Abstract

JAMES MARABLE RUTLEDGE. Growth Characteristics and Physiological Stress Tolerance of Eight Bermudagrass Cultivars Intended for Athletic Fields and Golf Course Fairways. (Under the direction of Dr. Charles Peacock)

Bermudagrass (*Cynodon* [L.] Rich) is well suited for use as recreational turf in the southeastern United States due to its ability to aggressively recuperate and withstand heat, cold, and drought stress, while providing a uniform and aesthetically pleasing playing surface. Bermudagrass cultivars express these and other desirable traits at varying levels of intensity and therefore an individual cultivar may have greater drought tolerance than others while another may possess increased wear tolerance. Thus, the importance of cultivar evaluation lies in its value to turf managers in selecting the best suited cultivar for their specific application. Cultivars included in the trial were, 'TifSport', 'Tifway', 'Tifton 10', 'Navy Blue', 'GN-1', 'Patriot', 'Celebration' and 'Quickstand'. During 2003 and 2004, data were collected on a wide range of criteria including the response to mowing height differential, nitrogen fertility rates, root and thatch production, surface hardness, rate of lateral spread, disease incidence, visual turf quality, wear tolerance, drought tolerance, and low temperature stress tolerance.

Under mowing heights of 1.25 and 1.90 cm in 2003, TifSport exhibited the highest turf quality ratings at both heights of cut and mowing height had little effect on cultivar performance. Data in 2004 revealed a trend of increasing surface hardness with reduced mowing height. Nitrogen (N) fertility rates of 100, 150, and 200 kg N ha^{-1} had no effect on turf quality ratings, although all ratings tended to be less than ideal. Surface hardness and root and thatch production were masked by N rates during the study.at any time during the study. Similarly in 2003, TifSport had the greatest root mass during the

growing season, while GN-1 and Navy Blue produced the greatest amount of thatch. Root and thatch data were highly variable throughout the course of the study. Surface hardness is of interest because it has been directly linked to player injury and is highly variable among cultivars. Celebration had the least surface hardness during 2004 and thus would be the least likely cultivar tested to contribute to player impact injury. Rate of lateral spread data was gathered in 2004 by extracting cores from each plot and monitoring regrowth using digital imaging over a period of four weeks. Celebration achieved the greatest recovery at 86% by the fourth week, followed by TifSport and Quickstand, each with 70% recovery. Disease incidence data was collected solely on an observational basis; no disease was induced during the study. In May 2004, Spring Dead Spot (*Ophiosphaerella korrae*) was observed on Tifway, TifSport, Navy Blue, and GN-1 plots. Tifway had a greater percent disease by area than did all other cultivars and was followed by Navy Blue which had more disease than all cultivars but Tifway. Visual ratings over both years consistently ranked TifSport and Celebration higher due to their deep green color, fine texture, and high density. Wear tolerance was initiated in late July 2004 using a modified Brinkman Traffic Simulator. Wear treatments were applied twice weekly for a total of five weeks. Traffic simulation had an effect on Quickstand, GN-1, Navy Blue, and Tifton 10. Other cultivars did not significantly differ in percent cover from the non-trafficked plots. Drought stress tolerance was tested in a greenhouse environment using field cores. Visual ratings taken weekly and the length of time after irrigation was removed that leaf firing occurred were the methods used to determine the effect of drought stress on the various cultivars. Navy Blue resisted leaf firing until the seventh week of the study; longer than any other cultivar. Visual ratings for Navy Blue also remained higher for a longer period of time over the course of the study indicating less drought stress. Low temperature stress tolerance testing was conducted using two methods, dormant field cores and excised stolons in February of 2003 and 2004. Field cores were potted and placed in a Low Temperature Stress Simulator (LTSS) at a temperature of either -1^{o}C or -7^{o}C for varying exposure lengths of 12, 24, 48, or 72 h, respectively. After 30 d of recovery in a greenhouse, dry weights were taken to identify cultivar differences in dry matter production. Patriot and Quickstand exhibited greater recovery rates than all other cultivars in the core study at -7^{o}C. Exposure lengths of 12 and 24 h resulted in greater survivability across all cultivars than did the 48 and 72h exposures at -7^{o}C. The stolon study was composed of a single 24 h exposure length with temperatures ranging from 3^{o}C to -10^{o}C. Stolon survival was recorded after 30 d of recovery in a greenhouse. Results between the core and stolon studies showed a strong correlation (r_s = 0.82 and a probability of 0.01) with 'Quickstand' and 'Navy Blue' being more cold tolerant than all other cultivars with the exception of 'Patriot'. 'Patriot' proved more cold tolerant than 'Tifton 10', 'TifSport', 'Tifway', and 'Celebration'.

Data from the study clearly indicate differences in specific characteristics among these eight cultivars. Cultivars that performed poorly in some facets of the study, performed exceptionally well in others. With the knowledge gained from the study, turf professionals have the ability to view a wide range of performance characteristics and select a cultivar based on their needs.

GROWTH CHARACTERISTICS AND PHYSIOLOGICAL STRESS TOLERANCE OF EIGHT BERMUDAGRASS CULTIVARS INTENDED FOR ATHLETIC FIELDS AND GOLF COURSE FAIRWAYS

by
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APPROVED BY:

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Chair of Advisory Committee

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Dedication

This thesis and the work that went into it are dedicated to my parents for their never ending encouragement and support. It is only through their confidence that I have reached goals I never dreamed attainable. I also thank my grandparents who taught me it is only through hard work and honesty that success is realized. Their unwavering advice and selfless sacrifice is appreciated more than they know. Lastly, thanks to my siblings whose own success continues to drive us all to greater accomplishments.

It is with the sincerest love and gratitude that I thank all of you.

-James

Biography

The author, James M. Rutledge was born September 18, 1980 in Boone, North Carolina to Martha J. and Stephen E. Rutledge. He spent the majority of his childhood in Banner Elk, North Carolina where he graduated from Avery County High School in May 1999. During high school, he began work at Linville Golf Club where his interest in turf management developed.

Mr. Rutledge enrolled at North Carolina State University in August of 1999 where he pursued a Bachelor of Science Degree in Crop Science with a concentration in turfgrass management. His summers were spent at Linville Golf Club where he continued to work closely with the turfgrass industry. After graduating Cum Laude in May 2003, Mr. Rutledge decided to begin work a Master of Science Degree at North Carolina State University. Under the direction of Dr. Charles Peacock, Dr. Art Bruneau, and Dr. Rich Cooper he began his project immediately following graduation. Over the next two years his interest continued to grow in the field of turfgrass science as new doors were opened. He has recently been accepted at Purdue University to pursue a doctoral degree and is currently in the process of deciding what career path to now follow.

Acknowledgements

I would first like to relay my sincerest appreciation to Dr. Charles Peacock who presented me with this opportunity and then diligently pushed me to make the most of it. I would additionally like to thank my other two committee members Dr. Art Bruneau and Dr. Rich Cooper whom lent me their advice and wisdom throughout my time here at North Carolina State University. Without their mentoring and hard work this project would not have been possible. I also owe a debt of gratitude to fellow graduate students David Lee, Casey Reynolds, Patrick Gregg, Lee Butler, and Brandon Cawthorn for their guidance and aid along the way. Without their support and friendship the pursuit of this degree would have been far less enjoyable.

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Literature Review

Bermudagrass (*Cynodon* [L.] Rich) has been manipulated for use by man for centuries. Its inherent ability to thrive in a variety of climates throughout the world, coupled with its aggressive, low growth habit has made it a popular grass for both forage and turf uses. Over the past half century, bermudagrasses have been increasingly used for recreational uses such as lawns, athletic fields, and golf courses. Currently, bermudagrass has its greatest economic value in these three areas. With advanced breeding techniques, new cultivars are being produced and marketed at a greater rate than ever before. It is of great importance that these cultivars are adequately tested to insure that their performance meets the claims of their developers.

Standard bermudagrass cultivars may vary in a number of characteristics. Several valued characteristics include low temperature stress tolerance and simulated athletic traffic tolerance. Though historic data relative to these criteria is limited for bermudagrasses released during the past 5 to 10 years, much low temperature stress and athletic traffic tolerance research has been done on some of the older bermudagrass cultivars.

Negative effects of traffic on turfgrass have been observed on turf stands supporting a variety of applications. Athletic foot traffic creates the same negative effects of compaction and abrasion that livestock, equipment, or any other source of traffic would. These effects are often exaggerated on athletic fields due to the high intensity and concentration of traffic. For this reason, it is of interest to investigators to create ways to consistently and artificially simulate traffic. In the 1970's interest in the effects of athletic traffic on turfgrass began to increase. The first traffic simulator developed to simulate vertical, compacting forces, and horizontal tearing of the turf was developed by Canaway (1976). The simulator incorporated rotating wheels with spikes inserted to simulate foot traffic. Other traffic simulators at the time were linked to a center-pivot around which the simulator rotated (Shearman and Beard, 1975). These two types of simulators were used in early cultivar trials to determine traffic durability as well as recuperative potential. Quantification of results was commonly reported using visual turf quality ratings and estimated percent cover. The first bermudagrass trial for wear tolerance was conducted by Beard et. al. (1981). Effects were quantified by analyzing the amount of verdure remaining (g) after traffic had been induced upon the turfgrass. Tifway was included in the study and had 4.31g of verdure remaining after the simulation. The first standardization of equipment used for traffic simulation occurred in 1989 with the advent of the Brinkman Traffic Simulator. The Brinkman simulator was composed of a steel frame with two, 1.2m long rollers with bolts extending from them to simulate cleats. The simulator was designed to be pulled behind a tractor and a tearing action was created by the rollers being allowed to turn at varying rates of speed (Cockerham and Brinkman, 1989). In addition to the evolution of the traffic simulator, methods of data collection have also evolved. Digital image analysis is now the most common and accurate method by which to evaluate the effects of traffic on turfgrass. Percent cover can be accurately calculated instead of being visually estimated. This eliminates much human error from the process (Richardson et al., 2001).

Avoidance of winter-kill injury by selecting low temperature tolerant cultivars is an effective and commonly used approach. Management and environmental factors influence low temperature stress tolerance while genetics also plays a significant role (Beard et al., 1980; Ervin et al., 2004). Management strategies associated with improved low temperature stress tolerances of bermudagrasses include: reduced nitrogen fertility, and increased potassium fertilization prior to winter. High nitrogen concentrations in plant tissue lead to increased plant tissue hydration. Elevated moisture levels in plant tissue has been directly linked to a reduction in cold tolerance (Beard, 1973). Beard (1973) also states that adequate levels of phosphorus and potassium are important in ensuring cold hardiness. The primary environmental factor influencing low temperature stress tolerance of turfgrasses in a particular year is the length of time over which "hardening off" occurs. The rate at which a turfgrass acclimates itself to the change in temperature on a yearly basis is known as hardening off. If temperature change is slow and consistent, there is a greater chance that the turfgrass will acclimate and not suffer winter injury. Abrupt, short acclimation periods lead to increased winter injury (Davis and Gilbert, 1970). Many studies have evaluated absolute low temperature stress tolerance of various cultivars (Anderson and Taliaferro, 1995) (Anderson et. al., 2003) (Chalmers and Schmidt, 1979) (Shashikumar and Nus, 1993). Few researchers have evaluated the effect of multiple exposure lengths on bermudagrass survival at low temperatures. Anderson et al. (2003) reported that exposure lengths of 2, 24, and 72 h at a constant temperature of -5.4^{o}C resulted in cultivar recovery rates of 67, 30, and 11 %, respectively. This study established the fact that length of exposure, as well as absolute low temperature contributed to extent of winter injury incurred by the turfgrass. Length of exposure and absolute low temperature were both addressed in the study to better grasp the effect on the specific cultivars of interest.

Limited research has been conducted on some cultivars included in the study. Patriot and Celebration have least data because they are two of the newest cultivars in the trial that are currently on the market. This research evaluated many relative factors including low temperature stress tolerance, drought tolerance, lateral spread, nitrogen fertility requirements, mowing height effects, root and thatch production, disease susceptibility, turf quality, and wear tolerance. Data reflecting these variables is valuable to turfgrass managers in the southeastern United States considering establishment of bermudagrasses. The data is applicable to golf course fairways, athletic fields, aand home lawns. Turf managers may select which parameters are most applicable to their individual needs depending on climate, location, management intensity and many others in order to select the most appropriate cultivar for their application. The knowledge gained will enable managers to make educated decisions regarding which cultivar will perform best, thus reducing future management inputs or potential reestablishment due to poor performance.

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Evaluation of Growth Characteristics of Six Bermudagrass Cultivars Established During 2001

Abstract

Bermudagrass (*Cynodon* [L.] Rich) cultivar selection is an important consideration when establishing an athletic field or golf course fairway in the Southeastern United States. The cultivar selected will greatly affect how well the turf performs and the management intensity required to ensure that the turf consistently stays at its peak quality. The objective of this study was to evaluate cultivar performance using a variety of approaches including: analyzing root and thatch production, assessing turf quality, and determining surface hardness. Cultivars evaluated included: 'TifSport', 'Tifway', 'Tifton 10', 'Navy Blue', 'GN-1', and 'Quickstand'. Nitrogen fertility rates of 100, 150, and 200 kg N ha^{-1} had no effect on turf quality ratings, surface hardness, or root and thatch production. Mowing heights of 1.25 cm and 1.9 cm had no effect on the relative ranking of mean turf quality ratings in the study. TifSport had significantly higher mean turf quality ratings than all other cultivars for both mowing heights. In the first year of the experiment, TifSport produced the greatest root mass, while GN-1 and Navy Blue produced the greatest amount of thatch. Clegg impact values were taken to quantify surface hardness differences among cultivars both in the spring and fall. Tifton 10 and GN-1 had the lowest surface hardness readings over both years of the study while sampling date had no effect on surface hardness. Overall turf quality ratings taken biweekly showed TifSport had better turf quality than all other cultivars on all but two

occasions. In May of the second year of the experiment, the three year old plots of Tifway, TifSport, Navy Blue, and GN-1 were infected with Spring Dead Spot (*Ophiosphaerella korrae*). Tifway had a greater percent disease by area than did all other cultivars and was followed by Navy Blue which had significantly more disease than all cultivars but Tifway.

Introduction

Bermudagrass (*Cynodon ssp.*) is a durable turfgrass that is commonly chosen in the Southeastern United States for use on both athletic fields and golf course fairways. Bermudagrass has an inherent ability to tolerate and even thrive in warm, humid climates while also withstanding significant traffic. Genetic variability as well as management strategies greatly influence the ability of bermudagrass to tolerate such conditions. It is known that cultivars of bermudagrass perform differently depending on their origin and breeding variation. Therefore, the objective of this study was to determine which of the newer cultivars released into the market perform best under a variety of management strategies. Treatments in the study included variable fertility rates and mowing height. Data was collected on root and thatch production, surface hardness, turf quality ratings, and disease incidence to evaluate treatments.

Nitrogen fertility rates are of interest from both an environmental as well as a financial point of view. Application rates are dependent on multiple factors but are commonly advised at 50 kg N ha^{-1} every four to six weeks during the growing season (Bruneau et. al., 2001). It has been shown that bermudagrass can “sustain viability” at rates as low as 12.5 kg N ha^{-1} every four weeks during the growing season (Sifers and Beard, 1987). A large range between the minimum requirement and the optimum recommendation is apparent. Finding a nitrogen fertility rate where quality remains at an acceptable level with minimal input would be of value to turf managers.

Cultivar variation in texture and density greatly influence management strategies. Cultivars with finer texture and greater density tend to require mowing at a greater frequency while also performing more favorably under lower mowing heights (Bruneau et. al., 2004). In addition, finer textured bermudagrasses with dense canopies tend to produce more thatch which can affect surface hardness (Stewart, 2003). Surface hardness is greatly influenced by soil type; however, it may also vary with cultivar and thus is an important consideration when selecting a bermudagrass cultivar for use on athletic fields. Cultivars with excessively high surface hardness measurements can lead to increased player injury (Orchard et. al., 1999). Surface hardness can be quantified by using a Clegg Impact instrument. The Clegg has been used in many similar studies and has proven to be an accurate and reliable tool for measuring surface hardness (Stewart, 2003).

Turf quality ratings along with root and thatch measurements are commonly used tools to quantify effects of fertility and mowing height treatments (Johnson et. al., 1987). Turf quality ratings were recorded on a scale of one (bare ground) to nine (ideal quality). By taking factors such as color, density, and texture into consideration, a turf quality rating when done by the same individual throughout the growing season can be an accurate and useful tool for evaluating turf performance. Thatch is a combination of dead and living plant tissues that accumulates between the soil surface and green vegetative material (Carrow et al., 1987). Root and thatch production data is directly influenced by the overall health of the turf but can differ among cultivars. Although there is potential for variability within these methods using field cores, reliable information can still be gained.

Disease incidence was documented solely based on observation; no disease pressure was artificially induced on the field plots. Spring Dead Spot (*Ophiosphaerella korrae*) was observed in the spring of 2004. This disease is common in the southeast and has been documented to occur on established bermudagrass (Martin et.al., 2001). Bermudagrass cultivars vary greatly in their sensitivity to the disease and thus cultivar differences were noted by the end of May. By waiting until the end of May when full green up had occurred, disease injury could easily be evaluated. Disease incidence has been recorded using a wide range of methods. Commonly documented methods include: visual percent disease estimations, line intersect methods, and digital image analysis. Digital image analysis is a relatively new method of analysis and the one chosen for this study. This method has increased accuracy when evaluating percent disease and is consistent when analyzing many plots (Butler and Tredway, 2005).

The purpose of this research is to identify differing characteristics among the six cultivars that will aid turf managers in making an appropriate decision when selecting a cultivar.

Materials and Methods

The study was conducted from May through October 2003 and 2004 at the Sandhills Research Station in Jackson Springs, NC. The soil at the research station is classified as a Candor sand (Sandy, siliceous, thermic Arenic Paleudult) with 0 to 1 percent slope and an initial pH of 5.5. The Candor series consists of very deep, somewhat excessively drained soils with rapid permeability in the upper sandy horizons and moderate to moderately slow permeability in the lower horizons. The site has a mean annual temperature of 16°C, with the mean annual high being 21°C while the mean annual low is 11°C. The site receives a mean annual rainfall of 120cm (Reynolds, 2003).

Treatments were arranged using a split-split plot design replicated eight times. One sub-subplot containing a single cultivar measured 2.7m x 2.7m and there were six per replication, one for each cultivars included in the study. A subplot measured 8.2m x 5.5m and encompassed six sub-subplots. Lastly, a block was composed of three subplots and measured 16.4m x 8.2m. Treatment effects included three fertility rates randomized within each block, as well as a stripped sub-subplot mowing height differential in 2003 (Firgure1).

Figure 1: Plot map of a single replication during 2003.

	100 kg N ha^{-1}		200 kg N ha^{-1}		150 kg N ha^{-1}	
1.90 cm	TS	NB	TW	GN	T10	QS
1.25 cm						
1.25 cm	GN	QS	QS	TS	NB	TW
1.90 cm						
1.90 cm	TW	T10	NB	T10	TS	GN
1.25 cm						

NOTE: A replication during 2004 was the same as above with the exception of no mowing height differential.

Nitrogen fertility rates in both 2003 and 2004 were 100, 150, and 200 kg N/hectare/year with individual application rates of 50 kg N/hectare. A 34-0-0 fertilizer containing urea as the nitrogen source was weighed and evenly spread over each sub-subplot using quart jar with holes punched in the lid. Fertilizer applications were immediately followed with 0.5 cm of irrigation to prevent leaf burn and assure the fertilizer reached the root zone. Soil samples were taken in April and affirmed that potassium levels were adequate and all other nutrients were abundantly supplied. Nitrogen fertility treatments were initiated in May of both years and are described in Table 1.

Table 1. Nitrogen fertility rates applied during 2003 and 2004 to bermudagrass plots at the Sandhills Research Station in Jackson Springs, NC

Seasonal Total	Application Rate	Application Dates 2003	Application Dates 2004
—— kg N ha^{-1} ——			
100	50	16 May	25 May
		3 July	20 July
150	50	16 May	25 May
		19 June	6 July
		24 July	10 Aug
200	50	16 May	25 May
		12 June	24 June
		10 July	27 July
		7 Aug	17 Aug

Note: All applications were made using a 34-0-0 urea based fertilizer

Mowing height treatments were initiated in May of 2003 and maintained throughout the growing season. Sub-subplots were mowed at heights of 1.25 or 1.9 cm twice weekly. A riding triplex reel mower was used to mow the 1.9 cm cutting height plots, while a walk behind single reel mower was used to mow the 1.25 cm cutting height plots.

Rooting and thatch production were assessed during the experiment to aid in quantifying the effects of mowing height and nitrogen fertility on the performance of bermudagrass cultivars. On 4 Aug 2003, cores were taken from the field plots (one core from each sub-subplot) measuring 20 cm deep x 10.8 cm diam. The following day, the cores were sheared at the point where the thatch ended and the soil began. All vegetative material except roots was removed and discarded. Using a 14 mm mesh screen, roots were washed to remove the majority of the soil from the sample. Root material was placed in a drying oven at 60^{o}C for at least 5 d until no moisture remained in the samples. Samples were weighed, and placed in a muffle furnace at 500^{o}C for 12h. Samples were again weighed, from which the difference was calculated thus giving the root weights for each cultivar. In 2004, the same procedure was repeated using four randomly selected replications instead of the eight used in 2003 to allow time for including thatch content in the analysis. When shearing the cores, the thatch was retained and all verdure was removed. The remaining thatch was dried, weighed, ashed, and reweighed using the same procedure as for the root tissue and differences were recorded.

Clegg Impact Values (CIV's) were obtained during the last week of May and August of 2003 and 2004 using a Clegg Impact Tester (Lafayette Instrument Co. Lafayette, IN). The Clegg Impact Tester is comprised of a 5 cm diam. metal tube 45 cm long through which a 0.5 kg weight is dropped and impacts the turf surface. The 0.5 kg weight is connected by a coaxial cable to an LCD screen that displays the CIV when the weight is dropped. At the point of impact between the 0.5 kg weight and the ground, a sensor records the point of maximum deceleration which is recorded as the CIV. When used in the field, the weight was dropped through the tube four consecutive times in the same spot and the CIV of the forth drop was recorded. The Clegg Impact Tester was not used in the field for 2 d following any significant rain or irrigation event. Due to sandy textured soil, the research plots drained quickly.

Turf quality was rated visually every two weeks beginning in May and ending in October of both years. Turf quality ratings take into account variables such as texture, density, and color to arrive at an overall quality value. A rating scale of one to nine was used, with one representing completely brown turf and nine being an ideal dense, dark green, and fine textured turf plot. A rating of five represented acceptable turfgrass quality in this study.

Disease incidence in the study was reported solely based on natural occurrence and no disease pressure was artificially induced. In May 2004, during spring green up, Spring Dead Spot (SDS) (*Ophiosphaerella korrae*) was documented and analyzed using digital image analysis to estimate percent disease. Pictures of each sub-subplot were taken 28 May at a constant height and camera resolution to ensure the uniformity of images. Images were taken from 0800 to 1130 hrs to avoid shadows cast by monopod. Pictures were then cropped and resized to remove any part of the picture that included turf that was not part of the immediate plot. All images were equally sized to 600 x 600 pixels and analyzed for percent disease using Sigma Scan Pro (v.5.0, SPSS, Inc., Chicago, IL). The percentage of green pixels was analyzed for each picture using a color threshold of; hue = 35 - 235 and saturation = 0 – 100 (Butler, 2005). Percent disease was calculated by subtracting the green pixels from the total pixels in each image.

Analysis of all experimental data was done using an Analysis of Variance (ANOVA) in the Statistical Analysis System (SAS Institute Inc., 2002). When data was shown to be significant in the ANOVA test at $P \leq 0.05$, either a Waller-Duncan k-ratio t-test or LSD test was used for mean separation. The LSD test was used on the Clegg impact and Spring Dead Spot data because these data sets contained less than three sampling dates for which the Waller-Duncan test cannot be used.

Results and Discussion

Nitrogen Fertility

Nitrogen fertility rates did not affect performance as measured by root and thatch samples or turf quality ratings. The lack of response could suggest that these cultivars can perform at acceptable levels with less nitrogen than is typically recommended for bermudagrass. However, TifSport is the only cultivar that exhibited turf quality ratings greater than 7 on more than 4 out of 15 total rating dates over both years of the study. This level of performance although adequate for cover and color was achieved; this level of performance would not be considered ideal quality for a highly visible turf such as an exclusive golf club or professional athletic field. Therefore, nitrogen rates applied during the trial were not high enough to produce an ideal quality of turf for an intensively managed and highly visible situation. Slight year to year variation is attributed to differences in field weather conditions between years.

Mowing Height

Mowing height differentials had relatively little effect on cultivar performance. Under both mowing heights, the order of cultivar ranking for turf quality remained similar (Table 2). TifSport maintained higher turf quality for both mowing heights than all other cultivars. Tifton 10 exhibited the greatest margin of difference between the two mowing heights, performing better at the increased height of cut but was still the poorest performing cultivar at both mowing heights. Under the 1.25 cm cutting height, Tifton 10 exhibited lower mean turf quality ratings than all cultivars and Navy Blue, GN-1 and Tifway had higher quality than Quickstand. Navy Blue and GN-1 also exhibited better quality than Quickstand and Tifton 10 at the 1.90 cm cutting height.

Table 2. Bermudagrass quality as affected by mowing height during 2003.

	Mowing height (cm)	
Cultivar	1.25	1.90
	Turfgrass Quality†	
TifSport	7.2a*	7.0a
Navy Blue	6.5b	6.6b
GN-1	6.4b	6.6b
Tifway	6.6b	6.6bc
Quickstand	6.0c	6.3cd
Tifton 10	5.6d	6.2d

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

† Visual ratings scale: 1= dormant or brown turf, 5= acceptable quality turf, and 9= dark green, dense, ideal quality turf.

Rooting/Thatch Accumulation

Rooting and thatch production were evaluated to determine if they varied among cultivars, possibly in response to mowing and nitrogen fertility. When evaluated in August 2003, TifSport had produced more root mass than any other cultivar (Table 3). However, sampling in June 2004 revealed no differences. Samples collected in August 2004 showed Tifton 10 had significantly less root mass than TifSport, Quickstand, Tifway, and GN-1. On all three sampling dates, Tifton 10 showed a trend toward fewer roots; however, it was not significant until August 2004. Root mass dropped from the June sampling period to the August sampling period. This reduction in root mass was difficult to explain since it has been documented that root mass usually tends to increase during the growing season for bermudagrasses (DiPaola and Beard, 1978). Unseasonably cloudy, wet, and cool days were numerous during the summer of 2004 at the Sandhills Research Station and were hypothesized to contribute to the decline. Bunnell et. al. (2005) report that 'TifEagle' exposed to sunlight for 12, 8, and 4 hrs daily over an 8 week period exhibited mean turf quality ratings (1 to 9) of 7.73, 7.34, and 5.24, respectively. Daily sunlight exposure lengths of 12 and 8 hrs exhibited higher turf quality ratings and greater lateral growth than the corresponding 4 hr daily exposure length. A second factor to consider is the high variability of sampling in the field. Samples were extremely small and thus the much more likely to be highly variable. Thatch production, however, followed a more predictable trend and increased for each cultivar from June to August. In June, Navy Blue and GN-1 had accumulated more thatch than all other cultivars (Table 4). In August, GN-1, Navy Blue, and TifSport had more thatch than Quickstand and Tifton 10. The thatch increase for cultivars from June to August is reasonable and is expected with bermudagrass.

Table 3. Bermudagrass cultivar root mass measured during 2003 and 2004.

	Root Mass		
	2003	2004	
Cultivar	Aug	June	Aug
	mg / 1831 cm^3		
TifSport	1193a*	820a	447a
Navy Blue	835b	800a	414a
Quickstand	823b	755a	400a
Tifway	808b	728a	347a
GN-1	775b	719a	307a
Tifton 10	688b	600a	174b

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

Table 4. Thatch weights of eight bermudagrass cultivars measured in 2004.

	Thatch Mass	
Cultivar	June	Aug
	g / 92 cm^2	
TifSport	20b	26ab
Navy Blue	23a	27ab
Quickstand	20b	23c
Tifway	20b	24bc
GN-1	23a	28a
Tifton 10	18b	23c

*Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

Surface Hardness

Clegg impact values revealed cultivar differences while showing no mowing height or sampling date effect (Tables 5 & 6). Tifton 10 and GN-1 had softer surfaces than all other cultivars. These results did not correlate with thatch mass samples and thus thatch did not directly influence surface hardness. It is unclear what other factors may be contributing to surface hardness and it may be influenced by thicker, more rigid stems that are more difficult to compress. Under a mowing height of 1.25 cm, Quickstand produced the hardest surface of all cultivars on both testing dates. At the higher cutting height of 1.90 cm, Quickstand was harder than all cultivars but Navy Blue at the June sampling date and harder than all cultivars but Tifway and TifSport in August. During 2004 there was only one mowing height of 1.9cm. Quickstand and Tifway displayed greater surface hardness than did Tifton 10 and GN-1 in June of 2004. This is consistent with the 2003 findings as well. In August all cultivars exhibited greater surface hardness than GN-1 (Table 6). Over both years and all treatments, GN-1 and Tifton 10 consistently proved to have lower CIV's (Tables 5 & 6). This would be considered a positive attribute by reducing player injury when contact is made with the turf surface (Stewart, 2003).

Table 5. Clegg Impact Values (CIV) as affected by mowing height in 2003.

	Mowing height (cm)			
	June		Aug	
Cultivar	1.25	1.9	1.25	1.9
	CIV†‡			
Quickstand	9a*	8a	8a	7a
Tifway	8b	7b	7b	6ab
Navy Blue	8b	7ab	7b	6b
TifSport	8b	7b	7b	6ab
Tifton 10	7c	6c	5c	5c
GN-1	6c	5c	5c	5c

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the LSD t test. (Means were averaged over all nitrogen fertility rates)

† One CIV is the equivalent of 10 gravities.

‡ CIV increases with increasing surface hardness.

Table 6. Clegg Impact Values (CIV) mowed at 1.9 cm during 2004.

	Mowing height (cm)	
Cultivar	June	Aug
	CIV†‡	
Quickstand	6.0a*	6.3a
Tifway	5.8ab	6.1a
Navy Blue	5.3bc	5.8a
TifSport	5.3bc	5.7a
Tifton 10	5.1c	6.2a
GN-1	4.9c	4.9b

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the LSD t test.

† One CIV is the equivalent of 10 gravities.

‡CIV increased with increasing surface hardness.

Turfgrass Quality

Turf quality ratings throughout the year were analyzed to display overall performance of the cultivars during 2003 and 2004. Through the course of the study, cultivars tended to fall into three general groups. Over both years, TifSport exhibited greater mean turf quality ratings than did all other cultivar on twelve out of fifteen total sampling dates. TifSport ratings tended to be higher early in the spring and late in the fall suggesting superior spring green up and fall color retention. GN-1, Navy Blue, and Tifway were the only cultivars to exhibit quality equal to that of TifSport on 3, 2, and 1 rating date(s) of the fifteen over both years of the study. Coarse textured Tifton 10 and light colored Quickstand ranked low throughout the growing season due to their inherent poor quality. Tifway, Navy Blue, and GN-1 had no differences in quality ratings on any sampling date in 2003 (Tables 7 & 8). In 2004, these three cultivars ranked below

TifSport and above Tifton 10 for turf quality on eight out of ten sampling dates. Yearly differences were minimal and the data ordering remain relatively consistent over both years with one exception. Tifway turf quality was lower in 2004 than in 2003 (Table 8). This variation in performance was directly linked to severe Spring Dead Spot early in 2004 that affected rating through the majority of the year.

Table 7. Turfgrass quality ratings gauge overall performance of the various cultivars in 2003.

Cultivar	May	June		July	
	28	11	25	9	23
	Quality Ratings†				
TifSport	6.6a*	7.0a	7.2a	7.2a	7.6a
Tifway	5.8b	6.4b	6.7b	7.0ab	7.0b
Navy Blue	5.9b	6.3bc	6.6b	7.1ab	6.9b
GN-1	5.7bc	6.3bc	6.7b	7.1ab	6.8b
Quickstand	5.5cd	6.0cd	6.1c	6.8b	6.4c
Tifton 10	5.3d	5.8d	5.8c	6.3c	6.1c

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

† Visual ratings scale: 1= dormant or brown turf, 5= acceptable quality turf, and 9= dark green, dense, ideal quality turf.

Table 8. Turfgrass quality ratings of six bermudagrass cultivars in 2004.

Cultivar	May	June		July		Aug			Sept	
	Quality Ratings[†]									
TifSport	6.5a*	6.9a	7.1a	7.4a	7.5a	7.6a	7.0ab	7.5a	7.4a	6.2a
GN-1	4.8b	5.9b	6.3b	6.8b	6.8b	7.4a	7.0a	6.8b	7.1b	5.8b
Navy Blue	4.6b	5.3c	5.4c	6.1c	6.3c	6.9b	6.6ab	6.6b	6.8c	5.6b
Quickstand	4.4b	6.0b	6.1b	6.3bc	6.3c	6.3c	6.2c	6.1c	6.2d	5.1c
Tifway	3.8c	4.5d	4.6d	5.4d	6.0cd	6.7b	6.6b	6.8b	6.8c	5.5b
Tifton 10	2.6d	3.8e	4.7d	5.1d	5.7d	6.0c	5.9c	5.7d	5.9d	4.7d

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

[†] Visual ratings scale: 1= dormant or brown turf, 5= acceptable quality turf, and 9= dark green, dense, ideal quality.

Disease Incidence

The major reduction in the quality of Tifway from 2003 to 2004 was directly linked to the fact that Tifway encountered severe Spring Dead Spot in May of 2004 (Table 9). The effect of the disease was significant and the resulting injury was apparent throughout the majority of the growing season. No fungicide treatments were applied prior to infection and therefore damage was extensive and recovery was slow. The incidence of Spring Dead Spot was evaluated using digital imaging in addition to turf quality ratings. Digital image analysis accurately revealed that Tifway experienced greater disease severity than did all other cultivars with a mean percent disease of 7.3 %. Navy Blue experienced more disease than TifSport, Tifton 10, and Quickstand.

Table 9. Spring Dead Spot incidence on bermudagrass cultivars in May 2004.

Cultivar	Disease Incidence†
	%
Tifway	7.3a*
Navy Blue	1.7b
GN-1	0.8bc
TifSport	0.1c
Tifton 10	0.0c
Quickstand	0.0c

*Means with the same letter are not statistically different at $P \leq 0.05$ using the LSD t test.

† Disease Incidence is expressed as mean percent disease per plot

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Evaluation of Growth Characteristics of Eight Bermudagrass Cultivars Established During 2002

<u>Abstract</u>

Bermudagrass (*Cynodon* [L.] Rich) cultivars selected for use on athletic fields and golf course fairways must possess the ability to thrive under a variety of stresses brought about by extensive use. Excessive wear from traffic affects cultivars differently and alters management strategies regardless of cultivar. An objective of the study was to evaluate cultivar performance under traffic simulation using a variety of approaches including analyzing root mass, assessing turf quality, and determining surface hardness. Other objectives included learning how the rate of lateral spread, nitrogen fertility, and mowing height affected cultivar performance. The study was conducted during 2003 and 2004 evaluating the following cultivars: ‘TifSport’, ‘Tifway’, ‘Tifton 10’, ‘Navy Blue’, ‘GN-1’, ‘Patriot’, ‘Celebration’ and ‘Quickstand’. Mowing heights of 1.9 cm and 3.2 cm had no effect on cultivar mean turf quality ratings. During 2003, there were no rooting differences among cultivars regardless of mowing height and fertility treatments. Clegg impact values were determined to quantify surface hardness differences among cultivars both in the spring, fall, and immediately following the termination of the traffic simulation. For each sampling date and mowing height during 2004, Celebration exhibited the lowest surface hardness of any cultivar which may result in a reduction in player injuries on athletic fields. Clegg Impact Values (CIV) ranged from 6.7 on the first sampling date to 4.4 on the last sampling date. Turf quality ratings taken biweekly

showed that TifSport, Tifway, Patriot and Celebration had higher ratings than Navy Blue on all rating dates during 2004. Recovery rates as assessed by the rate of lateral spread were completed over a four-week period after which Celebration had achieved the greatest recovery at 86% followed by TifSport and Quickstand, each with 70% recovery. Simulated traffic had the greatest effect on Quickstand, GN-1, Navy Blue, and Tifton 10 by a reduction in percent cover. The effect of simulated traffic on these cultivars established data which professionals can use to base their cultivar selection decision. Coupled with other data gained from the study, a manager can combine various qualities of the grasses that they deem important and thus make the most appropriate choice for their specific needs.

Introduction

Bermudagrass (*Cynodon ssp.*) is a commonly used turfgrass specie in the southeastern United States for use on both athletic fields and golf course fairways. It is favored for its ability to withstand physical stress while also being able to quickly recuperate from injury. Cultivars of bermudagrass greatly vary in their inherent ability to withstand traffic and recover from the resulting injury. The latest and most common method of simulating wear stress on turfgrass is the Brinkman Traffic Simulator. It consists of two rollers equipped with athletic spikes that turn in a steel frame at varying rates of speed to compact and aggressively tear the turf surface as athletes do on a playing field (Cockerham and Brinkman, 1989). Quantifying the effects of traffic wear on turfgrass can be done in a variety of ways. Beard et al. (1981) measured verdure prior to implementing traffic treatments and then again after treatments were complete. Results were recorded as percent reduction in verdure, visual ratings of wear, and by percent chlorophyll per unit area remaining after traffic simulation. Visual rating of turfgrass quality and/or percent cover is a common and reliable method of analysis. This method consists of a turf professional observing the plots on a specified time interval and visually assigning a quality rating and/or percent cover value to each plot. Although subjective, this method is generally accepted to be accurate and reliable when consistently performed by a single individual. More recently, researchers have begun using digital image analysis to aid in calculating percent cover of turfgrass. Percent cover is commonly used to evaluate wear, and with digital imagining can be done more efficiently and accurately than traditional visual ratings (Butler and Tredway, 2005). Photographs of each plot are taken from a specified height above the plot and then downloaded onto a computer for analysis. At this point the images can be edited or resized to maximize image analysis of the plot. The analysis is done using a program called Sigma Scan Pro (v.5.0, SPSS, Inc., Chicago, IL) that is able to identify and calculate the number of green pixels vs. the total number of pixels from which percent cover is calculated. Digital analysis removes much human error in rating, and if done correctly is a reliable, repeatable method of quantifying percent cover (Richardson et al., 2001).

Nitrogen fertility rates are important from both an environmental and financial view point. Application rates are dependent on multiple factors but application is commonly advised at 50 kg N ha^{-1} every four to six weeks during the growing season (Bruneau et. al., 2001). It has been shown that bermudagrass can “sustain viability” at rates as low as 12.5 kg N ha^{-1} every four weeks during the growing season (Sifers and

Beard, 1987). A large range between the minimum requirement and the optimum recommendation is apparent. Finding a nitrogen fertility rate where quality remains acceptable with minimal input would be of value to turf managers.

Cultivar variation in texture and density can greatly influence management strategies. Cultivars with finer texture and greater density tend to require more frequent mowing while also performing more favorably under lower mowing heights (Bruneau et. al., 2004). In addition, finer textured and denser canopied bermudagrasses tend to produce more thatch that influences surface hardness (Stewart, 2004). Surface hardness is significantly influenced by soil type, but may vary among cultivars and thus is an important consideration when selecting a bermudagrass for use on athletic fields. Cultivars with excessive surface hardness measurements might contribute to increased player injury (Orchard et. al., 1999). Surface hardness is quantified using a Clegg Impact tester. The Clegg Impact tester has been used in many similar studies and has proven to be an accurate and reliable tool (Stewart, 2004).

Turf quality ratings along with root mass measurements are useful methods of quantifying the effects of fertility and mowing height treatments (Johnson et. al., 1987). By considering factors such as color, density, and texture; turf quality ratings can be an accurate method of evaluating turf performance. Rooting is directly influenced by the overall health of the turf. Although there is potential for large variability when using field cores to assess rooting, this method can still provide useful information.

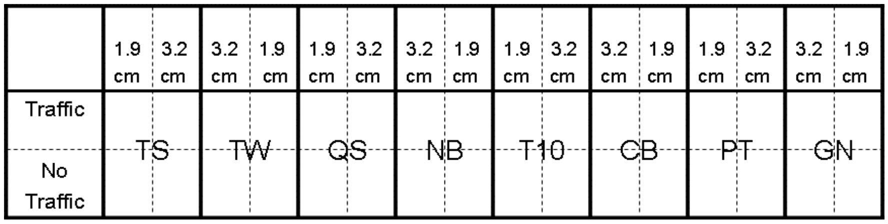
The rate of lateral spread of stoloniferous and rhizomatous turfgrasses such as bermudagrass is of interest to turf managers and researchers in establishing how well cultivars may recover from injury and/or thinning. Athletic fields must exhibit durability to wear stress while also being able to quickly recover from injury. Recent research has evaluated the relative performance of many bermudagrass cultivars included in national cultivar (NTEP) trials. Karcher et al. (2005) reported that Celebration ranked 11th, GN-1 ranked 30th, Patriot ranked 31st, Tifway ranked 38th, and TifSport ranked last at 42nd in an NTEP trial measuring divot recovery. Lateral spread may be directly linked to how well cultivars withstand and recover from the negative effects of traffic. This study will aid in further defining this relationship.

Materials and Methods

The study was conducted from May through October 2003 and 2004 at the Sandhills Research Station in Jackson Springs, NC. The soil at the research station is classified as a Candor sand (Sandy, siliceous, thermic Arenic Paleudult) with 0 to 1 percent slope and an initial pH of 5.5. The Candor series consists of very deep, somewhat excessively drained soils with rapid permeability in the upper sandy horizons and moderate to moderately slow permeability in the lower horizons. The site has a mean annual temperature of 16^{o}C, with the mean annual high being 21^{o}C and the mean annual low 11^{o}C. The site receives a mean annual rainfall of 120 cm (Reynolds, 2004).

The experiment utilized a split-split plot design with six replications. Each main plot measured 2.7m x 2.7m and was split perpendicularly by stripped mowing height and traffic treatments. Therefore, subplots measured 1.35m x 1.35m and were the same over the entire study (Figure 2). In addition to mowing height and traffic treatments, data on the rate of lateral spread, nitrogen fertility, and root mass were collected.

Figure 2: Plot map of a single replication in 2004 on plots established in 2002.



Nitrogen fertility response and rooting were determined during 2003 and not repeated during 2004 as a result of implementing traffic and lateral spread treatments. Soil samples were taken in April 2003 and 2004 that confirmed that potassium levels were adequate and all other nutrients were in abundance. Nitrogen fertility rates during 2003 were established at 100, 150, and 200 kg N/ha/yr with each individual application being at a rate of 50 kg N/ha. A urea based fertilizer with an added bulking agent that created an analysis of 34-0-0 was weighed and evenly spread over each sub-subplot. Fertilizer applications were followed with 0.5 cm of irrigation water to prevent leaf burn and assure the fertilizer reached the root zone. Nitrogen treatments were initiated during May of both years and are described in Table 10.

Table 10. Fertility rates applied during 2003 at the Sandhills Research Station in Jackson Springs, NC

Seasonal Total	Application Rate	Application Dates 2003	Application Dates 2004
—— kg N ha^{-1} ——			
100	50	16 May	25 May
		3 July	20 July
150	50	16 May	25 May
		19 June	6 July
		24 July	10 Aug
200	50	16 May	25 May
		12 June	24 June
		10 July	27 July
		7 Aug	17 Aug

Note: All applications were made using a 34-0-0 urea based fertilizer

Rooting was evaluated during the experiment to aid in quantifying treatment effects as well as to observe inherent rooting variation among cultivars. On 4 Aug 2003, one core measuring 10.8 cm diam. x 20 cm deep was removed from each field plot. The following day, cores were sheared at the thatch/soil with all vegetative material excluding roots removed and discarded. Using a 14 mm mesh screen to prevent the loss of roots, individual samples were washed to remove the majority of soil from the sample. Roots were dried at 60^{o}C for at least 5 d until no moisture remained in the samples at which point they were removed from the oven and weighed. Following weighing, samples were placed in a muffle furnace at 500^{o}C for 12h. Once removed from the furnace the samples were again weighed, from which the difference was calculated to determine root weight for each cultivar.

Mowing height variables were initiated during May 2003 and were maintained throughout the growing season. Plots were mowed at either 1.25 or 1.9 cm twice weekly. A riding triplex reel mower was used to mow the 1.9 cm height, while a walk behind single reel mower was used to mow the 1.25 cm height. In 2004, mowing heights were increased to 1.9 cm and 3.2 cm to better simulate the height of cut of bermudagrass athletic fields.

Clegg Impact Values (CIV's) were obtained during the last week of May and Aug of 2003 and 2004 using a Clegg impact tester (Lafayette Instrument Co. Lafayette, IN). In 2004, an additional reading was recorded during the last week of September to account for the effect of simulated traffic. The Clegg impact tester is comprised of a 45-cm-metal tube through which a 0.5 kg weight is dropped until it impacts the ground. The 0.5 kg weight is connected by a coaxial cable to an LCD screen which displays the CIV when the weight is dropped. At the point of impact between the 0.5 kg weight and the ground, the sensor records the point of maximum deceleration which is recorded as the CIV. When used in the field, the weight is dropped through the tube four consecutive times in the same location and the CIV of the fourth drop is recorded. The Clegg impact tester was not used in the field following any rain or irrigation event to ensure soil moisture levels had minimal effect on the variation among sampling dates.

Turf quality was rated visually every two weeks from May through October of both years. Quality was defined to include variables such as texture, density, and color that were taken into consideration when determining quality. A rating scale of one to nine was used, with 1= dead turf, 5= acceptable quality, and 9= ideal dense, dark green, and fine textured turf.

Traffic simulation began on 27 July 2004 and continued through 26 August 2004 for a total of five consecutive weeks of artificially induced traffic. A modified Brinkman Traffic Simulator was used for the study and weighted to 454 kg. Replications in the study were stripped, allowing the simulator to be pulled across an entire replication at once. Traffic treatments were applied equally to all replications twice weekly, consisting of two passes in opposite directions over each replication perpendicular to the stripping of the cutting height treatment. The simulator was pulled across the plot using a John Deere turf tractor equipped with turf tires to reduce non-simulated compaction. Turf quality ratings were taken weekly over the five week period and immediately after the last week of the traffic simulation. Digital photographs of each subplot were obtained and analyzed using Sigma Scan Pro (v.5.0, SPSS, Inc., Chicago, IL) software to determine percent cover differences among cultivars. Digital images were taken between the hours of 0800 and 1130 hrs on 28 August to avoid shadows cast by the monopod. Images were cropped to a uniform size of 560 x 620 pixels and analyzed for percent green tissue (hue = 45 – 255 and saturation = 0 – 100). Pictures were also obtained and analyzed for non-trafficked subplots for comparison. Turf quality ratings continued until the beginning of October to further evaluate recovery differences among cultivars.

Lateral spread of the various cultivars was analyzed during 2004 using digital imaging techniques. On July 7, one core was taken from all non-trafficked, 1.9 cm mowing height subplots measuring 10.8 cm diam. x 5 cm deep. The cores were discarded and the holes remaining were filled level to the soil surface with white sand. Over a five week period, weekly digital photographs of the sand-filled area were taken using a constant height and camera setting to ensure uniformity of images. Each cultivar spread laterally toward the center of the sand circle until by the fifth week the holes were no longer evident due to regrowth. The rate of cover of the different cultivars was documented by the digital images taken over the five week period. At the end of the observation period, the images were analyzed using Sigma Scan Pro (v.5.0, SPSS, Inc., Chicago, IL) software to calculate percent cover within the 10.8 cm diam. area. A black template was constructed in Adobe Photoshop with a 10.8 cm diam. transparent hole in the center since a circular picture cannot be taken. The template was overlaid onto each plot images and scanned for percent green cover (hue = 45 – 255 and saturation = 0 – 100). The border of the template (45,364 pixels) was subtracted from the total amount of pixels to arrive at 131,777 pixels in the 10.8 cm diam. circle. The percent cover was calculated from only the circular portion of the template.

Data analysis for all of the experimental data was done using an Analysis of Variance (ANOVA) in the Statistical Analysis System (SAS Institute Inc., 2002). When data was shown to be significant in the ANOVA test at $P \leq 0.05$, either a Waller-Duncan k-ratio t-test or LSD test was used. For mean separation the LSD test was used for the Clegg impact and traffic simulation data because these data sets contained less than three variables (Traffic/No traffic) for which the Waller-Duncan test is inappropriate.

Results and Discussion

Nitrogen Fertility

Nitrogen application rates during 2003 showed no differences in turf quality ratings, rooting, or surface hardness during the study. The lack of response is difficult to explain. The most influential factor in the lack of separation is the fact that there were insufficient replications. More useful data could have been obtained if nitrogen treatments were stripped in the study thus creating a total of six replications during 2003.

Rooting

Rooting data was unaffected by any of the applied treatments. Furthermore, there was no cultivar or sampling date interactions. The lack of finding any significant rooting effects is attributed to vast field variation in sampling. Selecting a single random sample for analysis from a plot is subject to many sources of potential error. Rooting of bermudagrass in field studies is not uniform and slight variation in soil composition within a plot may result in high root concentrations in parts of the plot and low concentrations in others. For this reason, the rooting variation within plots was greater than the effect of any treatment implemented over the course of the study.

Mowing Height

Mowing height had no effect on turfgrass quality during either 2003 or 2004; although, surface hardness did vary with mowing height during 2004. During the first sampling date in June, mowing height did not influence Clegg Impact Values (CIV's) of 9.2 at the 1.9 cm mowing height and 9.1 at the 3.2 cm mowing height over all cultivars. Differences were observed on the second sampling date in July when CIV's of 8.9 at the lower height of cut compared to 8.0 at the higher cutting height were apparent over all cultivars. CIV's of 7.6 at 1.9 cm and 6.9 at the 3.2 cm height of cut were also different and recorded on the last sampling date in September. Under lower cutting heights, bermudagrasses exhibited greater surface hardness. This is directly linked to less vegetative material above the soil surface to aid in absorbing impact (Stewart, 2004).

Surface Hardness

The Clegg Impact tester revealed surface hardness differences not only between mowing heights but also between traffic treatments and cultivars. Clegg values from non-trafficked subplots at a mowing height of 1.9 cm were compared to evaluate cultivar differences. Sampling date was not a factor during 2003 or 2004. Surface hardness showed a decreasing trend over the course of the season although this was not statistically significant. During June 2003, no differences were observed at the 1.25 cm mowing height. GN-1 exhibited greater surface hardness at the 1.90 cm mowing height than Patriot and Celebration. In August 2003, Celebration and Tifton 10 exhibited the softest surfaces with a CIV of 5.9 and 6.7, respectively, at the 1.9 cm mowing height (Table 11). Over both mowing heights in July, Navy Blue exhibited great surface hardness than Celebration. During 2004, there were three sampling dates for CIV data at mowing heights of 1.9cm and 3.2cm. On each sampling date, for every mowing height, Celebration exhibited the lowest CIV of any cultivar. Values ranged from 6.7 on the first sampling date to 4.4 on the last sampling date (Table 12). Celebration is a dense cultivar of bermudagrass that is fast growing and quick to recover. These qualities play a significant role in its ability to produce low surface hardness values. In June and again in July, Navy Blue had the highest CIV of 10.8 and 10.6, respectively.

Table 11. Clegg Impact Value[†‡] (CIV) for bermudagrass cultivars as affected by mowing height in 2003.

	03 June		28 Aug	
	Mowing Height (cm)			
Cultivar	1.25	1.9	1.25	1.9
	Clegg Impact Value			
Navy Blue	9.6a*	8.9ab	10.2a	9.1a
Quickstand	9.2a	9.0ab	10.5a	8.3ab
GN-1	9.4a	9.9a	9.8ab	8.7ab
TifSport	10.1a	8.9ab	9.1abc	8.5ab
Patriot	9.6a	7.5b	9.6ab	7.9b
Tifway	10.1a	8.8ab	8.4bc	8.7ab
Tifton 10	9.7a	7.8ab	9.0abc	6.7c
Celebration	9.2a	7.0b	7.9c	5.9c

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the LSD t test.

[†] One CIV is the equivalent of 10 gravities.

[‡]CIV increased with increasing surface hardness.

Table 12. Clegg Impact Value[†‡] (CIV) for bermudagrass cultivars as affected by mowing height in 2004.

	01 June		26 July		02 September	
	Mowing Height (cm)					
Cultivar	1.9	3.2	1.9	3.2	1.9	3.2
	Clegg Impact Value					
Navy Blue	11.1a*	10.8a	10.6a	8.2bcd	8.9a	7.9a
Quickstand	10.9a	9.8bc	9.2c	8.6abc	8.8a	7.9a
GN-1	9.8b	10.2ab	9.9b	9.1a	8.4ab	7.6ab
TifSport	9.4b	9.0cde	9.1c	8.6abc	7.4cd	6.9c
Patriot	8.1c	8.8de	8.2d	7.6d	6.9d	6.0d
Tifway	9.6b	9.3bcd	8.7cd	8.6ab	7.3cd	7.4abc
Tifton 10	8.1c	8.2e	8.6cd	8.0cd	8.0bc	7.2bc
Celebration	6.7d	6.6f	6.4e	5.5e	5.0e	4.4e

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the LSD t test.

[†] One CIV is the equivalent of 10 gravities.

[‡] CIV increased with increasing surface hardness.

Turfgrass Quality

Turfgrass quality was evaluated biweekly during the study. During 2003, Tifway and Patriot outperformed Navy Blue on 4 of 5 ratings dates except 25 June, when no differences occurred among cultivars (Table 13). This lack of differences on 25 June may be due to the fact that all cultivars were at their peak of quality at or around this rating date and therefore variability was at a minimum. TifSport, Tifway, Patriot and Celebration performed equally well over all rating dates and showed greater turf quality than Navy Blue on all rating dates during 2004 (Table 14). GN-1 also performed poorly due to the fact that TifSport and Tifway had greater turf quality on 7 out of 10 rating dates during 2004. Multiple cultivars had turf quality ratings below the lowest acceptable level of five prior to full spring green up. There was no visible winter kill in any field plots. Navy Blue, however, had mean turf quality ratings at or below five on every rating date during 2004.

Table 13. Turfgrass quality ratings for eight bermudagrass cultivars during 2003.

Cultivar	May	June		July	
	28	11	25	9	23
	Quality Ratings†				
Tifway	5.5a*	6.2ab	6.0a	6.5a	6.4a
Tifton 10	5.2abc	6.3a	5.7a	6.3ab	6.2ab
Patriot	5.3ab	5.9abc	6.3a	6.1ab	6.1ab
TifSport	5.2abc	5.8bcd	5.7a	6.5a	6.5a
Quickstand	5.1abc	5.8bcd	5.9a	5.8bc	5.8bc
GN-1	4.9abc	5.6cd	5.7a	5.7bc	5.2cd
Celebration	4.7bc	5.4de	5.5a	5.7bc	5.8bc
Navy Blue	4.6c	5.0e	5.7a	5.2c	5.0d

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

† Visual ratings scale: 1= dormant or brown turf, 5= acceptable quality turf, and 9= dark green, dense, ideal quality turf.

Table 14. Turfgrass quality ratings for eight bermudagrass cultivars in 2004.

Cultivar	May	June		July		Aug			Sept	
	26	9	23	7	21	4	18	31	15	29
	Quality Ratings†									
TifSport	5.7a*	6.6a	6.9a	7.1a	7.1a	7.4a	7.3a	7.0a	7.2a	7.3a
Tifway	5.8a	6.3a	6.8a	6.8a	6.6ab	7.0ab	6.8abcd	6.8a	6.9a	7.0ab
Celebration	5.3a	5.3ab	6.1ab	6.2ab	6.3ab	6.9ab	7.0ab	6.8a	7.2a	6.8abc
Patriot	4.8a	6.1a	6.6a	6.5a	6.3ab	6.8abc	6.9abc	6.4ab	6.7a	6.8abc
Tifton 10	3.1b	4.3bc	4.8bc	4.5cd	5.6bc	6.3abc	6.1bcd	5.8b	6.1ab	5.8abcd
Quickstand	3.1b	4.4bc	5.2bc	5.3bc	5.6bc	5.8bcd	5.9cd	5.7b	5.8ab	5.7bcd
GN-1	3.0b	4.0c	4.8bc	4.7c	4.7cd	5.7cd	5.8d	6.1ab	5.6ab	5.5cd
Navy Blue	2.8b	3.7c	3.8c	3.6d	4.3d	5.0d	4.5e	4.3c	4.7b	4.8d

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

† Visual ratings scale: 1= dormant or brown turf, 5= acceptable quality turf, and 9= dark green, dense, ideal quality turf.

Traffic Simulation

Simulated athletic traffic affected cultivars differently during 2004(Table 15). After digitally analyzing all pictures, non-trafficked subplots exhibited less variation in percent cover than the trafficked subplots. However, non-trafficked subplots of GN-1 and Navy Blue had lower percent cover than did Celebration, Patriot, Quickstand, Tifway, and TifSport. Differences in percent cover of non-trafficked plots are important since these values can be attributed to natural genetic differences among cultivars and influence the final values of the trafficked subplots. Among trafficked subplots, Celebration exhibited 95% cover following the five week traffic treatments. This was greater than Quickstand, GN-1, Navy Blue, and Tifton 10 which maintained 79%, 69%, 63%, and 60% cover, respectively (Table 15). These data are useful when selecting a cultivar for use on an athletic field by displaying the cultivar(s) with the greatest percent cover after the trial taking all variables into account. However, a *P*-value indicating the magnitude of the difference in percent cover between the non-trafficked subplots and the trafficked subplots is most useful in explaining the sole effect of the traffic simulation on the bermudagrass cultivars. Using *P*-values ≤ 0.05 as significant; traffic simulation had little effect on Tifway, TifSport, Celebration, and Patriot while percent cover of Quickstand, GN-1, Navy Blue, and Tifton 10 were significantly affected by traffic on 28 August 2004.

Table 15. Percent cover as affected by five consecutive weeks of simulated traffic (Traf) on eight bermudagrass cultivars (Cult).

Cultivar	(a) No Traffic	(b) Traffic	Traf x Cult†
	———— % Cover	————	*P*-value‡
Celebration	99a*	95a	.3376
Patriot	96a	90ab	.1231
Quickstand	96a	79bc	.0002
Tifway	96a	92ab	.4007
TifSport	96a	92ab	.4007
Tifton 10	92ab	60d	<.0001
GN-1	87bc	69cd	.0001
Navy Blue	83c	63d	<.0001

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the LSD t test.

† Traffic by Cultivar interaction.

‡ *P*-value is significant at $P \leq 0.05$ and reports if the difference between column (a) and (b) are significant.

Rate of Lateral Spread

The rate of lateral spread plays a significant role in the recovery rate of bermudagrass following exposure to various stresses including disease, winterkill, and traffic. Variation among cultivars was observed in the study (Table 16) and hypothesized to be a factor in the relative performance of the cultivars in the traffic simulation portion of the study. One week after the experiment was initiated, Celebration exhibited 18% coverage, which was more than Tifton 10, Tifway, GN-1, TifSport, and Navy Blue which had 10%, 10%, 8%, 8%, and 6% cover, respectively. By 3 August, after four weeks of regrowth, Celebration had 86 % cover followed by Patriot, Quickstand, and TifSport each with 70% cover, respectively. Navy Blue had 38% cover after week four which was less than all cultivars except GN-1 with 54% cover (Table 16). Lateral spread data was relatively consistent with that of the traffic simulation, thus suggesting that it is a contributing factor in recovery from athletic traffic injury. The data were not correlated well enough to indicate if this attribute is the primary factor in traffic recovery or not. More research is needed in this particular area to identify to what extent lateral spread affects recovery rates of bermudagrass cultivars from traffic.

Table 16. Rate of lateral spread of eight bermudagrass cultivars expressed in percent cover[†] in 2004.

	2004			
Cultivar	July			August
	13	20	27	3
	% Cover			
Celebration	18a*	34a	55a	86a
Patriot	12ab	26ab	41abc	70ab
Quickstand	12ab	30ab	52ab	70ab
Tifton 10	10b	21abc	38abc	67b
Tifway	10b	18bc	32bcd	63b
GN-1	8b	18bc	31cd	54bc
TifSport	8b	18bc	38abc	70ab
Navy Blue	6b	10c	15d	38c

*Means within columns followed by the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

[†]Percent cover represented the percent of turf cover vs. sand cover in the 10.8 cm diam. sample area.

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Drought and Low Temperature Stress Tolerance of Eight Bermudagrass Cultivars

Study I: Low Temperature Stress Tolerance

Abstract

Low temperature stress tolerance is an important characteristic of bermudagrass (*Cynodon* [L.] Rich) cultivars established in the transition zone of the United States. This study sought to establish low temperature and exposure length ranges relative to cultivar survivability, as well as to compare survival differences between isolated stolons and intact field cores. Dormant bermudagrass cores were exposed to temperatures of 3, -1 and -7^{o}C for 12, 24, 48, or 72 h and then were allowed to recover in a greenhouse for 30 d. 'Patriot' and 'Quickstand' exhibited greater low temperature stress tolerance than other cultivars in the second year. In the same treatment, 'Navy Blue' and 'Tifton 10' also survived and thus exhibited greater low temperature stress tolerance than did 'TifSport', 'Tifway', 'GN-1', or 'Celebration'. Exposure lengths of 12 and 24h resulted in greater survivability across all cultivars than did the 48 and 72h exposures to -7^{o}C. In a separate experiment, stolons (an internode with two nodes) were excised from cores and exposed to temperatures ranging from 3 to -10^{o}C and were subsequently allowed to recover in a greenhouse. Results between the two studies show correlation (r_s = 0.82 and a probability of 0.01) with 'Quickstand' and 'Navy Blue' being significantly more cold tolerant than all other cultivars with the exception of 'Patriot'. 'Patriot' proved more cold tolerant than 'Tifton 10', 'TifSport', 'Tifway', and 'Celebration'.

Introduction

Bermudagrass (*Cynodon sp.*) is widely used throughout the Southern United States and reaches its limits of adaptation where low temperature stress causes frequent plant mortality (Gatschet et al., 1994). Bermudagrass cultivars vary in their inherent ability to tolerate extreme low temperatures (Ahring and Irving, 1969). Although management and environmental factors influence low temperature stress tolerance, genetics play a significant role (Beard et al., 1980; Ervin et al., 2004). Therefore, avoidance of winter-kill injury by selecting low temperature tolerant cultivars is a commonly used approach. One objective of this research was to identify precise temperature ranges and exposure lengths that affect survivability. Many studies have evaluated absolute low temperature stress tolerance of various cultivars. Few researchers have evaluated the effect of multiple exposure lengths on bermudagrass survival at low temperatures. Anderson et al. (2003) reported that exposure lengths of 2, 24, and 72 h resulted in cultivar recovery rates of 67, 30, and 11 %, respectively. A second objective of the study was to evaluate survival differences among isolated stolons verses entire field cores. Undisturbed cores withdrawn from the plots closely mimic field conditions in the laboratory by not disrupting soil, root, rhizome, and thatch interactions. Testing isolated stolons provides a simpler, but more artificial method to test low temperature stress tolerance of the regenerative tissue hypothesized to be most susceptible to low temperatures.

Materials and Methods

Seven-month-old plots of the bermudagrass cultivars TifSport, Tifway, Tifton 10, GN-1, Navy Blue, Quickstand, Celebration, and Patriot were used during the first year of research and the same 19-month-old plots were used during 2004. Plots were grown on a Candor sand (Sandy, siliceous, thermic Arenic Paleudult) with 0 to 1 percent slope and an initial pH of 5.5 at the Sandhills Research Station in Jackson Springs, North Carolina (Reynolds, 2003). It was from these plots that samples were collected and then subjected to low temperature stress. Samples were collected during February of 2003 and 2004 for both the core and stolon experiments.

Core Study

During February 2003, one 5-cm-square by 8-cm-deep core was removed from each field plot for each of six replications. The experiment was conducted similarly during 2004 with the only difference being the addition of two exposure lengths. Exposure length was defined as the length of time which cores were held at their respective low temperature. Dormant field cores were placed in a cooler for transport from the Sandhills Research Station to Raleigh and then immediately potted in 10 cm x 10 cm pots filled with coarse sand. Cores were randomly placed in a low temperature stress simulator similar to that described by Beard and Olien, (1963). Simulator temperature was initially 3^{o}C and was decreased at a rate of 1.5^{o}C per hour to a constant temperature of either -1^{o}C or -7^{o}C. Depending on assigned exposure length, cores were held at the final temperature for 12, 24, 48, or 72 h. Samples were then removed and placed in a greenhouse to recover for a period of 30d with an optimum mean greenhouse temperature range of 20^oC to 32^oC. When surviving cores broke dormancy, shoot tissue growth was harvested, oven dried, and weighed after 30d of regrowth.

Stolon Study

During the second week of February 2003 and 2004, 10.8-cm-diameter cores were removed from field plots of each cultivar. Stolons, defined as two above ground nodes connected by an internode with all vegetative material removed, were selected from these cores (Chalmers and Schmidt, 1978). After selection, stolons were collected on damp paper towels and then placed in plastic freezer bags in subgroups of ten stolons each and placed directly in a low temperature stress simulators (Price's Scientific, Programmable Mini-Chamber; Durham, NC). Stolons were held at 3^oC for 24 h before temperatures were reduced to their designated final temperature at a rate of 1.5^oC per hour. The final low temperatures reached were held for 24 h after which the temperature was increased at a rate of 1.5^oC/h until 3^oC was reached. Each of the ten stolons was directly potted into 10cm x 10cm pots of planting medium (Scott's Metro Mix 200; Marysville, OH) and placed in the greenhouse for 30d.

Statistical analysis was accomplished using mean separation by the Duncan's New Multiple Range Test at $P = 0.05$ following an analysis of variance using the general linear models procedure (SAS Institute, 2001). As a result of recording data in the stolon study as either a one (survived) or two (dead), a binomial distribution was created. To achieve homogeneity of variance, an arcsin transformation was used (Dickey et al., 1997).

Results and Discussion

Core Study

Cultivar differences were noted in 2003 for the -1^{o}C treatment while all samples exposed to -7^{o}C perished. Navy Blue and Patriot averaged 15% and 11% recovery, respectively, and were more cold tolerant than TifSport, Tifton 10, Tifway, and Celebration (Table 17). During 2004, cultivar differences were observed for the -1^{o}C treatment, however the differences were not considered as informative as in 2003 because all cultivars performed relatively well and Patriot and GN-1 actually exceeded the regrowth recorded in the control treatment (Table 17). It is difficult to hypothesize why this phenomenon was observed and more research is needed to explain the variation. Within the -7^{o}C treatment during 2004 there were significant cultivar differences with Patriot and Quickstand exhibiting the best low temperature stress tolerance, averaging 28% and 21% recovery compared to the control, respectively. Navy Blue and Tifton10 averaged 5% and 1% recovery, respectively, compared to 0% recovery for TifSport, Tifway, GN-1, and Celebration (Table 17). Yearly differences among cultivar survival at the -1^{o}C and -7^{o}C treatments in the core study could be attributed to varying degrees of yearly acclimation as well as maturity. This type of yearly response variability due to acclimation was also documented by Chalmers and Schmidt (1979). Acclimation has been shown to be a significant factor in the determination of absolute low temperature stress tolerance levels (Davis and Gilbert, 1970). During 2003 when samples were collected, the bermudagrass plots were 7 months old and were 19 months old when samples were collected in 2004. The age of the turf may very well have played a role in its ability to withstand low temperature stress which would explain the low survival in

2003. Exposure duration differences were significant only within the -7°C treatment where temperature had the greatest effect on cultivar survivability. Averaged over all cultivars, the 12 and 24 h exposure lengths had significantly greater survivability (9.8% and 9.4% recovery, respectfully) compared to the 48 and 72 h exposures (2.4% and 0% recovery, respectfully) at the -7°C temperature treatment.

Stolon Study

The critical low temperature to achieve 0% survival was not reached at temperature treatments $\geq$-6°C for any cultivar (Table 18). Therefore, the -8°C treatment is most applicable to establishing cold tolerance differences among cultivars. Quickstand, Navy Blue, and Patriot with 35%, 28%, and 18% stolon survival, respectfully, were significantly more cold tolerant than TifSport, Tifway, and Celebration (0% stolon survival) within the -8°C treatment (Table 18). The final temperature treatment of -10°C resulted in complete mortality for all cultivars. This confirmed the critical low temperature of survival to be similar to the temperature (-7°C) observed in the core study.

Subjecting the stolon and core studies to a Spearman rank correlation revealed positive correlation between the studies. The ranking of -8°C treatment results in the stolon study correlated well with both the -7°C, 12 and 24 h treatments of the core study with an r_s value of 0.82 and a probability of 0.01. Quickstand, Navy Blue, and Patriot in these treatments consistently exhibited better cold tolerance than all other cultivars.

Table 17. Bermudagrass core regrowth 30d after exposure to low temperature stress.

	Stress Temperature (^{o}C)			
	2003		2004	
Cultivar	-1	-7	-1	-7
	% Regrowth†			
Patriot	11ab*	0a	135a	28a
Quickstand	8abc	0a	91cd	21a
Navy Blue	15a	0a	73de	5b
GN-1	8abc	0a	127ab	0c
Tifton 10	0c	0a	60e	1b
TifSport	4c	0a	107bc	0c
Tifway	0c	0a	88cd	0c
Celebration	0c	0a	90cd	0c

† Regrowth=100*[1- (a – b/a)]

a= Average plant dry weight at $3^{o}C$ (control)

b= Average plant dry weight at stress temperature

*Means within columns followed by the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

Table 18. Mean stolon survival of selected bermudagrass cultivars following exposure to cold temperature stress.

	Temperature (°C)					
Cultivar	3	-2	-4	-6	-8	-10
	% Stolon Survival†					
Quickstand	95ab*	95a	90a	98a	35a	0a
Navy Blue	75b	83ab	80abc	53bc	28a	0a
Patriot	90ab	95a	90ab	23cd	18ab	0a
GN-1	95a	70b	58c	13d	8bc	0a
Tifton 10	93ab	93a	78abc	63b	3c	0a
TifSport	95a	95a	80abc	55bc	0c	0a
Tifway	95a	95a	80abc	53bc	0c	0a
Celebration	85ab	90a	55bc	35bcd	0c	0a

† Percentage of surviving stolons out of 40 subjected to low temperature stress for 24h.

*Means within columns followed by the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test. Data were transformed prior to ANOVA using an arcsin transformation [sqrt(cover/100)].

Conclusions

To a large extent, cultivar separation was observed for both studies at the same relative temperatures of -7°C and -8°C. Positive correlation between experiments supports the assumption that stolon survival is a major factor in the regeneration of bermudagrass after exposure to low temperature stress. However, it is possible that a cultivar such as Patriot relies more on sources of regeneration such as rhizomes and thatch interactions as a result of its greater survival in the core evaluation verses the stolon evaluation. The performance of GN-1, Tifway, TifSport, and Quickstand are supported by previous low temperature stress tolerance experiments (Anderson et.al, 2002). Anderson et al. (2002) expressed results as T_{mid} values where T_{mid} represented the midpoint of the survival temperature response curve. Quickstand was the most cold tolerant with a T_{mid} value of -8°C. TifSport, Tifway, and GN-1 followed with values of -7.2, -6.7, and -5.9°C, respectively. More work is needed to better identify the specific mechanism by which cultivars survive cold temperatures and what role, if any, soil and thatch play in cold hardiness of bermudagrass.

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<u>Study II</u>: Drought Stress Tolerance

<u>Abstract</u>

Drought tolerance is increasingly becoming a more valued characteristic of turfgrass species in many areas of the United States because of increased watering restrictions. Bermudagrass (*Cynodon* [L.] Rich) is used extensively in the southeastern United States on athletic fields and golf course fairways due to its durability, aesthetics, and drought tolerance. The objective of the study was to evaluate the drought resistance of eight bermudagrass cultivars including, 'TifSport', 'Tifway', 'Tifton 10', 'Navy Blue', 'GN-1', 'Patriot', 'Celebration' and 'Quickstand'. Two cores from each cultivar were removed from two-year old field plots during August 2003 and 2004 and were allowed to root and become acclimated in a greenhouse for four weeks before drought stress was induced. During the acclimation period the bermudagrass was irrigated twice daily for fifteen minutes. This was enough water to initiate drainage from the bottom of the pots and thus enough water to replenish the root mix to field capacity. The study continued seven weeks without water, during which time visual ratings were taken weekly and the time at which leaf firing occurred was recorded. Leaf firing appeared on Navy Blue an average of 6.0 weeks after water was withheld in 2003. This was longer than GN-1, Celebration, TifSport, Quickstand, and Tifway that showed signs of leaf firing, 4.8, 4.1, 3.8, 3.8, and 3.6 weeks after drought stress was induced. Navy Blue did not show signs of leaf firing until 7.0 weeks after water was withheld which was longer than all other cultivars in 2004.

Introduction

As human populations continue to grow in the southeastern United States, demands on fresh water resources will increase. Water restrictions for landscapes have become more frequent in the southeast where water was once thought to be an abundant resource. As demands on water supplies grow, it's crucial that water be used more efficiently, particularly for amenity uses such as lawns, athletic fields and golf course fairways. Turfgrasses are able to survive drought conditions in two primary ways, avoidance and tolerance (Turgeon, 2005). Avoidance is the ability of a turfgrass to undergo physiological changes such as deeper roots to extract water longer or leaf curling to reduce transpiration water loss. Tolerance is the ability of a turfgrass to survive when exposed to critically low levels of water regardless of various physiological response advantages. Research has revealed substantial variation among species and even cultivars within species as to their inherent ability to tolerate drought stress (Kim et. al., 1988). Relative to other warm-season turfgrasses, Kim et. al. (1988) found that bermudagrass had superior drought resistance compared to bahiagrass (*Paspalum notatum* Flugge), buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.), seashore paspalum (*Paspalum vaginatum* Swarts.), and St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze.), Centipedegrass (*Eremochloa ophiuroides* [Munro] Hack.) and zoysiagrass (*Zoysia japonica* Steud.) possessed drought resistance as bermudagrass. Cultivar differences have recently been documented for the cultivars evaluated in this trial. In April 2005, Baldwin et. al. (2005) reported that Celebration produced rooting superior to TifSport. It was also found that as time intervals of induced drought stress increased, rooting depth also increased. Increased rooting is directly linked to drought avoidance and drought tolerance (Hays et. al., 1991). Drought stress is commonly monitored by using visual ratings and by recording the time at which leaf firing begins. Leaf firing is first exhibited by the plant when under severe drought stress and is noticeable when leaves curl and begin to turn yellow along the edges which quickly turn tan and then brown (Ebdon and Kopp, 2004).

Materials and Methods

Cores were removed from 13 and 25 month old plots of the bermudagrass cultivars TifSport, Tifway, Tifton 10, GN-1, Navy Blue, Quickstand, Celebration, and Patriot in 2003 and 2004 and were evaluated in this research. Plots were grown on a Candor sand (Sandy, siliceous, thermic Arenic Paleudult) with 0 to 1 percent slope and an initial pH of 5.5 at the Sandhills Research Station in Jackson Springs, North Carolina.

Samples were collected in August 2003 and 2004 when the bermudagrass was at its peak of vigor and performance. Two 5-cm x 8-cm-deep cores were removed from each field plot, for a total of 12 replications in the greenhouse. Once taken from the field, cores were immediately transported to a greenhouse where all native soil was washed from each core. This procedure ensured uniform rooting material for all cores. With uniform material as the rooting medium, the rate of dry down was very consistent among samples. Fritted clay was used as rooting medium for the study due to its favorable dry down properties (White, 1996). Bare root samples were placed in 30-cm-diam. pots that were 35 cm deep, filled with the fritted clay. Each pot contained a single replication of all eight cultivars which were randomly placed within each pot. Plants were irrigated for fifteen minutes, twice a day and kept mowed for four weeks until established. Fifteen minutes of irrigation water was sufficient to induce drainage in from the pots and thus raise the water levels in the pots to field capacity. A daily mean greenhouse temperature range of 20^{o}C to 32^{o}C was maintained throughout the study. During the second week of September, irrigation and mowing ceased. Visual ratings began two weeks later when visual differences in color and quality began to appear. A rating scale of one to five was used to evaluate quality with one representing dead turf, three indicating initial leaf firing, and five representing a healthy, unstressed grass plant. Leaf firing was recorded after leaf wilting had occurred, when the plant initially exhibit signs of yellowing, tanning, or browning of leaf tissue (Ebdon and Kopp, 2004). Ratings continued weekly for seven weeks of induced drought stress.

Data analysis for all of the experimental data was done using an Analysis of Variance (ANOVA) in the Statistical Analysis System (SAS Institute Inc., 2002). When data was shown to be significant in the ANOVA test at $P \leq 0.05$, a Waller-Duncan k-ratio t-test was used for mean separation.

Results and Discussion

Drought stress affected cultivars differently in the study. The amount of time between introduction of drought stress and the time of leaf firing varied among cultivars. In a given year, cultivars were consistent in their performance; however, rankings between years varied. In 2003, Navy Blue first experienced leaf firing when rated 6 weeks after drought stress was induced. This was longer after water was withheld than Celebration, Tifway, GN-1, TifSport, and Quickstand (Table 19). Within this group of cultivars, Celebration and GN-1 exhibited leaf firing after Tifway, TifSport, and Quickstand. In 2004, Navy Blue outperformed all other cultivars in the study and did not indicate signs of leaf firing until 7.0 weeks after drought stress were initiated. Celebration followed with a mean firing time of 6.8 weeks which was greater than all cultivars except Navy Blue. During 2004, Quickstand exhibited leaf firing more quickly than all other cultivars.

Table 19. Weeks required to induce leaf firing for eight bermudagrass cultivars subjected to drought stress during 2003 and 2004.

Cultivar	2003	2004
	—— Weeks until leaf firing ——	
Navy Blue	6.0a	7.0a
Celebration	4.1cd	6.8b
Patriot	5.8ab	6.3c
Tifway	3.6d	5.9cd
Tifton 10	6.3a	5.8d
GN-1	4.8bc	5.7d
TifSport	3.8d	5.5d
Quickstand	3.8d	4.9e

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

In both years, all cultivars began drought tolerance testing with mean visual ratings at or above 4.0. Cultivar separation became evident during the second week following drought induction and continued to develop throughout the study (Figure 3 & 4). By the seventh and final week during 2003, Tifton 10, Navy Blue, and Patriot had higher mean ratings of 3.3, 3.2, and 2.8, respectively, compared to Quickstand, TifSport, or Tifway rated at 2.1, 1.8, and 1.5 respectively (Table 20). On five of the six rating dates, Tifton 10 and Navy Blue exhibited higher ratings than GN-1, Quickstand, TifSport, and Tifway. During 2004, Navy Blue exhibited less leaf firing than all other cultivars from week 4 through week 7 (Table 21). Celebration followed Navy Blue by outperforming all cultivars except Navy Blue with a mean rating of 3.3. Quickstand consistently produced the lowest mean turf quality ratings, significantly poorer than all cultivars except GN-1 on all rating dates.

Figure 3: Visual quality ratings for eight drought stressed bermudagrass cultivars in 2003.

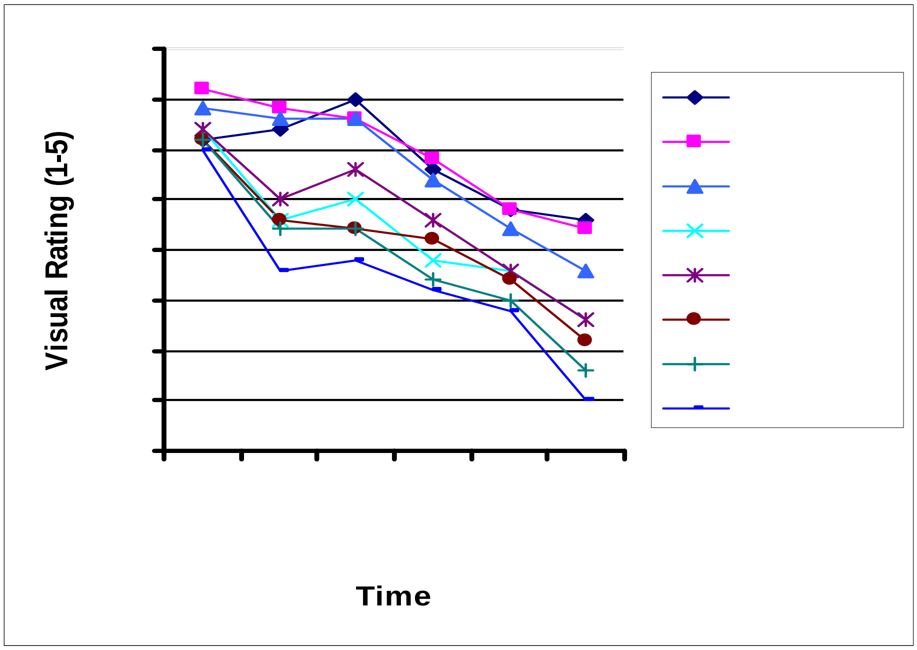
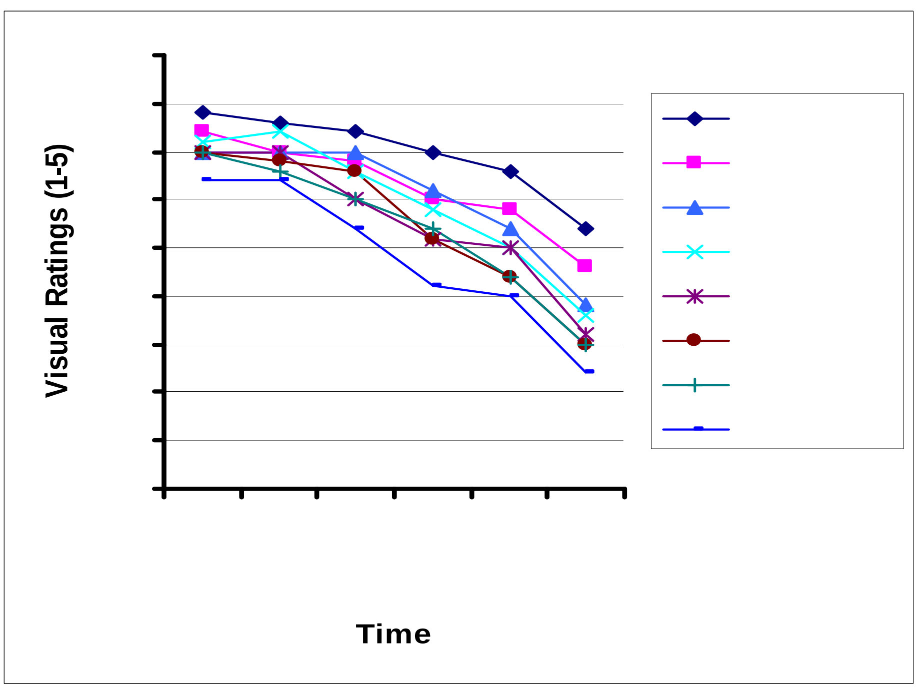


Figure 4: Visual quality ratings for eight drought stressed bermudagrass cultivars in 2004.



Relative performance of cultivars was similar in each year with one noticeable exception. The relatively poor performance of Celebration during 2003 was unexpected and is difficult to explain given its aggressive, deep rooting characteristics (Baldwin et. al., 2005). Celebration performed more predictably in 2004.

Table 20. Visual quality ratings for eight drought stressed bermudagrass cultivars in 2003.

Cultivar	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
	Quality Ratings†					
Tifton 10	4.1a	4.2a	4.5a	3.8a	3.4a	3.3a
Navy Blue	4.6ab	4.4a	4.3a	3.9a	3.4a	3.2a
Patriot	4.4bc	4.3a	4.3ab	3.7ab	3.2ab	2.8ab
Celebration	4.2bc	3.3b	3.5bc	2.9bac	2.8abc	2.3bc
GN-1	4.2bc	3.5bc	3.8cd	3.3bcd	2.8bc	2.3bcd
Quickstand	4.1bc	3.3bc	3.2de	3.1cd	2.7bc	2.1cd
TifSport	4.1bc	3.2bc	3.2de	2.7cd	2.5c	1.8de
Tifway	4.0c	2.8c	2.9e	2.6d	2.4c	1.5e

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

† Visual ratings scale: 1= Dead turf; 3= Leaf firing; 5= Ideal quality.

Table 21. Visual quality ratings for eight drought stressed bermudagrass cultivars in 2004.

Cultivar	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
	Quality Ratings†					
Navy Blue	4.9a	4.8a	4.7a	4.5a	4.3a	3.7a
Celebration	4.7ab	4.5ab	4.4b	4.0b	3.9b	3.3b
Patriot	4.5b	4.5bc	4.5b	4.1b	3.7bc	2.9c
Tifway	4.6b	4.7cd	4.3b	3.9bc	3.5c	2.8cd
TifSport	4.5b	4.5cd	4.0b	3.6cd	3.5c	2.6de
Tifton 10	4.5b	4.4cd	4.3c	3.6d	3.2d	2.5e
GN-1	4.5b	4.3de	4.0c	3.7d	3.2de	2.5e
Quickstand	4.2c	4.2e	3.7d	3.1e	3.0e	2.2f

* Means within columns with the same letter are not statistically different at $P \leq 0.05$ using the Waller-Duncan k-ratio t test.

† Visual ratings scale: 1= Dead turf; 3= Leaf firing; 5= Ideal quality.

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General Conclusions

Classifying cultivars based on an overall perspective can be misleading and it is important to look at each cultivar on an individual basis in order to select the cultivar that is best suited for your specific needs.

Chapter I:

1. Nitrogen fertility rates of 100, 150, and 200 kg N ha^{-1} had no effect on turf quality ratings, surface hardness, or root and thatch production.
2. Mowing heights of 1.25 cm and 1.9 cm had no effect on the relative ranking of mean turf quality ratings in the study.
3. TifSport had significantly higher mean turf quality ratings than all other cultivars for both mowing heights. Overall turf quality ratings taken biweekly showed TifSport had significantly greater turf quality than all other cultivars on all but two occasions.
4. Tifton 10 and GN-1 had the least surface hardness over both years of the study while neither date nor mowing height had any effect on surface hardness.
5. Tifway had a greater percent Spring Dead Spot (*Ophiosphaerella korrae*) by area than did all other cultivars and was followed by Navy Blue which had significantly more disease than all cultivars but Tifway.

Chapter II:

1. Mowing heights of 1.9 cm and 3.2 cm had no effect on cultivar mean turf quality ratings.
2. During 2003, there were no rooting differences among cultivars regardless of mowing height and fertility treatments.
3. For each sampling date and mowing height during 2004, Celebration exhibited the lowest surface hardness of any cultivar which may result in a reduction in player injuries on athletic fields.
4. Turf quality ratings taken biweekly showed that TifSport, Tifway, Patriot and Celebration had higher mean ratings than Navy Blue on all rating dates during 2004.
5. Recovery rates as assessed by the rate of lateral spread were completed over a four-week period after which Celebration had achieved the greatest recovery at 86% followed by TifSport and Quickstand, each with 70% recovery.
6. Simulated traffic had the greatest effect on Quickstand, GN-1, Navy Blue, and Tifton 10 in terms reduction in percent cover.

Chapter III:

1. ‘Patriot’ and ‘Quickstand’ exhibited greater low temperature stress tolerance than other cultivars in 2004.
2. Exposure lengths of 12 and 24h resulted in greater survivability across all cultivars than did the 48 and 72h exposures to -7^{o}C.
3. Results between the two studies show correlation (r_s = 0.82 and a probability of 0.01) with ‘Quickstand’ and ‘Navy Blue’ being significantly more cold tolerant than all other cultivars with the exception of ‘Patriot’.
4. Leaf firing appeared on Navy Blue an average of 6.0 weeks after water was withheld in 2003. This was longer than GN-1, Celebration, TifSport, Quickstand, and Tifway that showed signs of leaf firing, 4.8, 4.1, 3.8, 3.8, and 3.6 weeks after drought stress was induced.
5. Navy Blue did not show signs of leaf firing until 7.0 weeks after water was withheld which was longer than all other cultivars in 2004.

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