
16	Experimental	93 a-f	2.3 d
17	Experimental	98 ab	2.7 cd
18	Experimental	97 a-d	2.3 d
19	Experimental	94 a-e	2.0 d
20	Experimental	98 a	2.3 d
21	Experimental	97 a-c	2.3 d
22	Experimental	98 ab	2.7 cd
23	Experimental	78 jk	4.0 bc
24	Experimental	93 a-e	2.3 d
25	Experimental	89 a-h	2.3 d
26	Experimental	98 a	2.7 cd
27	Experimental	93 a-e	4.7 b
28	Experimental	93 a-e	3.0 cd
29	Experimental	88 d-j	2.0 d
30	Tifway	79 i-k	5.3 b
31	TifSport	78 jk	7.7 a
32	Patriot	83 f-k	2.3 d
33	OKC 70-18	77 k	2.7 cd
34	OKC 10-82	50 l	7.0 a
35	BerPC 99-6	84 e-k	2.0 d
36	Riviera	88 c-i	2.3 d
LSD Value (0.05)		9.5	1.5

† Percent living cover during turf establishment was evaluated visually on a 0 to 100 scale and reflecting the percent living cover of turf at eight weeks after planting.
‡ Fall color retention was rated after 1 Sep of a given year, once a fall frost event had occurred. It was rated on a 1 to 9 scale where 9 equaled no damage with fully green turf and 1 equaled most severe damage with straw-brown and completely dormant turf.
§ Fischer's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level.

Table 6. Mean spring green-up for thirty-six bermudagrass entries from 2005 to 2007.

		Spring Green-Up†							
		2005		2006			2007		
Entry	Cultivar	11-Apr	28-Apr	3-Apr	14-Apr	1-May	14-Mar	20-Mar	26-Mar
1	Experimental	3.0 c-e‡	5.7 d-g	4.3 c-h	6.3 b-h	8.7 ab	3.7 a-c	6.0 ab	8.7 ab
2	Experimental	4.0 bc	7.3 a-c	4.7 b-h	6.0 c-h	8.7 ab	4.0 ab	6.3 a	8.7 ab
3	Experimental	6.0 a	8.0 a	4.7 b-h	7.0 a-f	9.0 a	3.3 a-d	5.7 ab	8.3 a-c
4	Experimental	3.7 b-d	7.0 a-d	5.0 b-g	7.0 a-f	9.0 a	2.7 c-f	6.0 ab	9.0 a
5	Experimental	1.3 g	3.7 hi	3.7 e-j	5.0 f-j	9.0 a	2.0 e-h	3.7 c-g	8.0 a-c
6	Experimental	3.3 cd	6.3 b-f	2.7 h-j	4.3 g-j	8.7 ab	1.7 f-h	4.3 b-g	7.0 c-e
7	Experimental	4.0 bc	6.0 c-g	4.0 d-i	5.3 e-i	9.0 a	2.0 e-h	4.7 a-e	7.0 c-e
8	Experimental	2.0 e-g	4.7 gh	4.0 d-i	5.7 d-h	8.7 ab	1.7 fgh	3.7 c-g	7.3 b-d
9	Experimental	1.3 g	2.0 j	4.3 c-h	6.7 a-g	9.0 a	1.3 gh	2.7 f-h	7.3 b-d
10	Experimental	4.0 bc	7.3 a-c	4.7 b-h	7.7 a-e	9.0 a	2.3 d-g	5.0 a-d	8.3 a-c
11	Experimental	4.7 b	7.0 a-d	5.3 a-f	7.7 a-e	9.0 a	2.3 d-g	5.7 ab	9.0 a
12	Experimental	2.7 d-f	6.7 a-e	4.0 d-i	5.0 f-j	9.0 a	3.3 a-d	5.7 ab	8.0 a-c
13	Experimental	2.7 d-f	6.0 c-g	6.7 ab	8.3 a-c	9.0 a	2.0 e-h	6.0 ab	9.0 a
14	Experimental	3.7 b-d	7.3 a-c	7.3 a	8.0 a-d	9.0 a	3.0 b-e	5.7 ab	9.0 a
15	Experimental	1.0 g	2.0 j	3.3 f-j	5.0 f-j	8.7 ab	1.0 h	2.3 gh	7.7 a-d
16	Experimental	4.0 bc	7.0 a-d	5.3 a-f	7.0 a-f	9.0 a	3.0 b-e	5.7 ab	8.3 a-c
17	Experimental	2.0 e-g	5.3 e-g	5.3 a-f	6.7 a-g	8.7 ab	2.7 c-f	5.0 a-d	7.7 a-d
18	Experimental	1.3 g	6.0 c-g	4.3 c-h	5.7 d-h	8.3 a-c	1.7 f-h	4.3 b-f	7.3 b
19	Experimental	3.0 c-e	6.7 a-e	4.3 c-h	5.7 d-h	8.7 ab	1.3 gh	3.0 e-h	5.7 ef
20	Experimental	1.3 g	5.3 e-g	3.0 g-j	5.0 f-j	8.0 a-c	1.7 f-h	3.3 d-h	7.0 c-e
21	Experimental	1.3 g	5.0 f-h	5.7 a-e	8.0 a-d	9.0 a	3.0 b-e	5.7 ab	8.7 ab
22	Experimental	2.0 e-g	6.0 c-g	5.0 b-g	6.3 b-h	8.3 a-c	2.7 c-f	5.3 a-c	8.3 a-c
23	Experimental	2.0 e-g	4.7 gh	2.0 ij	2.7 j	7.3 c	1.0 h	1.7 h	4.3 fg
24	Experimental	3.3 cd	6.3 b-f	5.7 a-e	7.3 a-f	9.0 a	2.0 e-h	4.7 a-e	8.7 ab
25	Experimental	4.0 bc	7.3 a-c	4.7 b-h	6.3 b-h	9.0 a	2.0 e-h	4.7 a-e	9.0 a
26	Experimental	3.3 cd	6.3 b-f	5.3 a-f	6.3 b-h	8.7 ab	4.3 a	5.7 ab	8.7 ab
27	Experimental	3.7 b-d	7.7 ab	5.0 b-g	7.7 a-e	9.0 a	1.7 f-h	4.3 b-f	7.7 a-d
28	Experimental	3.3 cd	7.0 a-d	6.3 a-c	8.7 ab	9.0 a	2.7 c-f	5.7 ab	8.7 ab
29	Experimental	3.3 cd	6.7 a-e	6.0 a-d	9.0 a	9.0 a	2.0 e-h	5.0 a-d	8.3 a-c
30	Tifway	2.0 e-g	4.7 gh	2.0 ij	3.0 ij	8.0 a-c	1.0 h	2.3 gh	4.0 g
31	TifSport	1.7 fg	5.0 f-h	3.0 g-j	4.0 h-j	8.0 a-c	2.3 d-g	3.7 c-g	6.3 de
32	Patriot	4.0 bc	7.0 a-d	3.3 f-j	5.3 e-i	9.0 a	1.0 h	2.3 gh	7.0 c-e
33	OKC 70-18	3.0 c-e	6.0 c-g	4.0 d-i	6.0 c-h	9.0 a	2.3 d-h	4.7 a-e	7.7 a-d
34	OKC 10-82	1.0 g	3.0 ij	1.7 j	2.7 j	7.3 c	1.7 f-h	2.7 f-h	3.7 g
35	BerPC 99-6	1.0 g	3.0 ij	3.0 g-j	4.3 g-j	7.7 bc	1.0 h	2.0 gh	4.3 fg
36	Riviera	2.0 e-g	4.7 gh	3.7 e-j	5.3 e-i	8.3 a-c	1.7 f-h	3.7 c-g	6.3 de
LSD Value (0.05)		1.0	1.5	2.3	2.5	1.1	1.1	1.9	1.7

† Spring green-up measures the transition from dormancy to active growth in the spring. It was evaluated at least once annually to note the cultivars which have greened up earlier or more completely by the designated rating date. Spring green-up was rated on a 1 to 9 scale where 1 equaled tan dormant turf and 9 equaled fully green turf.
‡ Fischer's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level.

Table 7. Mean shoot density and leaf texture for thirty-six bermudagrass entries from 2004 to 2007.

		Density†				Leaf Texture‡			
		2004	2005	2006	2007	2004	2005	2006	2007
Entry	Cultivar	8-Oct	26-Jul	14-Aug	6-Jun	8-Oct	26-Jul	14-Aug	6-Jun
1	Experimental	6.7 d-f¶	6.7 f-h	7.3 ef	6.7 gh	7.0 c-e	7.3 cd	7.3 ef	7.7 cd
2	Experimental	6.3 ef	7.0 e-g	8.0 cd	7.0 fg	6.7 de	7.3 cd	7.7 de	7.3 de
3	Experimental	6.0 f	7.0 e-g	8.0 cd	7.3 ef	6.3 e	7.7 b-d	8.3 bc	7.7 cd
4	Experimental	7.3 b-e	8.0 b-d	8.0 cd	8.0 cd	7.3 b-d	8.0 bc	8.0 cd	8.0 bc
5	Experimental	7.0 c-f	7.3 d-f	8.0 cd	7.0 fg	7.7 bc	8.0 bc	8.0 cd	7.7 cd
6	Experimental	6.0 f	6.3 gh	7.0 fg	6.0 i	6.7 de	6.0 f	7.0 f	7.0 e
7	Experimental	6.3 ef	6.3 gh	7.0 fg	6.3 hi	6.7 de	7.0 de	7.0 f	7.0 e
8	Experimental	7.0 c-f	7.3 d-f	7.7 de	7.0 fg	7.3 b-d	7.0 de	8.0 cd	7.3 de
9	Experimental	7.3 b-e	8.0 b-d	8.0 cd	7.7 de	7.7 bc	7.7 b-d	8.0 cd	7.7 cd
10	Experimental	6.3 ef	7.7 c-e	8.0 cd	8.0 cd	7.7 bc	7.3 cd	8.0 cd	8.0 bc
11	Experimental	6.0 f	7.3 d-f	8.0 cd	7.0 fg	6.7 de	7.3 cd	8.0 cd	7.7 cd
12	Experimental	7.0 c-f	7.3 d-f	8.0 cd	7.3 ef	8.0 b	7.7 b-d	8.0 cd	8.0 bc
13	Experimental	6.7 d-f	7.3 d-f	8.0 cd	7.0 fg	7.3 b-d	8.0 bc	8.3 bc	7.7 cd
14	Experimental	6.7 d-f	8.3 a-c	8.0 cd	7.7 de	7.7 bc	8.3 ab	8.7 ab	8.0 bc
15	Experimental	7.7 b-d	7.7 c-e	8.0 cd	7.3 ef	7.0 c-e	7.7 b-d	8.7 ab	7.7 cd
16	Experimental	7.0 c-f	7.7 c-e	8.0 cd	7.7 de	7.3 b-d	8.3 ab	8.0 cd	8.0 bc
17	Experimental	8.0 a-c	9.0 a	8.0 cd	8.3 bc	7.7 bc	8.3 ab	8.7 ab	8.3 b
18	Experimental	8.0 a-c	8.0 b-d	8.0 cd	8.0 cd	8.0 b	8.3 ab	8.3 bc	8.0 bc
19	Experimental	7.7 b-d	7.0 e-g	8.0 cd	7.7 de	7.7 bc	7.3 cd	8.3 bc	7.7 cd
20	Experimental	8.0 a-c	8.7 ab	8.0 cd	8.7 ab	8.0 b	8.3 ab	8.3 bc	8.0 bc
21	Experimental	7.7 b-d	7.7 c-e	8.3 bc	8.0 cd	7.0 c-e	8.0 bc	8.3 bc	8.0 bc
22	Experimental	8.0 a-c	7.7 c-e	8.0 cd	7.3 ef	7.3 b-d	7.7 b-d	8.0 cd	7.3 de
23	Experimental	6.3 ef	8.0 b-d	8.0 cd	7.0 fg	7.0 c-e	7.0 de	7.7 de	7.3 de
24	Experimental	7.0 c-f	7.3 d-f	8.0 cd	7.0 fg	7.0 c-e	7.0 de	8.0 cd	7.7 cd
25	Experimental	6.7 d-f	7.7 c-e	8.0 cd	7.3 ef	6.7 de	7.7 b-d	8.0 cd	7.7 cd
26	Experimental	8.3 ab	8.3 a-c	8.0 cd	8.0 cd	8.0 b	8.3 ab	8.7 ab	8.0 bc
27	Experimental	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a
28	Experimental	9.0 a	9.0 a	8.7 ab	8.7 ab	9.0 a	9.0 a	9.0 a	9.0 a
29	Experimental	7.3 b-e	7.3 d-f	8.0 cd	8.0 cd	7.7 bc	8.0 bc	8.7 ab	8.0 bc
30	Tifway	6.7 d-f	8.0 b-d	8.0 cd	7.3 ef	7.3 b-d	7.0 de	7.7 de	7.7 cd
31	TifSport	6.3 ef	8.0 b-d	8.0 cd	7.0 fg	7.0 c-e	7.3 cd	7.7 de	7.3 de
32	Patriot	6.0 f	7.3 d-f	7.0 fg	6.7 gh	7.0 c-e	7.0 de	7.3 ef	6.3 f
33	OKC 70-18	6.3 ef	7.0 e-g	8.0 cd	7.0 fg	6.7 de	7.0 de	8.3 bc	7.7 cd
34	OKC 10-82	6.7 d-f	7.3 d-f	8.0 cd	7.0 fg	6.7 de	7.3 cd	8.0 cd	7.3 de
35	BerPC 99-6	6.3 ef	6.0 h	7.0 fg	6.0 i	6.3 e	6.3 ef	7.0 f	6.0 f
36	Riviera	6.0 f	6.3 gh	6.7 g	6.0 i	6.7 de	6.3 ef	7.0 f	6.3 f
LSD Value (0.05)		1.0	1.0	0.4	0.6	0.7	0.9	0.6	0.6

† Shoot density visually estimates the number of tillers per unit area. It was rated visually on a 1 to 9 scale such that 1 was a very sparse canopy and 9 was a very dense canopy. For example, a rating of 9 could be a *C. transvaalensis* or a very dense hybrid bermudagrass cultivar.

‡ Leaf texture visually estimates the average width of the leaf blade for a cultivar. It was rated once annually on a scale of 1 to 9 where 1 was very coarse (wide leaf blades) and 9 was very fine leaves.

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

Table 8. Mean genetic color of thirty-six bermudagrass entries from 2004 to 2007.

Genetic Color†

Entry	Cultivar	2004 20-Oct	2005 26-Jul	2006 30-Oct	2007 6-Jun
1	Experimental	7.0 e-g‡	6.7 fg	8.7 ab	7.7 cd
2	Experimental	8.7 ab	8.0 b-d	8.0 b-d	8.0 bc
3	Experimental	7.3 d-f	7.3 d-f	8.0 b-d	7.7 cd
4	Experimental	7.3 d-f	8.3 a-c	8.3 a-c	7.7 cd
5	Experimental	7.0 e-g	9.0 a	7.7 c-e	8.0 bc
6	Experimental	6.7 fg	6.7 fg	8.0 b-d	7.0 ef
7	Experimental	6.3 g	7.3 d-f	8.7 ab	7.0 ef
8	Experimental	6.7 fg	6.0 g	7.7 c-e	6.0 g
9	Experimental	7.7 c-e	7.3 d-f	9.0 a	8.0 bc
10	Experimental	8.3 a-c	9.0 a	8.0 b-d	7.7 cd
11	Experimental	7.7 c-e	8.0 b-d	8.7 ab	8.0 bc
12	Experimental	7.3 d-f	7.0 ef	8.0 b-d	7.3 de
13	Experimental	8.0 b-d	9.0 a	8.7 ab	9.0 a
14	Experimental	6.3 g	7.3 d-f	6.7 fg	6.7 f
15	Experimental	8.0 b-d	7.0 ef	9.0 a	8.0 bc
16	Experimental	8.3 a-c	8.7 ab	8.0 b-d	8.3 b
17	Experimental	7.7 c-e	8.0 b-d	7.0 ef	7.0 ef
18	Experimental	7.0 e-g	7.0 ef	7.3 d-f	7.0 ef
19	Experimental	7.3 d-f	8.3 a-c	7.7 c-e	8.0 bc
20	Experimental	6.3 g	8.0 cd	7.0 ef	7.0 ef
21	Experimental	8.0 b-d	9.0 a	7.0 ef	8.0 bc
22	Experimental	6.3 g	6.0 g	6.0 g	5.7 g
23	Experimental	8.7 ab	9.0 a	9.0 a	9.0 a
24	Experimental	7.0 e-g	8.0 b-d	7.3 d-f	7.0 ef
25	Experimental	8.7 ab	8.0 b-d	8.3 a-c	7.7 cd
26	Experimental	7.3 d-f	6.7 fg	8.7 ab	7.3 de
27	Experimental	7.3 d-f	7.7 c-e	8.7 ab	7.0 ef
28	Experimental	7.0 e-g	9.0 a	8.7 ab	7.3 de
29	Experimental	8.0 b-d	9.0 a	7.7 c-e	8.0 bc
30	Tifway	9.0 a	9.0 a	9.0 a	9.0 a
31	TifSport	9.0 a	7.7 c-e	8.7 ab	9.0 a
32	Patriot	9.0 a	9.0 a	9.0 a	9.0 a
33	OKC 70-18	7.0 e-g	7.3 d-f	8.0 b-d	7.3 de
34	OKC 10-82	8.0 b-d	6.0 g	9.0 a	8.0 bc
35	BerPC 99-6	8.0 b-d	8.0 b-d	7.7 c-e	8.3 b
36	Riviera	7.7 c-e	7.3 d-f	7.3 d-f	8.0 bc
LSD Value (0.05)		0.8	0.8	0.8	0.6

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

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

Table 9. Mean seedhead expression for thirty-six bermudagrass entries from 2005 to 2007.

		Seedhead Expression†							
		2005			2006			2007	
Entry	Cultivar	16-Aug	16-Sep	19-Oct	1-May	23-Jun	17-Oct	4-Jun	18-Jun
1	Experimental	3.7 h‡	6.7 b	5.0 c	9.0 a	8.3 b	4.0 d	6.7 de	5.0 h-k
2	Experimental	7.7 a-c	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.7 ab	7.7 a-d
3	Experimental	7.3 a-d	8.7 a	9.0 a	9.0 a	9.0 a	8.0 ab	8.3 a-c	8.0 a-c
4	Experimental	7.7 a-c	9.0 a	9.0 a	9.0 a	9.0 a	8.7 a	9.0 a	8.3 ab
5	Experimental	7.0 b-e	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	7.7 a-c	5.7 f-j
6	Experimental	6.7 c-f	9.0 a	7.3 b	9.0 a	9.0 a	4.3 d	8.0 a-c	7.0 b-f
7	Experimental	7.3 a-d	8.7 a	8.0 ab	9.0 a	9.0 a	4.7 d	7.7 a-c	5.7 f-j
8	Experimental	6.0 d-g	8.3 a	9.0 a	9.0 a	9.0 a	6.7 bc	7.0 b-d	6.3 d-h
9	Experimental	8.3 ab	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.0 a-c	7.3 a-e
10	Experimental	7.0 b-e	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	7.0 b-d	7.0 b-f
11	Experimental	8.3 ab	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.3 a-c	8.0 a-c
12	Experimental	8.3 ab	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.0 a-c	7.3 a-e
13	Experimental	7.3 a-d	8.7 a	9.0 a	9.0 a	9.0 a	7.7 a-c	8.3 a-c	7.3 a-e
14	Experimental	8.7 a	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.7 ab	8.3 ab
15	Experimental	8.0 a-c	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.7 ab	7.7 a-d
16	Experimental	7.7 a-c	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.0 a-c	7.3 a-e
17	Experimental	8.3 ab	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.0 a-c	7.7 a-d
18	Experimental	8.7 a	8.7 a	9.0 a	9.0 a	9.0 a	9.0 a	7.3 a-d	6.3 d-h
19	Experimental	5.0 gh	9.0 a	9.0 a	9.0 a	9.0 a	6.3 c	5.7 d-f	2.0 l
20	Experimental	8.0 a-c	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.7 ab	8.3 ab
21	Experimental	7.7 a-c	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	7.0 b-d	7.0 b-f
22	Experimental	7.7 a-c	9.0 a	9.0 a	9.0 a	9.0 a	8.3 a	7.7 a-c	6.7 c-g
23	Experimental	7.0 b-e	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	3.7 g	3.7 k
24	Experimental	6.7 c-f	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.0 a-c
25	Experimental	7.7 a-c	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	5.7 d-f	5.3 g-j
26	Experimental	8.0 a-c	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.3 a-c	7.7 a-d
27	Experimental	8.3 ab	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	5.0 h-k
28	Experimental	7.0 b-e	9.0 a	9.0 a	4.0 b	9.0 a	9.0 a	8.7 ab	2.0 l
29	Experimental	7.3 a-d	8.3 a	9.0 a	9.0 a	9.0 a	9.0 a	8.7 ab	8.7 a
30	Tifway	7.3 a-d	9.0 a	9.0 a	9.0 a	8.7 ab	9.0 a	5.0 e-g	4.3 jk
31	TifSport	7.3 a-d	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.3 a-c	6.3 d-h
32	Patriot	8.7 a	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.3 ab
33	OKC 70-18	5.3 fg	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	8.3 a-c	6.0 e-i
34	OKC 10-82	4.7 gh	9.0 a	9.0 a	9.0 a	5.7 c	9.0 a	8.3 a-c	4.7 i-k
35	BerPC 99-6	5.7 e-g	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	4.7 fg	2.0 l
36	Riviera	6.0 d-g	9.0 a	9.0 a	9.0 a	9.0 a	8.3 a	5.7 d-f	5.3 g-j
LSD Value (0.05)		1.5	0.8	1.1	0.1	0.4	1.5	1.7	1.6

† Seedhead expression measured the timing and intensity of inflorescence of a cultivar. It was evaluated visually on a scale of 1 to 9 where 1 signified the most quantity and the largest, most conspicuous seedheads present in the plot and 9 indicated no visible seedheads.

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

Table 10. Mean scalp damage ratings for thirty-six bermudagrass entries from 2005 to 2006.

		Scalp Damage†			
		2005		2006	
Entry	Cultivar	31-Aug	19-Oct	23-Jun	27-Jul
1	Experimental	2.7 d-h‡	8.3 a-c	7.0 e-g	5.7 c-g
2	Experimental	3.0 c-h	7.0 a-f	8.7 ab	5.0 d-h
3	Experimental	1.3 gh	4.7 g-j	7.0 e-g	4.7 e-i
4	Experimental	1.7 f-h	6.7 b-g	7.7 c-e	4.0 g-j
5	Experimental	2.3 e-h	3.0 j	8.0 b-d	3.7 h-k
6	Experimental	4.0 c-e	8.0 a-d	8.7 ab	8.3 a
7	Experimental	4.7 cd	7.7 a-e	9.0 a	8.0 ab
8	Experimental	3.3 c-g	6.3 c-h	9.0 a	7.0 a-c
9	Experimental	1.7 f-h	3.0 j	6.7 fg	1.0 l
10	Experimental	3.3 c-g	5.7 e-i	7.3 d-f	4.0 g-j
11	Experimental	3.0 c-h	6.0 d-i	7.7 c-e	3.3 h-k
12	Experimental	1.0 h	6.7 b-g	8.3 a-c	5.0 d-h
13	Experimental	3.0 c-h	7.0 a-f	7.0 e-g	4.7 e-i
14	Experimental	1.0 h	4.0 ij	8.0 b-d	5.7 c-g
15	Experimental	2.0 e-h	2.7 j	6.7 fg	1.0 l
16	Experimental	2.7 d-h	4.3 h-j	7.7 c-e	4.7 e-i
17	Experimental	1.3 gh	5.7 e-i	8.3 a-c	4.7 e-i
18	Experimental	1.7 f-h	4.7 g-j	9.0 a	5.7 c-g
19	Experimental	3.0 c-h	6.3 c-h	8.7 ab	6.0 c-f
20	Experimental	2.0 e-h	6.0 d-i	7.7 c-e	4.3 f-j
21	Experimental	3.7 c-f	7.7 a-e	9.0 a	5.7 c-g
22	Experimental	1.0 h	6.7 b-g	8.0 b-d	5.0 d-h
23	Experimental	2.3 e-h	8.7 ab	9.0 a	4.7 e-i
24	Experimental	2.7 d-h	7.7 a-e	7.3 d-f	6.3 b-e
25	Experimental	2.7 d-h	8.0 a-d	8.7 ab	6.7 a-d
26	Experimental	1.0 h	5.3 f-i	8.7 ab	4.7 e-i
27	Experimental	1.0 h	6.7 b-g	7.0 e-g	2.0 kl
28	Experimental	1.0 h	6.7 b-g	8.7 ab	2.7 j-l
29	Experimental	3.7 c-f	8.0 a-d	6.3 g	4.0 g-j
30	Tifway	2.3 e-h	8.3 a-c	8.7 ab	4.3 f-j
31	TifSport	3.7 c-f	9.0 a	8.7 ab	5.7 c-g
32	Patriot	2.0 e-h	4.7 g-j	8.7 ab	3.0 i-k
33	OKC 70-18	5.0 bc	8.0 a-d	9.0 a	3.7 h-k
34	OKC 10-82	2.3 e-h	8.3 a-c	8.7 ab	7.3 a-c
35	BerPC 99-6	7.3 a	6.7 b-g	9.0 a	7.3 a-c
36	Riviera	7.0 ab	8.3 a-c	9.0 a	8.0 ab
LSD Value (0.05)		2.1	2.1	0.9	1.9

† Scalp Damage measured the severity of injury and visual disruption to the turf canopy by mowing. It was rated on a 1 to 9 scale where 1 equaled most severe scalp damage and 9 equaled no scalp damage.
‡ Fischer's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level.

Table 11. Mean turfgrass quality of thirty-six bermudagrass entries in 2004.

		2004 Turfgrass Quality†		
Entry	Cultivar	13-Aug	15-Sep	18-Oct
1	Experimental	7.3 a-d‡	7.0 c-g	7.0 d-f
2	Experimental	6.7 c-f	7.7 a-e	7.7 b-e
3	Experimental	6.7 c-f	6.3 e-i	6.7 e-g
4	Experimental	7.3 a-d	8.3 a-c	8.3 a-c
5	Experimental	8.0 a-c	8.0 a-d	7.3 c-e
6	Experimental	7.0 b-e	8.3 a-c	8.3 a-c
7	Experimental	7.0 b-e	7.3 b-f	7.3 c-e
8	Experimental	8.0 a-c	8.3 a-c	7.7 b-e
9	Experimental	6.7 c-f	6.0 f-i	6.7 e-g
10	Experimental	7.0 b-e	7.7 a-e	7.7 b-e
11	Experimental	6.3 d-f	7.0 c-g	7.7 b-e
12	Experimental	8.0 a-c	8.0 a-d	8.3 a-c
13	Experimental	7.7 a-d	7.3 b-f	7.3 c-e
14	Experimental	8.0 a-c	8.0 a-d	7.7 b-e
15	Experimental	5.3 fg	6.0 f-i	6.7 e-g
16	Experimental	7.7 a-d	8.3 a-c	8.3 a-c
17	Experimental	8.3 ab	8.0 a-d	8.3 a-c
18	Experimental	8.7 a	8.3 a-c	8.3 a-c
19	Experimental	7.3 a-d	7.7 a-e	7.7 b-e
20	Experimental	8.3 ab	8.7 ab	8.7 ab
21	Experimental	8.7 a	9.0 a	9.0 a
22	Experimental	8.0 a-c	8.7 ab	8.7 ab
23	Experimental	5.7 e-g	5.7 g-i	6.7 e-g
24	Experimental	8.7 a	8.7 ab	8.3 a-c
25	Experimental	8.0 a-c	8.0 a-d	8.0 a-d
26	Experimental	8.3 ab	8.3 a-c	7.3 c-e
27	Experimental	7.3 a-d	7.0 c-g	8.0 a-d
28	Experimental	6.7 c-f	7.3 b-f	7.7 b-e
29	Experimental	8.3 ab	8.7 ab	8.7 ab
30	Tifway	5.7 e-g	6.0 f-i	6.7 e-g
31	TifSport	6.3 d-f	6.7 d-h	6.7 e-g
32	Patriot	6.3 d-f	7.0 c-g	7.0 d-f
33	OKC 70-18	5.3 fg	5.0 i	5.7 gh
34	OKC 10-82	4.3 g	5.0 i	6.0 f-h
35	BerPC 99-6	6.3 d-f	5.7 g-i	5.7 gh
36	Riviera	6.7 c-f	5.3 hi	5.3 h
LSD Value (0.05)		1.3	1.4	1.2

† Turfgrass quality measures the aesthetic properties of a cultivar. It is evaluated monthly during the growing season. Turfgrass quality was rated on a 1 to 9 scale where 9 was ideal.
‡ Fischer’s protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level.

Table 12. Mean turfgrass quality of thirty-six bermudagrass entries in 2005.

		2005 Turfgrass Quality†				
Entry	Cultivar	25-May	14-Jul	16-Aug	16-Sep	26-Oct
1	Experimental	6.3 c-e‡	7.7 ab	6.0 f	7.0 d	5.0 g
2	Experimental	7.3 a-d	8.0 a	8.7 ab	9.0 a	6.3 d-f
3	Experimental	8.0 ab	8.0 a	9.0 a	9.0 a	5.7 fg
4	Experimental	7.3 a-d	8.0 a	9.0 a	9.0 a	6.7 c-f
5	Experimental	6.3 c-e	8.0 a	8.7 ab	9.0 a	6.3 d-f
6	Experimental	6.7 b-d	7.0 cd	7.7 cd	8.0 c	6.3 d-f
7	Experimental	6.7 b-d	7.3 bc	8.0 bc	8.3 bc	6.0 e-g
8	Experimental	7.0 b-d	7.7 ab	8.0 bc	8.0 c	5.7 fg
9	Experimental	4.7 fg	7.3 bc	7.0 de	9.0 a	6.7 c-f
10	Experimental	7.0 b-d	7.7 ab	8.7 ab	9.0 a	7.0 b-e
11	Experimental	7.0 b-d	8.0 a	9.0 a	9.0 a	6.3 d-f
12	Experimental	7.0 b-d	8.0 a	9.0 a	9.0 a	6.7 c-f
13	Experimental	7.0 b-d	8.0 a	8.3 a-c	8.7 ab	7.0 b-e
14	Experimental	8.7 a	7.0 cd	8.3 a-c	9.0 a	6.0 e-g
15	Experimental	4.0 g	8.0 a	6.0 f	9.0 a	5.0 g
16	Experimental	7.7 a-c	8.0 a	9.0 a	9.0 a	6.3 d-f
17	Experimental	6.7 b-d	8.0 a	9.0 a	9.0 a	6.0 e-g
18	Experimental	6.0 d-f	8.0 a	8.7 ab	9.0 a	6.3 d-f
19	Experimental	6.7 b-d	8.0 a	7.0 de	8.7 ab	7.0 b-e
20	Experimental	7.0 b-d	8.0 a	8.3 a-c	9.0 a	6.3 d-f
21	Experimental	6.7 b-d	8.0 a	8.7 ab	9.0 a	6.7 c-f
22	Experimental	7.3 a-d	7.7 ab	8.7 ab	9.0 a	6.7 c-f
23	Experimental	6.3 c-e	8.0 a	9.0 a	9.0 a	7.7 a-c
24	Experimental	7.7 a-c	8.0 a	8.0 bc	9.0 a	7.3 b-d
25	Experimental	7.7 a-c	8.0 a	9.0 a	9.0 a	7.3 b-d
26	Experimental	7.0 b-d	8.0 a	9.0 a	9.0 a	6.0 e-g
27	Experimental	8.7 a	7.3 bc	8.3 a-c	9.0 a	7.0 b-e
28	Experimental	7.3 a-d	6.7 d	8.0 bc	9.0 a	6.3 d-f
29	Experimental	8.7 a	8.0 a	8.7 ab	9.0 a	6.7 c-f
30	Tifway	6.3 c-e	8.0 a	9.0 a	9.0 a	8.0 ab
31	TifSport	7.0 b-d	8.0 a	8.7 ab	8.7 ab	8.7 a
32	Patriot	6.7 b-d	8.0 a	9.0 a	9.0 a	6.7 c-f
33	OKC 70-18	6.3 c-e	7.7 ab	7.0 de	9.0 a	7.7 a-c
34	OKC 10-82	4.3 g	7.3 bc	6.7 ef	9.0 a	7.7 a-c
35	BerPC 99-6	4.7 fg	7.3 bc	7.7 cd	8.7 ab	6.0 e-g
36	Riviera	5.0 e-g	6.7 d	7.0 de	8.0 c	7.0 b-e
LSD Value (0.05)		1.4	0.5	0.8	0.4	1.2

† Turfgrass quality measures the aesthetic properties of a cultivar. It is evaluated monthly during the growing season. Turfgrass quality was rated on a 1 to 9 scale where 9 was ideal.
‡ Fischer's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level.

Table 13. Mean turfgrass quality of thirty-six bermudagrass entries in 2006.

		2006 Turfgrass Quality†				
Entry	Cultivar	22-May	23-Jun	14-Aug	15-Sep	17-Oct
1	Experimental	7.3 a-c‡	8.0 c	7.7 a-c	6.7 b	6.3 e
2	Experimental	7.3 a-c	9.0 a	8.3 ab	9.0 a	9.0 a
3	Experimental	8.0 a	8.0 c	7.3 a-c	8.0 a	7.3 c-e
4	Experimental	8.0 a	8.3 bc	8.3 ab	8.7 a	8.7 ab
5	Experimental	8.0 a	8.3 bc	7.3 a-c	8.7 a	8.7 ab
6	Experimental	7.3 a-c	9.0 a	9.0 a	8.3 a	7.3 c-e
7	Experimental	7.3 a-c	9.0 a	8.3 ab	8.7 a	7.0 de
8	Experimental	7.0 b-d	9.0 a	9.0 a	8.3 a	7.3 c-e
9	Experimental	8.0 a	8.0 c	4.0 d	3.3 c	7.7 b-d
10	Experimental	8.0 a	8.3 bc	9.0 a	8.3 a	8.7 ab
11	Experimental	8.0 a	8.0 c	7.7 a-c	8.7 a	8.7 ab
12	Experimental	8.0 a	9.0 a	8.3 ab	8.0 a	8.3 a-c
13	Experimental	8.0 a	8.0 c	8.0 a-c	8.7 a	8.0 a-d
14	Experimental	8.0 a	8.7 ab	8.7 ab	9.0 a	8.3 a-c
15	Experimental	8.0 a	8.0 c	4.0 d	3.3 c	7.3 c-e
16	Experimental	7.7 ab	8.3 bc	8.0 a-c	8.0 a	8.7 ab
17	Experimental	8.0 a	8.7 ab	9.0 a	8.0 a	8.0 a-d
18	Experimental	6.7 cd	9.0 a	8.0 a-c	8.3 a	8.3 a-c
19	Experimental	7.0 b-d	9.0 a	8.0 a-c	8.3 a	7.7 b-d
20	Experimental	7.7 ab	9.0 a	8.7 ab	8.0 a	8.7 ab
21	Experimental	8.0 a	9.0 a	9.0 a	8.7 a	8.7 ab
22	Experimental	8.0 a	8.7 ab	9.0 a	9.0 a	8.0 a-d
23	Experimental	7.0 b-d	9.0 a	6.3 c	5.7 b	7.7 b-d
24	Experimental	8.0 a	8.3 bc	7.7 a-c	8.0 a	8.7 ab
25	Experimental	7.7 ab	8.7 ab	8.3 ab	8.7 a	9.0 a
26	Experimental	7.7 ab	9.0 a	8.0 a-c	8.3 a	9.0 a
27	Experimental	8.0 a	8.0 c	7.7 a-c	8.3 a	9.0 a
28	Experimental	7.0 b-d	9.0 a	8.7 ab	8.7 a	8.3 a-c
29	Experimental	8.0 a	8.0 c	8.0 a-c	8.7 a	8.3 a-c
30	Tifway	7.7 ab	9.0 a	7.0 bc	8.0 a	8.3 a-c
31	TifSport	7.0 b-d	9.0 a	9.0 a	8.0 a	8.7 ab
32	Patriot	7.7 ab	9.0 a	7.0 bc	8.3 a	8.7 ab
33	OKC 70-18	8.0 a	9.0 a	8.0 a-c	8.3 a	8.3 a-c
34	OKC 10-82	6.3 d	8.7 ab	8.7 ab	8.0 a	8.0 a-d
35	BerPC 99-6	6.7 cd	9.0 a	8.0 a-c	8.7 a	7.7 b-d
36	Riviera	6.7 cd	9.0 a	8.3 ab	8.7 a	8.3 a-c
LSD Value (0.05)		0.7	0.5	1.7	1.3	1.1

† Turfgrass quality measures the aesthetic properties of a cultivar. It is evaluated monthly during the growing season. Turfgrass quality was rated on a 1 to 9 scale where 9 was ideal.
‡ Fischer's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level.

Table 14. Mean turfgrass quality for thirty-six bermudagrass entries in 2007.

		2007 Turfgrass Quality†					
Entry	Cultivar	May	Jun	Jul	Aug	Oct	Times in Top Statistical Group‡
1	Experimental	8.0 a§	7.7 c-e	7.7 ab	8.7 b	6.7 cd	6
2	Experimental	8.0 a	9.0 a	8.0 a	9.0 a	8.0 a	15
3	Experimental	7.7 ab	9.0 a	7.3 bc	9.0 a	7.0 b-d	10
4	Experimental	8.0 a	9.0 a	8.0 a	9.0 a	8.0 a	16
5	Experimental	8.0 a	7.7 c-e	7.3 bc	9.0 a	7.7 ab	12
6	Experimental	8.0 a	8.3 a-c	8.0 a	9.0 a	6.7 cd	10
7	Experimental	8.0 a	8.3 a-c	8.0 a	9.0 a	6.3 d	8
8	Experimental	8.0 a	8.3 a-c	8.0 a	9.0 a	7.7 ab	11
9	Experimental	8.0 a	9.0 a	8.0 a	7.0 c	7.3 a-c	6
10	Experimental	8.0 a	9.0 a	8.0 a	9.0 a	8.0 a	13
11	Experimental	8.0 a	9.0 a	8.0 a	9.0 a	7.7 ab	12
12	Experimental	8.0 a	9.0 a	7.7 ab	9.0 a	8.0 a	16
13	Experimental	8.0 a	9.0 a	7.7 ab	9.0 a	7.0 b-d	12
14	Experimental	7.7 ab	9.0 a	7.3 bc	9.0 a	7.7 ab	10
15	Experimental	8.0 a	8.7 ab	7.3 bc	7.0 c	8.0 a	6
16	Experimental	8.0 a	9.0 a	7.3 bc	9.0 a	7.7 ab	15
17	Experimental	8.0 a	8.3 a-c	8.0 a	9.0 a	8.0 a	16
18	Experimental	8.0 a	8.3 a-c	8.0 a	9.0 a	8.0 a	15
19	Experimental	7.3 bc	6.0 f	7.7 ab	9.0 a	7.7 ab	10
20	Experimental	7.7 ab	9.0 a	8.0 a	9.0 a	8.0 a	16
21	Experimental	8.0 a	9.0 a	8.0 a	9.0 a	8.0 a	16
22	Experimental	8.0 a	8.7 ab	8.0 a	9.0 a	8.0 a	17
23	Experimental	8.0 a	7.3 de	7.7 ab	9.0 a	8.0 a	9
24	Experimental	8.0 a	9.0 a	8.0 a	9.0 a	8.0 a	15
25	Experimental	7.7 ab	8.3 a-c	8.0 a	9.0 a	8.0 a	17
26	Experimental	8.0 a	9.0 a	7.7 ab	9.0 a	8.0 a	15
27	Experimental	8.0 a	9.0 a	8.0 a	9.0 a	8.0 a	14
28	Experimental	7.0 cd	8.0 b-d	8.0 a	9.0 a	7.7 ab	9
29	Experimental	8.0 a	9.0 a	8.0 a	9.0 a	7.7 ab	16
30	Tifway	8.0 a	7.0 e	8.0 a	9.0 a	8.0 a	12
31	TifSport	8.0 a	8.0 b-d	7.0 c	8.7 b	8.0 a	10
32	Patriot	8.0 a	9.0 a	7.7 ab	8.7 b	7.0 b-d	10
33	OKC 70-18	8.0 a	8.7 ab	7.7 ab	8.7 b	7.7 ab	12
34	OKC 10-82	8.0 a	7.7 c-e	8.0 a	9.0 a	8.0 a	10
35	BerPC 99-6	6.3 e	4.3 g	7.0 c	9.0 a	7.0 b-d	5
36	Riviera	6.7 de	5.7 f	7.3 bc	9.0 a	7.0 b-d	5
LSD Value (0.05)		0.5	1.0	0.6	0.3	0.7	

† Turfgrass quality measures the aesthetic properties of a cultivar. It is evaluated monthly during the growing season. Turfgrass quality was rated on a 1 to 9 scale where 9 was ideal.
‡ Number of times (rating dates) that the entry's turfgrass quality mean appeared in the top statistical ranking group. There were 18 total quality rating dates (2004-2007).
§ Fischer's protected LSD test: within columns, means followed by the same letter are not significantly different at the p=0.05 level.

Sod Tensile Strength and Handling Quality

Plot Preparation for Sod Harvest

In the process of screening sod tensile strength and handling characteristics in this project, height of cut was not raised to that typically used on Oklahoma sod farms. This was due to the fact that entries were being tested for performance at the 1.3 cm fairway height of cut. According to the literature for bermudagrass sod research, there was no significant difference for sod strength within a given cultivar (both Tifway and Tifgreen were tested) based on varying height of cut from 1.25 cm to 2.50 cm (Mitchell and Dickens, 1979). Therefore, it was determined that for the purpose of screening cultivars for general sod characteristics, no special mowing practices would be required in preparation for this twice performed (Oct 2004 and June – July 2005) sod tensile strength and handling quality screening test.

Sod Tensile Strength

Cultivar effects for STS (Table 15) were highly significant. In 2004, STS ranged from a low of 19 (BerPC 99-6) to a high of over 186 kg dm^{-2} (entry 29). During 2005 STS ranged from a low of 44 (Riviera) to 157 (entry 29) kg dm^{-2}. The mean STS of Tifway, entries 6, 16, 21, and 29 were among the highest in 2004 and 2005 (Table 17). TifSport and Patriot had STS means greater than 95 kg dm^{-2} in 2004 and 2005. Riviera had STS means below 45 kg dm^{-2} in both years and grouped among the poorest performers for STS. There was no difference between BerPC 99-6 and Riviera for STS during either harvest. Sod tensile strength was well correlated with sod handling quality ($r=0.73$, $p=0.001$, $N=72$) within this experiment.

Sod Handling Quality

The cultivar effects for SHQ (Table 16) were highly significant. Tifway, TifSport, and Patriot had very good to excellent SHQ in 2004 and 2005 (Table 17). Most entries provided very good to excellent sod handling quality (means greater than or equal to 4.0) suggesting suitability for commercialization for sod applications. The entries with SHQ means below 4.0 in 2004 included entries 9, 14, 19, 27, 28, OKC 70-18, OKC 10-82, BerPC 99-6, and Riviera, with BerPC 99-6 the only entry with an unsatisfactory rating ($\leq$3.0). During 2005, Riviera was the only entry to have a mean SHQ below 4.0 with a mean value of 3.7. Although not compared, the mean SHQ of nearly all entries was equal to or greater than their 2004 rating during the 2005 harvest. BerPC 99-6 improved substantially in SHQ with a mean of 2.0 in 2004 and 4.3 in 2005. While it is uncertain the reason for the overall increase in SHQ from 2004 to 2005, plant maturity could have been responsible. The SHQ and STS of OKC 70-18 had mean values of 4.3 rating units and 81.6 kg dm^{-2}, respectively, in 2005. These values are higher than those found by Han (see Chapter II), where STS never exceeded 36 kg dm^{-2} during 5 harvests and in one harvest was rated for a SHQ at 4.0. In that work, sod was mowed at 3.8 cm at a frequency of 1 to 2 times wk^{-1} which is typical for the Oklahoma sod industry. A mowing height of 1.3 cm with mowing frequency up to 3 times wk^{-1} was used in this study. While OKC 70-18 always ranked in the lowest performance group for both SHQ and STS during both harvests in this research, the improvement in handling characteristics from 2004 to 2005 was encouraging. Additionally testing of production phase mowing heights below 3.8 cm and increased mowing frequencies seems justified in order to elucidate management practices to aid in improving STS and SHQ of OKC 70-18.

During both years of sod harvest, the seeded entries BerPC 99-6 and Riviera had the poorest sod tensile strength (STS) and sod handling quality (SHQ) within the trial (Table 17). There was no difference between the STS of BerPC 99-6 and Riviera. This is not unexpected considering that when breeding and developing seeded bermudagrasses, they are generally not selected with sod applications in mind, and a poor performance for sod production criteria would typically not be of major concern to a researcher.

Table 15. Analysis of variance for sod tensile strength of thirty-six bermudagrass entries.

Source	degrees of freedom	mean square	significance level
Cultivar (Cult)	35	19497	**
Block	2	1592	NS†
Error a (Cult x Block)	70	1282	
Date	1	3017	NS
Date x Cult	35	1355	*
Error b (Date x Block [Cult])	72	809	
Total	115		

* Significant at the 0.05 probability level.

** Significant at the 0.001 probability level.

† NS, nonsignificant at the 0.05 probability level.

Table 16. Analysis of variance for sod handling quality of thirty-six bermudagrass entries.

Source	degrees of freedom	mean square	significance level
Cultivar (Cult)	35	4.1	*
Block	2	0.8	NS†
Error a (Cult x Block)	70	0.4	
Date	1	36.8	*
Date x Cult	35	1.3	*
Error b (Date x Block [Cult])	72	0.4	
Total	115		

* Significant at the 0.001 probability level.

† NS, nonsignificant at the 0.05 probability level.

Table 17. Mean sod handling quality and mean sod tensile strength for two sod harvests of thirty-six bermudagrasses.

	Sod Characteristics†			
	Handling Quality‡		Tensile Strength	
	2004	2005	2004	2005
Entry			------------------kg dm^{-2} §------------------	
1 Experimental	4.6 a-c¶	5.0 a	105.3 f-l	93.8 i-k
2 Experimental	5.0 a	5.0 a	147.8 b-d	112.5 f-j
3 Experimental	5.0 a	5.0 a	121.6 d-h	115.9 e-j
4 Experimental	4.9 a	4.7 ab	91.2 g-n	83.7 kl
5 Experimental	4.8 ab	5.0 a	86.0 i-n	96.6 i-k
6 Experimental	4.7 a-c	5.0 a	143.5 b-e	149.4 bc
7 Experimental	4.7 a-c	5.0 a	126.5 c-f	126.4 c-f
8 Experimental	4.4 a-d	5.0 a	83.4 j-n	114.6 e-j
9 Experimental	3.4 f-h	5.0 a	62.7 no	86.3 k
10 Experimental	4.7 a-c	5.0 a	113.4 d-j	127.5 c-f
11 Experimental	4.7 ab	5.0 a	148.1 b-d	131.0 c-f
12 Experimental	5.0 a	5.0 a	124.6 d-g	117.5 e-i
13 Experimental	4.9 a	5.0 a	135.1 b-f	113.1 f-j
14 Experimental	3.8 e-g	4.8 ab	66.9 no	79.9 kl
15 Experimental	4.2 b-e	4.9 ab	72.3 l-o	85.4 k
16 Experimental	5.0 a	5.0 a	168.6 ab	145.2 b-d
17 Experimental	4.7 a-c	5.0 a	84.6 j-n	99.3 g-k
18 Experimental	4.6 a-c	5.0 a	102.3 f-m	117.7 e-i
19 Experimental	3.4 f-h	4.7 ab	78.3 k-n	94.8 i-k
20 Experimental	5.0 a	5.0 a	122.8 d-h	124.0 d-g
21 Experimental	5.0 a	5.0 a	185.6 a	162.7 ab
22 Experimental	4.9 a	5.0 a	131.4 c-f	139.2 b-e
23 Experimental	4.6 a-c	5.0 a	116.7 d-j	128.3 c-f
24 Experimental	4.8 ab	5.0 a	119.6 d-i	122.6 d-h
25 Experimental	4.6 a-c	5.0 a	111.4 e-k	124.3 d-f
26 Experimental	4.1 c-f	5.0 a	88.5 h-n	93.4 i-k
27 Experimental	3.7 e-g	4.7 ab	66.4 no	95.8 i-k
28 Experimental	3.3 gh	4.6 ab	63.4 no	78.8 kl
29 Experimental	5.0 a	5.0 a	186.2 a	175.1 a
30 Tifway	4.8 ab	5.0 a	161.3 a-c	143.7 b-d
31 TifSport	5.0 a	5.0 a	116.6 d-j	124.3 d-f
32 Patriot	4.7 a-c	5.0 a	102.6 f-m	98.0 h-k
33 OKC 70-18	3.8 d-g	4.3 b	68.8 m-o	81.6 kl
34 OKC 10-82	3.2 gh	4.5 ab	60.1 no	92.5 jk
35 BerPC 99-6	2.0 i	4.3 b	19.0 p	59.7 lm
36 Riviera	3.0 h	3.7 c	40.6 op	44.2 m
LSD (0.05)	0.7	0.6	34.8	25.0

† Sod was harvested in Oct 2004 and again Jun-Jul 2005, using a walk behind sod cutter in three replications per harvest date with three sub-samples per observation.

‡ Sod handling quality was measured on a 1 to 5 scale where 1=poor quality, complete breakage of sod during handling; 2=fair, not commercially recommended, substantial cracking of sod during handling; 3=good, our suggested minimum for industry handling, moderate cracking of the sod occurred; 4=very good, minimal cracking, our suggested minimum for cultivar commercialization; and 5 = excellent, very tight, no cracking. Factors influencing quality assessment was the uniformity and smoothness of sod pad edges as well as its ability to hold together under its own weight when suspended vertically by the laborer.

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

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

CONCLUSIONS

Once the turf was fully established, all entries in this study maintained percent living cover (PLC) at or very near 100 percent, suggesting that all entries are suitably adapted to the test site and maintenance regime. Knowing that all entries could survive the trial and its rigors, one can then focus on selection of only the most elite performers from this multi-year cultivar screening trial. While there were mean separations among entries for shoot density, leaf texture, and genetic color, all of the entries possessed satisfactory ratings considered suitable for use in the commercial market. Turfgrass quality ratings for all entries during the four years of this study were satisfactory and none of the entries should be excluded from consideration for commercialization based solely upon its monthly turfgrass quality performance.

Of all clonal entries, entry 1 expressed prolific seedhead production most frequently. For a clonal cultivar, frequent and or prolific seedhead expression is considered an aesthetically unfavorable trait. With so many other excellent clonal cultivars that rarely, if ever, expressed seedheads, entry 1 should not be considered for commercialization. Entries 9 and 15 consistently experienced severe scalping damage and there were many entries in this study which consistently exhibited significantly less damage; these two entries are not suitable candidates for commercialization. Patriot was also noted to have scalp damage within this study, a finding which was consistent with those published in the 2002-2006 NTEP bermudagrass trial (Morris, 2007). Patriot bermudagrass appears inherently more vulnerable to scalping damage than other cultivars. Although prone to scalping, the improved winter hardiness of Patriot, as well as its ability to tolerate wear and recover rapidly from injury, has made it a favorite among sports turf managers (Dennis Martin, personal communication, 2008). It was observed that seeded types in this study experienced very minimal scalp damage in comparison with the clonal entries. The mechanism by which these two seeded types more effectively avoid scalping injury than the clonal bermudagrasses should be explored.

Percent living cover during establishment, spring green-up, and fall color retention require further investigation before any conclusive statements can be made regarding these parameters. It is believed that the establishment PLC ratings in this particular study may have reflected not only the inherent spreading capabilities of the cultivars, but also their ability to successfully compete against rapidly establishing annual broadleaves and grasses weeds, thus compromising the integrity of the establishment spread measurement. It would be beneficial information to further explore the spring green-up behavior of the materials in this study, while including a few cultivars with known vulnerability to winterkill, to confirm whether the plots in Stillwater may have experienced such damage which went undetected within this study. Fall color retention findings for Tifway, TifSport and Patriot are consistent with the findings of the 2002-2006 NTEP bermudagrass trial which suggest that Patriot goes off color earlier than either Tifway or TifSport. Only one year of data were collected and additional studies should be conducted for fall color retention before making any conclusive statements as to the inherent cultivar performance of experimental entries within this study.

The sod tensile strength and sod handling quality were well correlated ($r=0.73$, $p=0.001$, $N=72$) within this study. The good correlation between STS and SHQ is consistent with findings reported in chapter II. This correlation of STS and SHQ suggests that the SHQ technique, when used in conjunction with the STS measurement, may assist researchers in selecting suitable sod performers in cultivar evaluations for final stage experimental materials. With the new SHQ technique, a researcher would have access to both quantitative measurements of tensile strength values for cultivars as well as qualitative assessments of sod handling. This may resolve the unending issue of searching for an undisputed critical minimum STS value for a given turfgrass species. Additionally, this qualitative SHQ rating may offer valuable information for making decisive conclusions regarding whether or not a cultivar will be acceptable commercial sod production. However, the STS measurement is still a necessary evaluation to quantitatively rank the entries which exhibit suitable sod handling.

Most entries within this study possessed very good to excellent sod handling quality (means ≥ 4.0). Entries which possessed mean SHQ greater than or equal to 4.0 are believed to be suitable for commercialization for sod applications using traditional harvest and handling methods. Therefore, clonal entries within this study which possessed “acceptable” (means ≥ 3.0) but not consistently the “very good” level (means ≥ 4.0) of sod handling quality during both of the two harvests (entries 9, 14, 19, 27, 28, and OKC 10-82) would not be acceptable for commercialization for sod production unless they are found to otherwise produce superior visual and functional characteristics allowing for their deficiencies in sod handling quality to be overlooked. In 2004, OKC 70-18 had mean SHQ of 3.8 which was considered at least “minimum commercially acceptable,” whereas in 2005, OKC 70-18 had mean SHQ of 4.3 which suggested it performed “very good” for sod handling in 2005. Further testing is recommended to evaluate whether sod maturity was indeed a factor influencing the improved SHQ means of many entries during the 2005 sod harvest.

Both seeded entries, BerPC 99-6 and Riviera, ranked low for SHQ and had marginal or unsatisfactory means. Riviera is a popular seeded bermudagrass for use on golf course fairways and athletic facilities and currently is grown as sod by four sod producers. If a seeded type bermudagrass is desired by the marketplace, sod producers will also engage in extended measures or relax handling quality standards to provide a desired product even if the sod handling quality of the cultivar is not considered superior. Although BerPC 99-6 ranked low for SHQ in this study, this should not by itself exclude this cultivar from further research or for commercialization as a seed-propagated bermudagrass. Selective breeding has not yet been focused on producing a seed propagated bermudagrass with superior sod handling characteristics. However, if feasible, excellent sod production characteristics would be an added bonus in addition to superior visual and functional characteristics of an otherwise elite seeded bermudagrass.

Tifway and Patriot provided STS and SHQ consistent with the findings in chapter II for the sod studies mowed 1 to 2 times wk^{-1} at 3.8 cm. However, OKC 70-18 provided higher mean STS and SHQ values in this study, which was mowed up to 3 times wk^{-1} at 1.3 cm, than what was reported for OKC 70-18 in chapter II. It was not anticipated that adjusting mowing height and frequency from golf course fairway management (3 times wk^{-1} at 1.3 cm) to traditional Oklahoma sod production management (1 to 2 times wk^{-1} at 3.8 cm) would affect a cultivar for sod strength testing. This belief was formed based upon work by Mitchell and Dickens (1979) which did not find mowing height to consistently affect the sod tensile strength of Tifway or Tifgreen. Mitchell and Dickens (1979) reported that in one year Tifway STS increased as mowing height increased, but that in another year, the opposite effect took place. Based upon increased STS and SHQ of OKC 70-18 in this work as compared to that found in chapter II, the effect of mowing height and frequency on a cultivar's STS and SHQ should be further explored. If STS and SHQ of OKC 70-18 can be increased by decreasing mowing height, increasing mowing frequency, and extending the length of the production cycle then such techniques may make commercial production of OKC 70-18 as well as other cultivars with weak handling characteristics commercially feasible.

Selecting superior turfgrass cultivars from a given population is primarily a process of elimination. During the first year, establishment rate of spread is identified. This criterion helps categorize a potential marketplace fit for a cultivar. Slower spreading cultivars would not be suitable for golf course and sports turf, but would be desirable for landscapes and home lawns. An initial sod harvest may also be achieved in the first year. For clonal bermudagrasses, favorable sod characteristics are of key economic importance. Therefore cultivars with very good and excellent SHQ and high ranking STS values were favored. After the second year sod harvest, any clonally-propagated cultivar whose sod characteristics were marginal or unacceptable, consistently ranking low would be eliminated from further consideration for sod production. In the second year, plant materials with unacceptable shoot density, leaf texture, and genetic color could be identified. By this point, two years of data (including juvenile and mature plant evaluations) would be available. Additional years of data would confirm the findings for these parameters. Beginning in the second year, scalp damage (SCDM) and prolific seedhead expression (SHE) could be identified among the cultivars. However, it would not be until the third year data is analyzed that decisions could be made to exclude a cultivar which had consistently unacceptable SCDM and SHE. Due to mild weather in some years and severe winters during others, spring green-up and fall color retention should be observed for multiple years before conclusions could be made to eliminate a given cultivar. While percent living cover and turfgrass quality are evaluated multiple times annually, conclusions regarding adaptability of a cultivar based on these two parameters would require long-term data collection, preferably over four or more years of plant growth. After unacceptable cultivars have been excluded from consideration for commercialization, then superior cultivars for performance parameters such as sod characteristics and divot recovery can be identified.

Due to excellent turf-type performance as compared to Tifway, TifSport, Patriot, and Riviera in divot injury recovery at one week after treatment (data not shown), sod tensile strength, sod handling characteristics and overall visual characteristics, entries 21 and 29 (now identified as OKC 1119 and OKC 1134 respectively) were selected for sponsorship by Oklahoma State University in the 2007-2011 National Turfgrass Evaluation Program (NTEP) Bermudagrass Trial. Additionally, these two materials are currently being tested for sod productions characteristics under a Non-Released Plant Material Transfer Agreement with Oakwood Sod Farms of Delmar, MD.

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VITA

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Master of Science

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Title of Study: DEVELOPMENT OF IMPROVED TURF-TYPE BERMUDAGRASSES

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Scope and Method of Study: Study I: 'Patriot' (OKC 18-4) and 'OKC 70-18' hybrid bermudagrasses (*C. dactylon* L. Pers. X *C. transvaalensis* Burtt-Davy) were evaluated for sod tensile strength (STS) and sod handling quality (SHQ). 'Tifway' (Tifton 419),and 'Midlawn' (A-22) were included as standards of comparison. The STS was measured as peak force (kg dm^{-2}) to tear apart sod pads that were 30.5 cm wide by 1.5-1.6 cm thick. The SHQ was rated on a 1 to 5 scale where 5 was excellent. Five sod harvests were conducted over 4 years. Study II: Thirty-two final stage bermudagrass (*Cynodon* species) selections were evaluated from 2004 to 2007 for visual performance (VP) features, STS and SHQ under golf course fairway (1.3 cm mowing height) conditions, Tifway, Patriot, 'TifSport' and 'Riviera' were included as standards of comparison. The VP ratings included spring green-up, shoot density, leaf texture, genetic color, seedhead expression, scalp damage, fall color retention and turf quality which were rated on a 1 to 9 scale where 9 was ideal. Percent living cover was evaluated on a 0 to 100 scale.

Findings and Conclusions: Study I: The SHQ strongly correlated with STS (r=0.89, p=0.001, N=20) for the five sod harvests comparing Tifway, Patriot, OKC 70-18, and Midlawn. Patriot provided STS greater than or equal to Tifway in 4 of 5 harvests. OKC 70-18 provided lower STS than Tifway in all 5 harvests. OKC 70-18 provided STS equal to Midlawn in 3 harvests and less than Midlawn in 2 harvests. Results agreed well with sod producer comments in that Patriot and Tifway have good sod handling characteristics while Midlawn has minimally acceptable to poor sod handling characteristics. Alternative methods of production and harvest should be explored for Midlawn and OKC 70-18. Tifway and Midlawn may serve as useful standards for future sod research. Study II: Substantial variation in visual performance traits were found amongst the entries evaluated. Experimental entries 21 and 29 generally performed equal to or better than Tifway for STS, SHQ and most visual characteristics. The STS and SHQ were well correlated (r=0.73, p=0.001, N=72) for the sod harvests with the 36 selections. Promising selections 21 and 29 have been sponsored for testing in the 2007-2011 National Turfgrass Evaluation Program (NTEP) bermudagrass trial as OKC 1119 and OKC 1134 respectively.

ADVISER'S APPROVAL: Dr. Dennis L. Martin