University of Kentucky

UKnowledge

Theses and Dissertations--Plant and Soil Sciences

Plant and Soil Sciences

2012

TEMPERATURE EFFECTS ON GERMINATION CHARACTERISTICS AND TRAFFIC TOLERANCE OF NEWLY ESTABLISHED STANDS OF NINETEEN COMMERCIALLY AVAILABLE CULTIVARS OF SEEDED BERMUDAGRASS

Michael Todd Deaton
University of Kentucky, mike.deaton@uky.edu

Right click to open a feedback form in a new tab to let us know how this document benefits you.

Recommended Citation
Deaton, Michael Todd, "TEMPERATURE EFFECTS ON GERMINATION CHARACTERISTICS AND TRAFFIC TOLERANCE OF NEWLY ESTABLISHED STANDS OF NINETEEN COMMERCIALLY AVAILABLE CULTIVARS OF SEEDED BERMUDAGRASS" (2012). *Theses and Dissertations--Plant and Soil Sciences*. 13.
https://uknowledge.uky.edu/pss_etds/13

This Doctoral Dissertation is brought to you for free and open access by the Plant and Soil Sciences at UKnowledge. It has been accepted for inclusion in Theses and Dissertations--Plant and Soil Sciences by an authorized administrator of UKnowledge. For more information, please contact UKnowledge@lsv.uky.edu.

STUDENT AGREEMENT:

I represent that my thesis or dissertation and abstract are my original work. Proper attribution has been given to all outside sources. I understand that I am solely responsible for obtaining any needed copyright permissions. I have obtained and attached hereto needed written permission statements(s) from the owner(s) of each third-party copyrighted matter to be included in my work, allowing electronic distribution (if such use is not permitted by the fair use doctrine).

I hereby grant to The University of Kentucky and its agents the non-exclusive license to archive and make accessible my work in whole or in part in all forms of media, now or hereafter known. I agree that the document mentioned above may be made available immediately for worldwide access unless a preapproved embargo applies.

I retain all other ownership rights to the copyright of my work. I also retain the right to use in future works (such as articles or books) all or part of my work. I understand that I am free to register the copyright to my work.

REVIEW, APPROVAL AND ACCEPTANCE

The document mentioned above has been reviewed and accepted by the student's advisor, on behalf of the advisory committee, and by the Director of Graduate Studies (DGS), on behalf of the program; we verify that this is the final, approved version of the student's dissertation including all changes required by the advisory committee. The undersigned agree to abide by the statements above.

Michael Todd Deaton, Student

Dr. David W. Williams, Major Professor

Dr. Dennis B. Egli, Director of Graduate Studies

TEMPERATURE EFFECTS ON GERMINATION CHARACTERISTICS AND TRAFFIC TOLERANCE OF NEWLY ESTABLISHED STANDS OF NINETEEN COMMERCIALLY AVAILABLE CULTIVARS OF SEEDED BERMUDAGRASS

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Agriculture
at the University of Kentucky

By

Michael Todd Deaton

Lexington, Kentucky

Director: Dr. David W. Williams, Associate Professor of Turfgrass Science

Lexington, Kentucky

2012

Copyright © Michael Todd Deaton 2012

ABSTRACT OF A DISSERTAION

GERMINATION CHARACTERISTICS AND TRAFFIC TOLERANCE OF NEWLY ESTABLISHED STANDS OF NINETEEN COMMERCIALLY AVAILABLE CULTIVARS OF SEEDED BERMUDAGRASS

Nineteen bermudagrass (*Cynodon dactylon* (L.) Pers.) cultivars were evaluated for field emergence, establishment rate, traffic tolerance, post-harvest seed coating, germination velocity, and total germination under varying temperature regimes. Two cultivars were evaluated for thermal modeling, day/night temperature fluctuations, day lengths, and effects of fluridone on speed and percentage of total germination.

The effect of cultivar was highly significant for visible field germination, time to 100% cover, and traffic tolerance in both 2010 and 2011. Riviera was the slowest or equivalent to the slowest for visible germination. Casino Royale was the fastest or equivalent to the fastest for visible germination. Yukon was the slowest to reach 100% cover in both years, while Sovereign was the quickest for 2010. Riviera and Sovereign were equivalent for the quickest to cover in 2011. Riviera and Yukon ranked highest and lowest, respectfully, in tolerance to simulated athletic traffic.

There were no significant effects ($p>0.05$) of post-harvest seed coatings. There were highly significant differences among cultivars in germination velocity and total germination when grown under 20-year average day/night temperatures representing data from Lexington, KY on 15 May to 1 August in 15 day intervals.

Evaluations for day/night temperature regimes, day length regimes, and effects of fluridone on the germination speed and percentage were also completed on Riviera and Casino Royale. Day/night regimes of 35/20, 35/25, and 40/25 degrees Celsius were evaluated. Significant differences ($p<0.05$) were observed, 35/20^{o}C producing the fastest and highest percentage of germination across both cultivars. Day length was evaluated for 8, 12, 14, and 16 hours with no significant differences ($p<0.05$) observed. Fluridone significantly ($p<0.05$) decreased the germination time and increased the percentage of total germination of Riviera while only significant differences ($p<0.05$) in germination time observed with Casino Royale.

KEY WORDS: seeded bermudagrass, germination characteristics, traffic tolerance, seeding date, fluridone

_Michael T. Deaton______________________
Student's Signature

30 July 2012_________________________
Date

TEMPERATURE EFFECTS ON GERMINATION CHARACTERISTICS AND TRAFFIC TOLERANCE OF NEWLY ESTABLISHED STANDS OF NINETEEN COMMERCIALLY AVAILABLE CULTIVARS OF SEEDED BERMUDAGRASS

By

Michael Todd Deaton

_David W. Williams______________
Director of Dissertation

_Dennis B. Egli_________________
Director of Graduate Studies

_30 July 2012__________________
Date

ACKNOWLEDGEMENTS

I would first like to express my sincerest gratitude to Dr. David Williams and Dr. A.J. Powell, for without them, this aspect of my life would not have taken place. Their willingness to take me on as a graduate student after a fifteen year separation from school is, and will always be, greatly appreciated. I want to thank Dr. Williams for being my dissertation director and for all of the assistance that he provided to me during my graduate school career and in the writing of this dissertation. I would like to also say a special thanks to Dr. Powell for all he has done for me over the many years that I have known him, from being my undergraduate advisor, to technical advice for my family business, to his contributions to my research and writing efforts and his willingness to serve on my committee. I would also like to thank the remaining members of my dissertation committee, Dennis Egli, Carol Baskin, and Robert Geneve, for their time and advice throughout the research and dissertation process. A special thank you also to Bruce Downie for his time spent on my committee and all of his assistance with my research and with the analysis of the data. I would also like to thank other faculty members, Glenn Aiken, Sharyn Perry, Mike Barrett, and Gregg Munshaw, who's participation made the research and writing components of the process much easier.

I would also like to thank Linda Williams, Ricky King, Rich Mundell, and Marcy Rucker for all of their help with my field and germination chamber work for this degree. They made my life much easier and my results and efforts would not have been nearly as good if they had not been so involved. I would also like to say a special thanks to my fellow graduate student Kenneth Cropper for all of his help and putting up with me at the farm, in the office, and in every class. To Daniela Sarti, Beau Neal, and Ana Balut, and Alex Williams, and my other fellow graduate students, I would like to thank you all for the study sessions and many laughs that we have shared over the last couple of years.

Last but most importantly, I would like to thank and express my love and gratitude to my wife Tena for her unwavering and great support for me in my pursuit of my graduate degrees, and for taking up all of the slack while I've been gone. I want to thank my parents, Ernie and Beulah, for all of their help with my children, Kendal and Brody, and my grandson, Carsen, in my absence. Finally, I want to thank God for his presence and guidance in my life, for without him, I would not have been able to achieve so many things in my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

Literature Review

Bermudagrass was introduced from Africa in 1751. It was primarily used as a forage grass in the Carolinas until 1927 when it was first utilized for golf turf and two years later in 1929 saw its first application as a lawn grass (Busey, 2010; USDA, 1948). Arizona common, also referred to simply as 'Common', has been propagated for seed production since the 1960's (Unruh et al., 1996). Until recently, seeded bermudagrasses have lagged far behind their vegetatively propagated hybrid counterparts (*C. dactylon x C. transvaalensis* Burtt-Davey) in overall turfgrass quality (Patton et al., 2008; Shaver et al., 2006; Karcher et al., 2004; Richardson et al., 2004). Until the release of improved varieties in the 1990s, the seeded types tended to have a coarse leaf with a more open type growth habit and lighter green color than the hybrids, such as the industry standard 'Tifway' (Baltensperger and Klingenburg, 1994).

Following strong breeding efforts and the release of cultivars such as Riviera in 2001 (Martin et al., 2007), a renewed interest in the seeded bermudagrasses emerged. It was not until this time that seeded cultivars achieved equal or superior quality characteristics, traffic tolerance, disease resistance, and resistance to winter kill in the transition zone (Patton et al., 2008; Munshaw et al., 2001). These improved cultivars opened the door for seeded bermudagrass to be used in fine turf applications such as sports and golf turf in the transitional climatic zone (Patton et al., 2008).

Seeded cultivars are important in the transitional climatic zone due to a shorter growing season compared to the warmer, more subtropical like climate as in the south east regions of the United States. The area defined as the transition climatic zone is the boundary between the temperate or cool and subtropical or warm climates in the eastern and middle United States (Turgeon, 2005; Beard, 1973). The transition zone runs from coastal Delaware and northern Virginia west through West Virginia, southern Ohio and Indiana, northern and central Kentucky, southern Missouri, northern Arkansas, and the northern regions of Oklahoma. The need for cold tolerant cultivars and lower costs for establishment versus sprigging or sodding makes the seeded cultivars a better fit for the transition zone (Munshaw et al., 2001). Seeding versus sodding can save as much as $5000.00 per acre (Patton et al., 2004b). Establishment rates comparable to sprigging that will tolerate traffic in the first season is an additional advantage to transition zone turf managers.

The release of improved seeded cultivars and the subsequent increase in usage has instigated considerable research in seeding dates and rates over the past two decades (Richardson et al. 2004). This information was critical due to the potential for the newly established bermudagrass to succumb to winter kill (Munshaw et al., 2001; Philley and Krans, 1998). Newly established bermudagrass is most vulnerable to winter kill damage after the first winter (Munshaw and Williams, 2002; Philley and Krans, 1998). Older stands have had two or more growing seasons to produce adequate stolons and rhizomes, which are the survival structures for the plant (Munshaw et al., 2001; Ahring et al., 1975). Production of stolons therefore is critical to the long term success of the stand and is directly influenced by seeding rates (Patton et al., 2004 b; Munshaw et al., 2001). Studies by Patton et al. (2004 b) and Munshaw et al. (2001) determined the optimal seeding rates for maximum stolon production to be between 0.11 kg pure live seed (PLS) and 0.22 kg

PLS per 92.9 m^2. Patton et. al. (2004 b) and Munshaw et al.(2001) also concluded that coverage was quicker with higher seeding rates but resulted in lower stolon production and mass.

Seeding dates also have been studied. Patton et al. (2004 a,b), and Richardson et al. (2004) conducted studies to determine the optimal seeding date for seeded bermudagrass. They reported that in order to achieve optimal stands, seeding should be completed in late spring to early summer (late May- early June). Plantings completed after this time run a higher risk of first year winter kill due to lack of stolon production and subsequently, carbohydrate reserves. Also seeding rates higher than 0.45 kg per 92.9 m^2 planted at the recommended time were more susceptible to first year winter kill. Increased rates achieve higher tiller densities more quickly than lower seeding rates which equals quicker cover, but significantly fewer stolons. Patton et al. (2004 b) reported that stands resulting from higher seeding rates end up with approximately the same number of tillers 28 days after seeding as the lower rates. This is a result of self thinning and is described by Lush's self-thinning rule (Lush, 1990). Shaver et al., (2006) also conducted studies to determine the effects of dormant or winter seeding and found that dormant or winter seeding produced quicker germination and equal or superior stand establishment over the conventional late spring seeding times for northwest Arkansas. Winter seeding could allow turf managers more flexibility in busy times to focus on other timely tasks (Shaver et al., 2006).

Consideration must be given to the expected environmental conditions for a particular seeding date and the amount of time the soil will be bare during bermudagrass establishment from seed. Annual grassy weeds such as crabgrass (*Digitaria spp.* L.) and goosegrass (*Eleusine indica* L.*)* will normally germinate rapidly during the recommended window for seeding bermudagrass. These weeds can greatly increase the chances of stand failure if not addressed at the time of emergence. They also tend to germinate quicker than bermudagrass and thus will shade the bermudagrass seed and compete for vital radiation, soil moisture, and nutrients.

Seeding solely by calendar causes other concerns that are related to temperature and germination of the desired species as well as weedy species. Weather data collected by the University of Kentucky Agricultural Weather Center show significant variation in temperature among years for the same day(s) of year. Intuitively, expected temperatures should be considered when planning establishment of bermudagrass by seed in order to maximize rapid germination.

Variability among seeded bermudagrass cultivars in temperature requirements to complete the germination process is an area that has not been well studied or documented. Studies by Patton et al. (2004 b), and Richardson et al. (2004) observed significant differences in visible germination time and stand establishment among cultivars. Patton et al. (2004 a) noted the use and utility of growing degree day (GDD) models to predict the germination of bermudagrass and zoysiagrass (*Zoysia japonica* Steud.). This study estimated GDD accumulation with the equation: (Max. Temperature + Min. Temperature)/2 – Base Temperature (10°C) daily from seeding to final rating date. The resulting GDD data indicated that Mirage bermudagrass requires >950 GDD to reach 95% cover. Based on this GDD model it required 30 to 60 days for Mirage and 90 to 105 days for Zenith zoysiagrass for the sites in Kentucky and Indiana.

Growing degree day or heat sum models can be used to predict germination at optimal moisture conditions. These models are based on thermal unit accumulation (temperatures over time) above a minimum base temperature at which the seed can progress toward the completion of germination (Bierhuizen and Wagenvoort, 1974; Wagenvoort and Bierhuizen, 1976). In the the upper transition zone where most of the seeded bermudagrass applications are sports and golf turf, water and light are generally not limiting factors for the completion of germination. Therefore, assuming optimal moisture conditions, temperature is most likely the limiting factor for completion of germination (Bierhuizen and Wagenvoort, 1974).

Over the years, heat sum models have been incorporated into more complex models to describe germination characteristics. Expanding on the long recognized cardinal temperatures (base - the minimum required temperature for progress toward the completion of germination; optimum - the temperature in which the progress toward the completion of germination is at a maximum level; and ceiling - the maximum temperature at which progress can be made toward the completion of germination) for germination introduced around 1860, hydrothermal time models have evolved to describe temperature and water thresholds for the germination process (Alvardo and Bradford, 2002). Modeling with weed species predicts seedling emergence patterns and is useful in weed management programs (Bradford, 2002).

The development and use of either thermal and/or hydrothermal models has been well studied and documented for species such as potato (*Solanum tuberosum* L.) (Alvarado and Bradford, 2002) and tomato (*Lycopersicon esculentum* Mill.) (Cheng and Bradford, 1999). With the successes of these models using other plant species, it is logical to think they can be applied to turfgrass species as well. However, studies of this nature for turfgrass species, especially bermudagrass, are limited or have not been attempted. Applications of thermal modeling for the upper transition zone would help to characterize the optimum temperatures to achieve maximum germination of bermudagrass seeds.

Bradford (2002) noted that seeds in a given lot or population may have a similar base temperature, but there are possible exceptions. Models are based on the assumption that a common base temperature exists among cultivars within a species. Delineating exceptions to the base temperature requires more elaborate and complex models to accurately describe the effects of temperature (Bradford, 2002).

Baskin and Baskin, (2001) described *C. dactylon* as having a non-dormant seed meaning the seed will germinate upon dissemination from the mother plant. Bermudagrass is also non-determinate and therefore capable of producing seed at any time during the growing season in the upper transition zone. With no seed dormancy and adequate environmental conditions, the germination process and seedling emergence could take place immediately after dissemination from the mother plant under non-limiting environmental conditions.

Within the species, cultivars of bermudagrass have been thought to be easy to establish due to quick germination compared to other warm season grasses (Philley and Krans, 1998). This is apparently true for the majority of the commercially available seeded bermudagrasses. However, there are almost certainly exceptions. Strong anecdotal evidence indicates that the cultivar Riviera can often be slow to germinate in the field. Slow germination is complicated by concurrent germination of weedy species and sometimes also sometimes by subsequent over-management (e.g., over-irrigating), often due to concerns of the turf manager that germination should occur quicker. The popularity of Riviera due to its high quality, superior traffic tolerance, and winter hardiness continues to make it appealing to most sports and golf turf managers, but it can often be one of the most difficult cultivars to establish from seed.

Objectives

My primary goal was to investigate and identify the factor(s) inhibiting the process of germination and establishment of Riviera seeded bermudagrass. My specific objectives were to:

1. Quantify differences among cultivars in time to visual germination under field conditions.
2. Quantify differences among cultivars in time to complete plot cover.
3. Quantify differences among cultivars in tolerance to simulated traffic.
4. Determine if post-harvest seed coating decreases the time to complete germination.
5. Characterize germination for two (one quick, one slow) seeded bermudagrass cultivars.
6. Evaluate the effect of various day lengths on the germination process for Riviera.
7. Evaluate the effect of various day/night temperature regimes on the germination process of Riviera.
8. Evaluate the effects of fluridone on the velocity of germination and total germination of two seeded bermudagrass cultivars.

This dissertation is organized into five chapters, with chapters two through four formatted as a refereed paper containing its own Introduction, Materials and Methods, Results, and Discussion sections. Chapter five ‘Conclusions’ will not attempt to summarize individual chapters, but instead present an overall perspective and suggest and discuss future directions and implications (Bixby-Brosi, 2011). All references are compiled into a single section ’References’ at the end of the dissertation.

Copyright © Michael Todd Deaton 2012

Chapter II

Germination and Establishment of Nineteen Commercially Available Seeded Bermudagrass (*Cynodon dactylon* (L.) Pers.) Cultivars

Bermudagrass was introduced from Africa in 1751. It was primarily used as a forage grass in the Carolinas. In 1927 it was utilized for the first time for golf turf and just two years later in 1929 saw its first application as a lawn grass (Busey, 2010, USDA, 1948). Common bermudagrass has been propagated since the 1960s for seed production but lacked the desirable turfgrass quality characteristics of its vegetatively propagated counterparts (Patton et al., 2008; Shaver et al., 2006; Karcher et al., 2004; Richardson et al., 2004). Until breeding improvements were made in the 'common' type bermudagrasses in the 1980s and 90s, sprigging was the most common means of propagation. New seeded cultivars released in the 1990s finally achieved equal or superior quality characteristics when compared to the interspecific 'hybrid' cultivars that had long been the industry standard in medium to high maintenance turf applications (Baltensperger and Klingenburg, 1994).

Seeded cultivars provided a substantially lower cost alternative compared to other means of stand establishment (Patton et al., 2004 a,b). In the early years of the twenty first century, little information was available for seeded bermudagrass establishment. With the release of many new seeded cultivars, studies were conducted to determine optimal seeding rate, date, and fertility requirements (Shaver et al., 2006; Patton et al., 2004 (a, b); Karcher et al., 2004; Munshaw et al., 2002).

Many characteristics should be considered in the process of choosing the appropriate cultivar of seeded bermudagrass. Most of the previous work has focused on seeding practices and was limited to either a small number or sometimes only individual cultivars. The release of these new seeded cultivars has now provided a gap in the information available (Patton et al., 2004). Continued breeding efforts have led to greater genetic diversity among the cultivars (Yerramsetty et al., 2005). Patton et al. (2008) reported on the establishment vigor of 28 bermudagrass cultivars compiled from National Turfgrass Evaluation Program (NTEP) data that indicated significant differences among cultivars.

Establishment vigor describes the rate of germination and seedling growth. Nonogaki et al., (2010), Bradford, (2002) and Bewley, (1997) defined germination in the physiological sense as the processes involved and culminating with protrusion of any part of the embryo, usually the radicle, through the testa or seed coat. As noted previously by Patton et al. (2008), there are significant differences in vigor among seeded bermudagrasses in which the completion of germination is just one facet in the process to stand establishment.

The processes that must take place for any seed to complete the germination process are initially triggered by the uptake of water by the quiescent seed. Upon imbibition, the seed must transition quickly from the quiescent state, resume and maintain a certain intensity of metabolism, undergo specific cellular events to prepare for radicle emergence, and prepare for seedling growth (Nonogaki et al., 2010). The speed at which these events occur is correlated to the availability of moisture. During the process there are three distinct phases of water uptake. Phase I begins with imbibition and the beginning of metabolic activity such as DNA repair, synthesis of proteins using extant mRNAs, mitochondria repair. This is a time of considerable solute leakage. Phase II is known as the lag phase where water enters and exits the seed with no discernable change in water content. It is also a time with continued DNA and mitochondria repair using extant mRNAs. It marks the beginning of mitochondria synthesis and protein synthesis using new mRNAs. Membranes have been repaired, solute leakage is stopped, and the cells regain their integrity. Phase III involves hypocotyl/epicotyl/radicle cell elongation as well as mobilization of stored reserves. DNA begins to replicate and cell division takes place post germination (Bewley, 1997).

The aforementioned processes are all dependent upon adequate moisture in the soil. The availability of free moisture to allow free exchange between the soil and the seed is crucial for the process of germination to proceed. Most seeded bermudagrasses are sold with a post-harvest, mechanically applied seed coating. This technology has been implemented in many species and is touted to provide many benefits such as enhanced establishment, providing nutrients and fungicides to promote early growth and ward off incidence of disease, and promoting the imbibition of water (Leinauer et al., 2010; Scott et al., 1985). Studies by Greipsson (1999), Scott (1975), and Vartha and Clifford, (1973) all indicated significant increases in establishment using coating technology. While the composition of these coatings differ, it is a good argument for the use of coating technology. Leinauer et al., (2010) also noted that germination was not significantly improved for coated versus uncoated seed 22 days after seeding, but establishment was greater at the end of the establishment period, or 92 days after seeding, for the coated seed. A study completed by Richardson et al., (2010) found coating only made a difference in sandy-type soils with poor moisture retention.

Other physiological process may be the basis for the differences in the completion of germination and establishment between cultivars within a species. Abscisic acid (ABA) and gibberellins (GA) have been well studied and their roles in the germination process are well known. With greater genetic diversity among the seeded bermudagrass cultivars, the amounts of each hormone present and how they are synthesized and catabolized may play a direct role in the large differences in germination characteristics.

Previous seeding date research has established an optimal seeding date based on establishment characteristics of several seeded cultivars. However, with the availability of many newly released cultivars that exhibit somewhat different establishment characteristics, these less specific recommendations may or may not be valid for all cultivars (Patton et al., 2004a).

The objectives of these studies were to quantify the differences among commercially available seeded bermudagrass cultivars in time to visible germination and time to complete stand establishment or complete cover in a field situation. Twenty-year average day/night temperatures from 15 May to 1 August in 15 day intervals were also evaluated in a laboratory setting to determine the optimal date based on temperature averages for selected dates.

Materials & Methods

Field Studies

Research was conducted in 2010 and 2011 at the A.J. Powell Jr. Turfgrass Research Center located in Lexington, Kentucky. The soil was a Maury silt loam (fine, mixed mesic typic Paleudalf) with a pH of 6.3 and approximately 4% organic matter in the top 5 cm. The studies were seeded successfully on 27 June 2010 and 30 June 2011.

Experimental design was a randomized complete block design with four replications. Experimental units were 1.5 m^2 and the treatment was cultivar. Nineteen commercially available cultivars were evaluated: ‘Arizona Common’ hulled, ‘Arizona Common’ unhulled, ‘Casino Royale’, ‘LaPaloma’, ‘Mirage II’, ‘Mohawk’, ‘New Mex Sahara’, ‘Princess 77’, ‘Riviera’, ‘Savannah’, ‘Southern Star’, ‘Sovereign’, ‘SR 9554’, ‘Sun Bird’, ‘Sun Devil II’, ‘Sun Sport’, ‘Sun Star’, ‘Transcontinental’, and ‘Yukon’. These cultivars were chosen based on the commercially available cultivars listed on the National Turfgrass Evaluation Program’s website (NTEP, 2007). From a list of more than 20 commercially available cultivars, only 19 were available through retail distributors.

Nitrogen in the form of urea (46-0-0) was applied at a rate of 24.4 kg ha^{-1} and lightly raked into the soil prior to seeding. Cultivars were seeded at a rate of 12.2 kg ha^{-1} pure live seed (Munshaw et al., 2001). Germination blankets were used to cover the plots to prevent cross contamination of the cultivars, and irrigation was applied as needed to maintain adequate moisture in the soil to allow the germination process to proceed uninhibited. At ten days post seeding, covers were removed to permit treatments to control annual grassy weeds in the test areas. Monosodium acid methanearsonate

(MSMA) was applied at a rate of 3.18 L ha^{-1} on 14 and 29 July 2010, and 11, 15 July and 1 August 2011 to control crabgrass (*Digitaria spp.* L.*)* and goosegrass (*Eleusine indica).* Plots were maintained for the remainder of the growing season as athletic field turf using a reel type mower (model no. 2653A; Deere & Co., Moline, IL.) at 1.9 cm. with clippings returned 5 d wk^{-1} during active growth and 3 d wk^{-1} as growth slowed with cooling temperatures in autumn. Nitrogen in the form of urea (46-0-0) was applied twice monthly at a rate of 24.4 kg N ha^{-1} through August and irrigation was applied as needed to prevent any visible drought stress.

Germination blankets were removed (to record data) and reinstalled daily after the seeding process was completed. Observations were recorded for germination status. Plots were counted as germinated when approximately 5% of the total plot area had visual green bermudagrass seedlings emerged from the soil surface. Observations for percent plot cover were made every Monday, Wednesday, and Friday until complete plot coverage was obtained or until early Aug. For statistical analysis, data were analyzed using F-Protected Least Significant Difference (LSD) means separation ($p \leq 0.05$ at α = 0.05), PROC GLM of SAS© (SAS version 9.2; SAS Institute, Cary NC).

Laboratory Germination Chamber Studies

Additional germination studies were conducted in the Turfgrass Science Laboratory on the University of Kentucky campus in 2011. The first study evaluated the effects of post-harvest seed coatings on the completion of germination of the nineteen cultivars of bermudagrass used in the field study. The second study evaluated the temperature effects of seeding dates within an average growing season. The design for both studies was a completely randomized design with four replications. For the coating study a non-coated seed treatment was produced by washing the coated seed under warm water (approximately 37.78°C) in a finely meshed soil sieve for approximately 5 minutes (Richardson and Hignight, 2010). This process effectively removed all of the coating material. Washed seeds were immediately plated and placed in germination chambers. For both studies, approximately 50 seeds/cultivar were placed in 100 X 15mm Petri dishes (Fisher Scientific, Pittsburg, PA) on a double layer of CDB 3.25 blue blotter paper (Anchor Paper Co., Saint Paul, MN). Each Petri dish received 13 ml water which allowed for free water in the dish without floating the seeds. Replications were randomly placed in germination chambers: Hoffman Mfg., Albany OR.(Model SG8F), Percival, Boone, IA.(Model I-66LLVL), Conviron, Winnepeg Canada (Model CMP 3244), Hoffman Mfg., Albany, OR. (Model SG2-22), Precision Scientific, (India Model 805). Standard Association of Official Seed Analysts (AOSA) protocol for bermudagrass was followed with regards to temperature and light (35/20°C; 8/16 h day/night, respectively) for the coating study (AOSA, 1998). Seeds that did not complete germination were counted and recorded on day 21.

The objective of the average temperature study was to evaluate thermal unit accumulation across and within temperature regimes and cultivars to show rates and requirements of each cultivar to complete germination. The average temperature seeding date study used chambers set to individual 20 year calculated averages for day and night temperatures independently which were 21.5/16.3°C (15 May), 24.3/18.9°C (1 June), 27.1/21.6°C (15 June), 28.3/22.8°C (1,15 July), and 29.7/23.1°C (1 Aug.) with 8/16 h day/night light. Only five temperature settings were used due to the 1 and 15 July temperature averages differing by less than one tenth of a degree for the night temperature with no difference in the day temperature. White fluorescent lamps provided light for both studies with a photon flux density ranging from 7 to 19 $\mu mols \cdot s^{-1} \cdot m^{-2}$.

Germination counts were made daily for 21 days post imbibition for both laboratory studies. Seeds were counted as germinated and removed when the radicle was visible under a 1.75 X magnifying lens. Thermal unit data was converted back to days and germination velocity and percentage were calculated. The speed or rate of germination was estimated using a Modified Timson index of germination of velocity: $\Sigma G/t$, where G is the sum of the percentage of germination at 1-d intervals, and t is the total germination period. Germination data for the average temperature study were arcsine transformed before statistical analysis (Khan and Unger, 1997). Statistical analysis was performed by PROC MIXED and PROC GLM of SAS (SAS Inc. Cary, NC).

Results

Field Studies

The main effect of cultivar produced significant differences (p=0.0001) for time to visible germination in 2010 (Figure 2.1, Table 2.1) and highly significant (p<.0001) differences in 2011 (Figure 2.2, Table 2.2). In 2010, germination of both Riviera and Yukon were slowest but were not statistically different from Sovereign, Arizona Common unhulled and Princess77. Casino Royale was the most rapid but not statistically different from Southern Star to visibly complete the germination process in 2010. In 2011, Arizona Common unhulled was the slowest and significantly different from the remaining cultivars tested for visible germination. The quickest to complete germination in 2011 and the statistical equivalents were Casino Royale, Sun Bird, Transcontinental, Arizona Common hulled, New Mex Saharah, Mohawk, and Savannah.

The main effect of cultivar produced highly significant (p<.0001) differences for time to complete plot cover for both 2010 and 2011 (Figures 2.3 and 2.4; Tables 2.1 and 2.2). In both years of the study, Yukon was the slowest to reach complete cover, but was not statistically different than Arizona Common unhulled. In 2010, Sovereign was the quickest to reach complete plot cover but was not statistically different from the remaining cultivars with the exception of Arizona Common unhulled and hulled, New Mex Saharah, Casino Royale, and Yukon. In 2011 Riviera was the fastest to complete plot cover but was not statistically different from Mirage II, Sovereign, Savannah, Sun Sport, LaPaloma, Southern Star, and Sun Devil II.

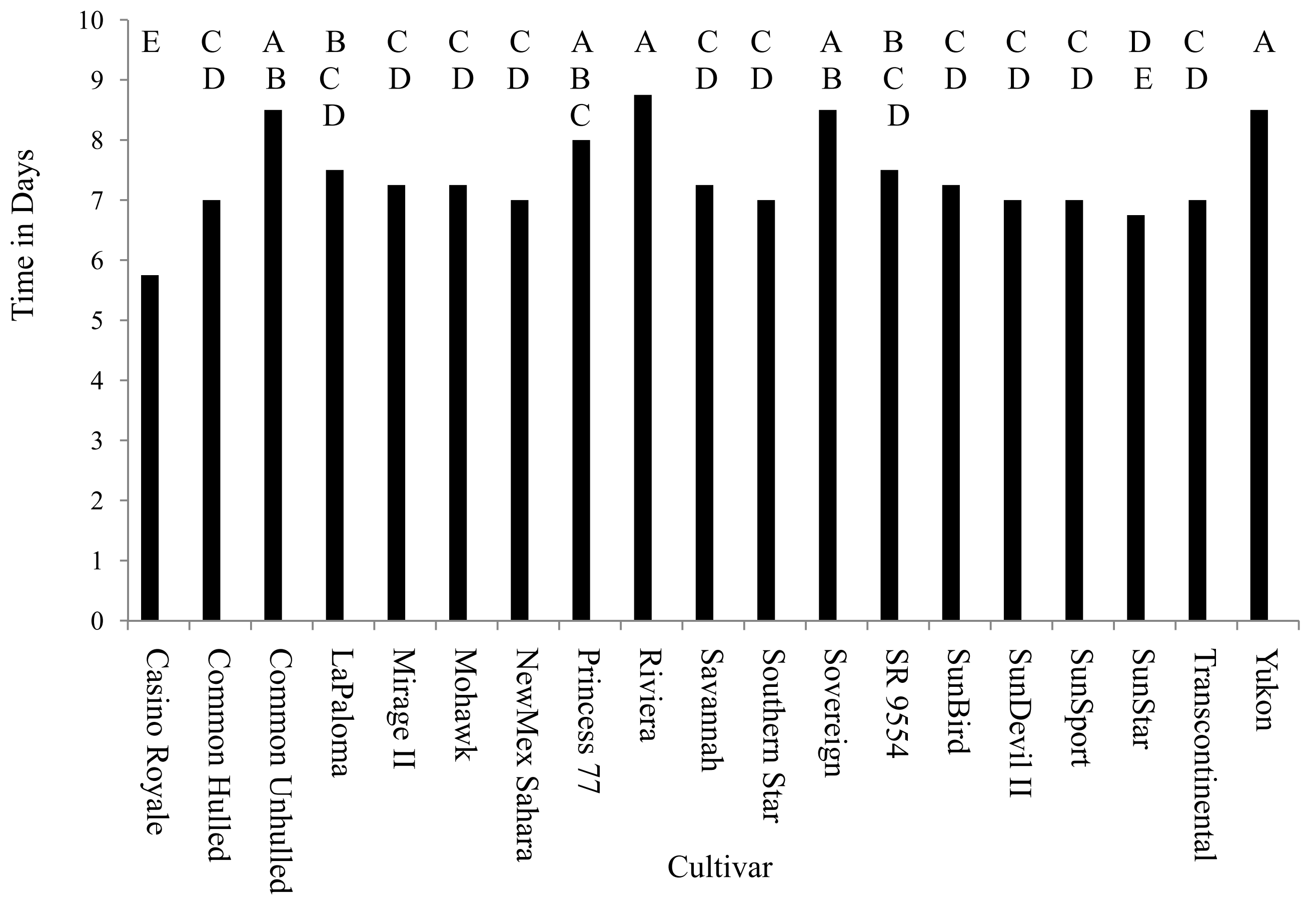


Figure 2.1. Mean visual germination time for nineteen cultivars of bermudagrass for 2010. Bars labeled with the same letter not significantly different by F-protected Fisher's LSD (p<0.05).

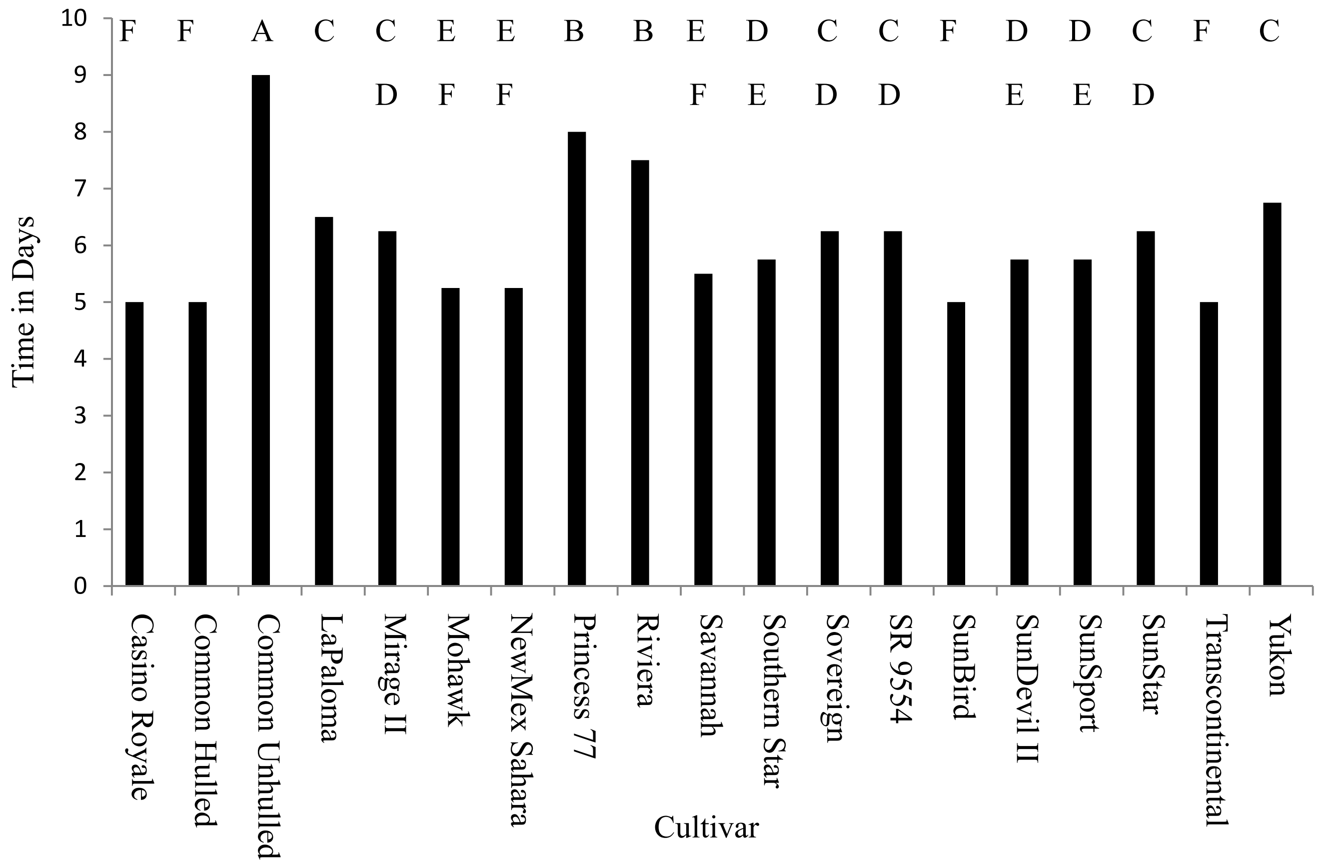


Figure 2.2. Mean visual germination time for nineteen cultivars of bermudagrass for 2011. Bars with the same letter are not significantly different by F-protected Fisher's LDS (p.0.05) 2011.

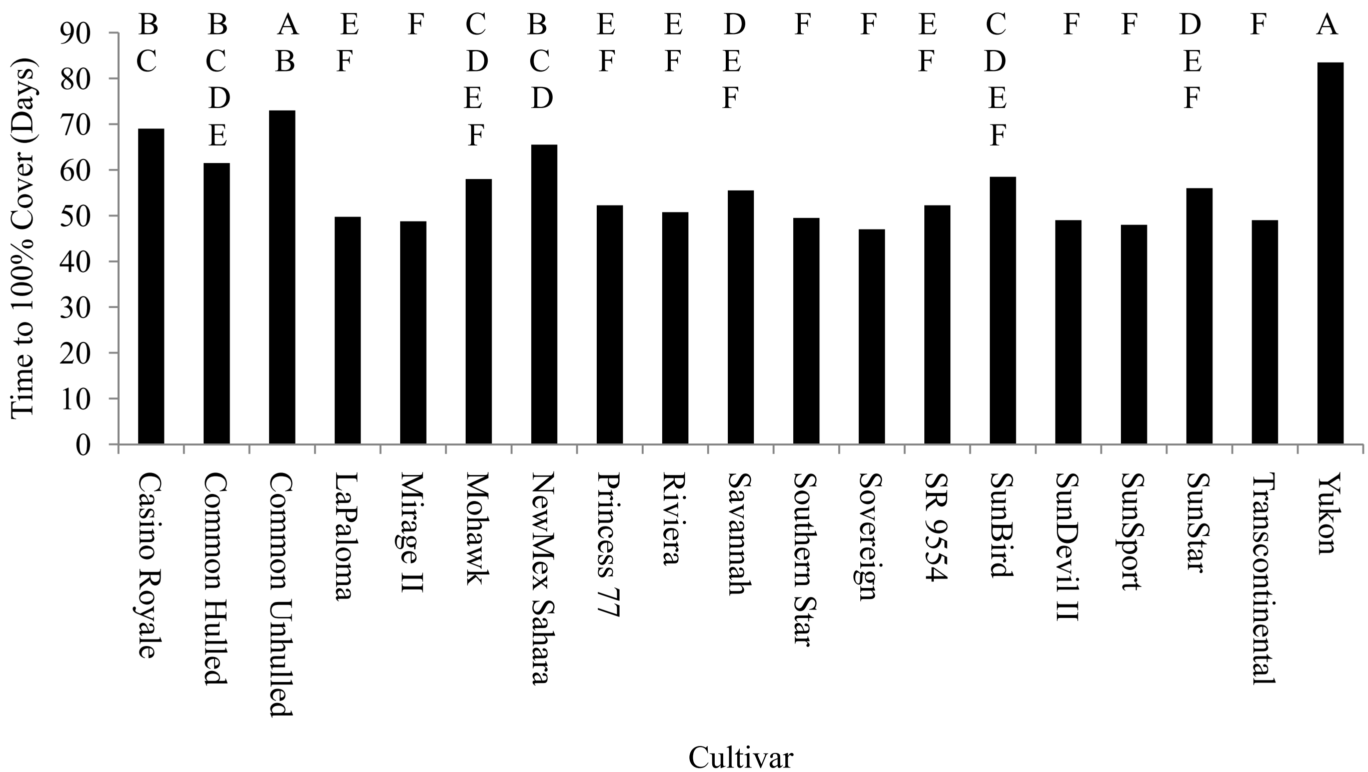


Figure 2.3. Mean time to complete plot cover for nineteen cultivars of bermudagrass for 2010. Bars labeled with the same letter are not significantly different by F-protected Fisher's LSD (p<0.05)

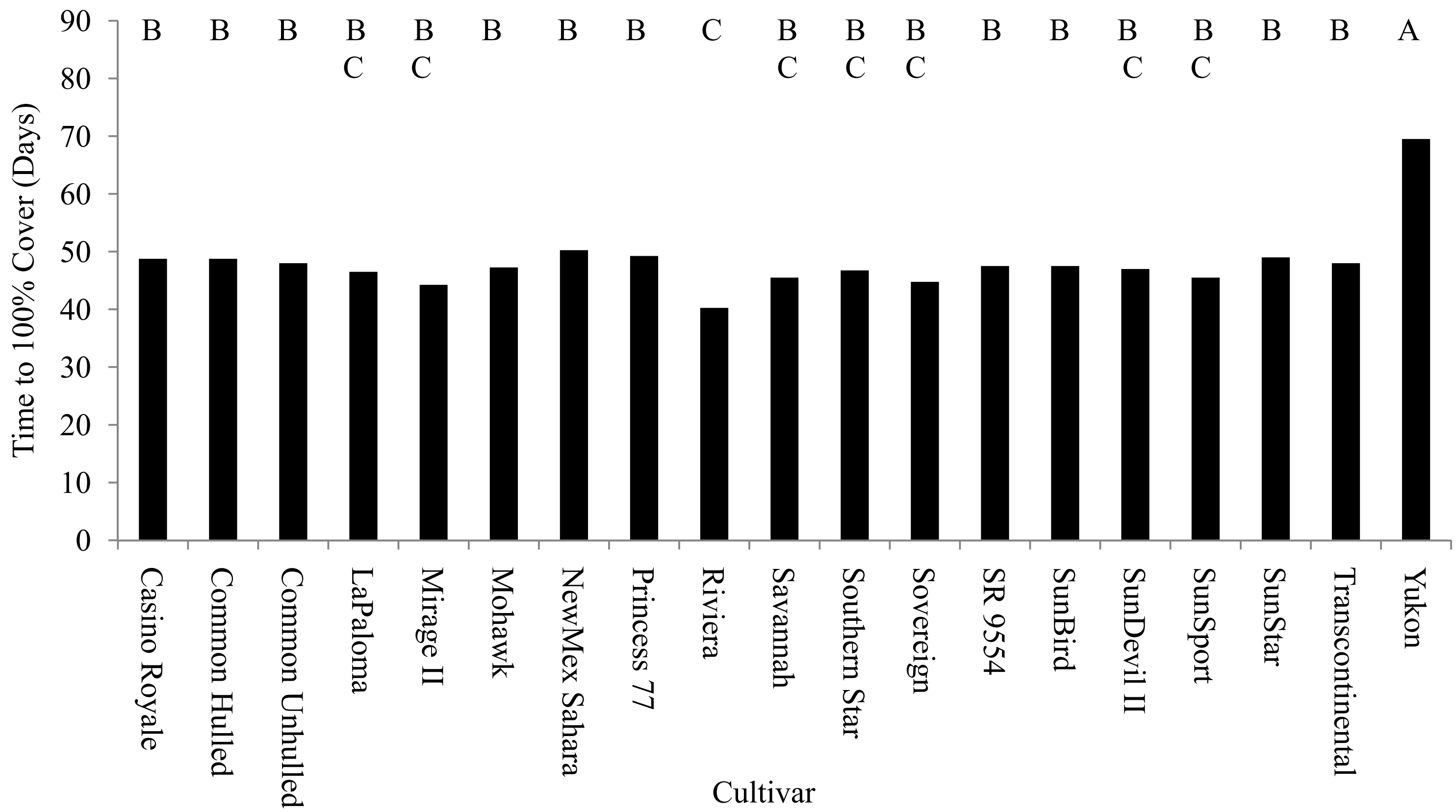


Figure 2.4. Mean time to complete plot cover for nineteen cultivars of bermudagrass for 2011. Bars with the same letter are not significantly different by F-protected Fisher's LSD (p.0.05).

Table 2.1. Mean time to visual germination and plot cover of nineteen cultivars of bermudagrass for 2010. Values with the same letter are not significantly different by F-protected Fisher's LSD (p>0.05).

Cultivar	Visual Germination (days)	Plot Cover (days)
Casino Royale	5.75 e	69.0 b,c
Sun Star	6.75 d,e	56.0 d,e,f
Common Hulled	7.0 d,c	61.5 b,c,d,e
Mirage II	7.0 c,d	48.75 f
New Mex Saharah	7.0 c,d	65.5 b,c,d
Southern Star	7.0 d,c	49.5 f
Sun Devil II	7.0 c,d	49.0 f
Sun Sport	7.0 c,d	48.0 f
Transcontinental	7.0 c,d	49.0 f
Mohawk	7.25 c,d	58.0 c,d,e,f
Savannah	7.25 c,d	55.5 d,e,f
Sun Bird	7.25 c,d	58.5 c,d,e,f
LaPaloma	7.5 b,c,d	49.75 e,f
SR 9554	7.5 b,c,d	52.25 e,f
Princess 77	8.0 a,b,c	53.25 e,f
Common Unhulled	8.5 a,b	73.0 a,b
Sovereign	8.5 a,b	47.0 f
Riviera	8.75 a	50.75 e,f
Yukon	8.75 a	83.5 a

Table 2.2. Mean time to visual germination and plot cover of nineteen cultivars of bermudagrass for 2011. Values with the same letter are not sigifiantly different by F-protected Fisher's LSD (p>0.05).

Cultivar	Visual Germination (days)	Plot Cover (days)
Common Hulled	5.0 f	48.75 b
Casino Royale	5.0 f	48.75 b
Sun Bird	5.0 f	47.5 b
Transcontinental	5.0 f	48.0 b
Mohawk	5.25 e,f	47.25 b
New Mex Saharah	5.25 e,f	50.25 b
Savannah	5.5 e,f	45.5 b,c
Southern Star	5.75 d,e	46.75 b,c
Sun Devil II	5.75 d,e	47.0 b,c
Sun Sport	5.75 d,e	45.5 b,c
Mirage II	6.25 c,d	44.25 b,c
Sovereign	6.25 c,d	44.75 b,c
SR 9554	6.25 c,d	47.5 b
Sun Star	6.25 c,d	49.0 b
LaPaloma	6.5 c	46.5 b,c
Yukon	6.75 c	69.5 a
Riviera	7.5 b	40.25 c
Princess 77	8.0 b	49.25 b
Common Unhulled	9.0 a	48.0 b

Laboratory Germination Chamber Studies

The main effect of cultivar for the seed coating study showed a highly significant ($p<.0001$) difference in the overall time to the completion of germination among the nineteen cultivars tested (Figure 2.5; Table 2.3). The main effect of coating did not produce any significant ($p<0.05$) differences among the cultivars in relation to time to completion of germination (Table 2.3). There were no significant ($p<0.05$) interactions observed for the effect of cultivar x coating (Table 2.3).

The average temperature study produced highly significant ($p<.0001$) differences among cultivars in mean germination velocity for each of the five average temperature dates (Figures 2.6-2.10; Table 2.4). Significant differences ($p<0.05$) were also observed for the main effect of temperature regime for the total percent germination (Table 2.5). Logically, as the temperature increases from mid-May through August, increases in germination velocity and total germination percentages were observed (Figures 2.11-2.29).

Discussion

As previously referenced, most of the recent studies evaluating cultivar germination velocity or speed, time to cover, and post-harvest seed coatings included only a few of the most popular bermudagrass cultivars that are now available. With many new cultivars commercially available it was important to complete a study to quantify the differences in these parameters. As evidenced by these studies there are significant differences among many of the cultivars with respect to all parameters evaluated.

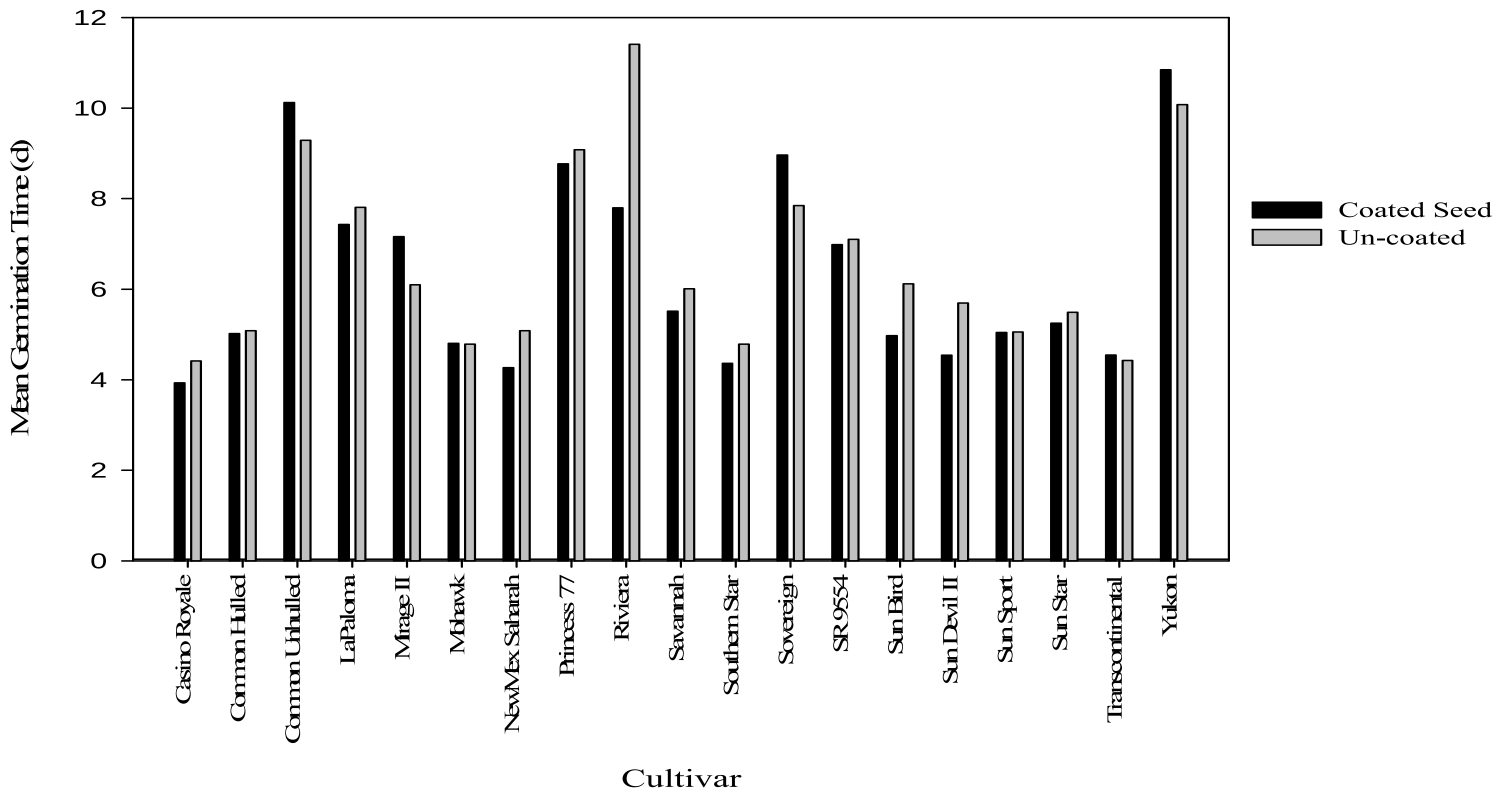


Figure 2.5. Mean germination time (days) of coated and non-coated seed of 19 commercially available seeded bermudagrass cultivars. No significant differences (p>0.05) were observed between coated or non-coated seeds within cultivars. The treatment by cultivar interaction was also not significant (p>0.05).

Table 2.3. Analysis of variance for the main effect of cultivar, coating, and cultivar x coating interaction.

Source of variation	F	Pr>F
Cultivar	16.62	<.0001
Coating	1.44	0.2319
Cultivar x Coating	1.05	0.4138
CV (%)		22.21

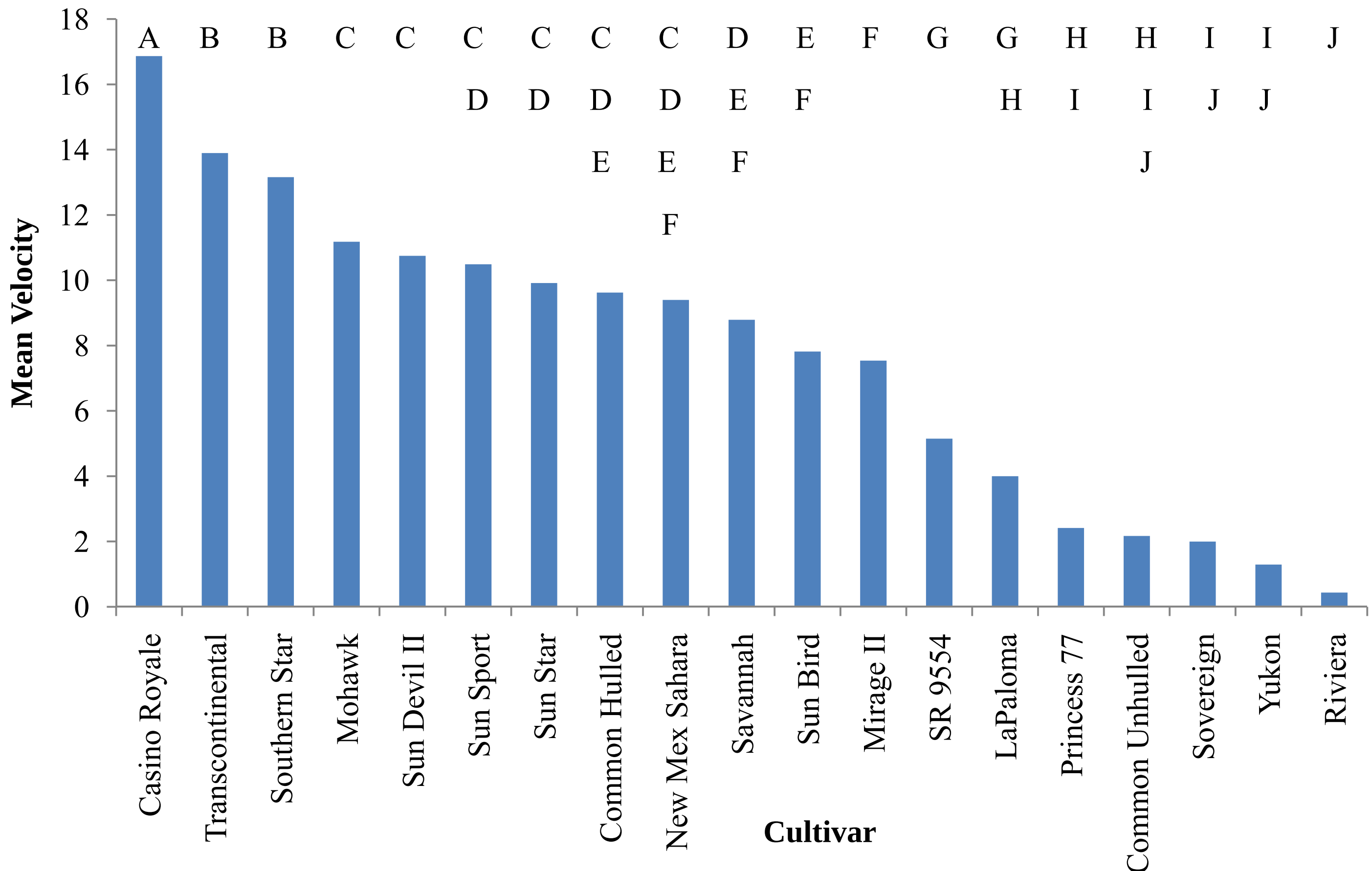


Figure 2.6. Mean germination velocity for nineteen bermudagrass cultivars at 20 year average day/night temperature for May 15 (21.5/16.3°C) in Lexington, Ky. The range for germination velocity in this study = 0 - 48. The higher the value the higher the germination velocity. Mean velocity calculated by modified Timson's index of germination and all data was arcsine transformed before statistical analysis. Bars with the same letter are not statistically different by F-protected Fisher's LSD (p>0.05).

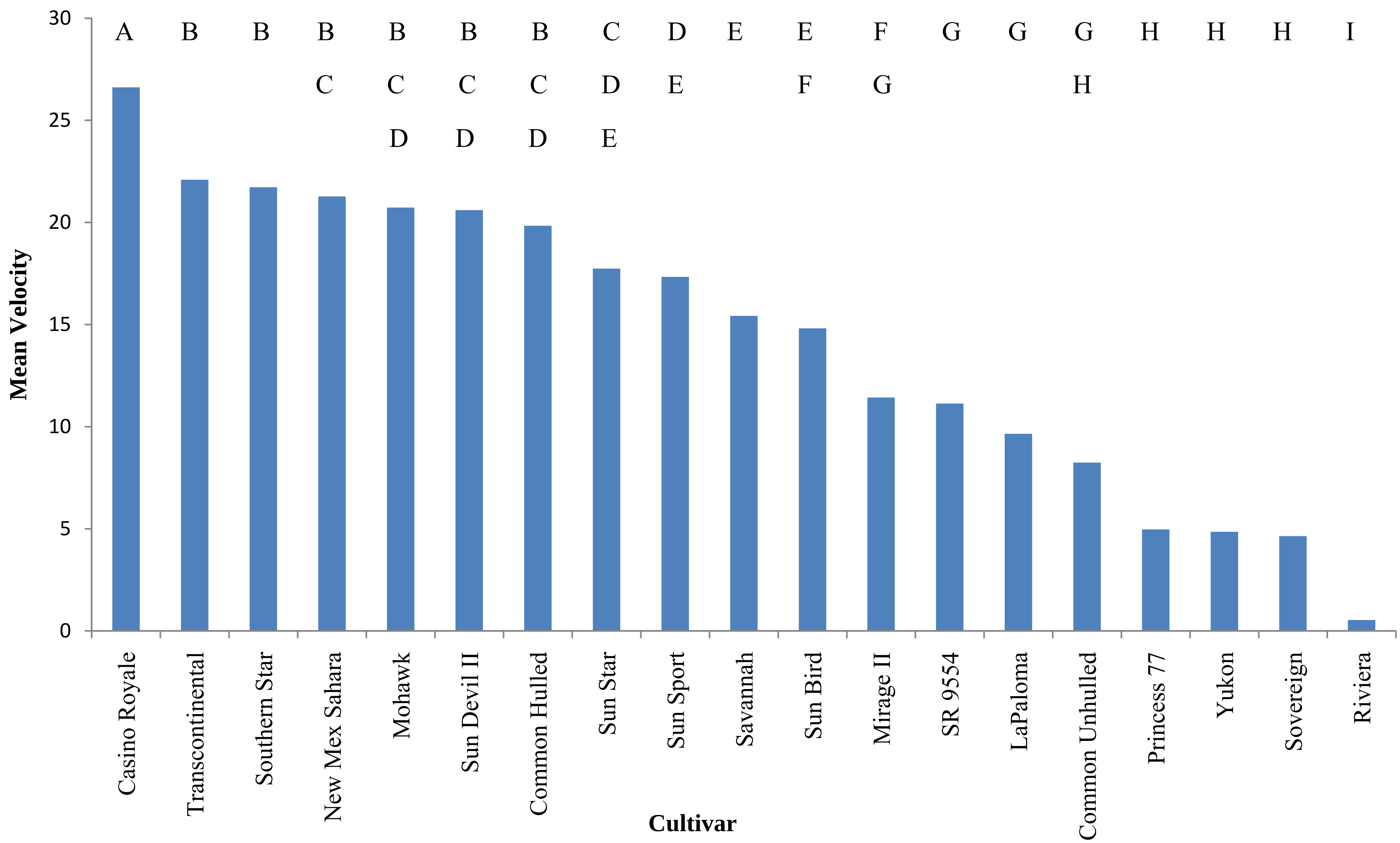


Figure 2.7. Mean germination velocity for nineteen bermudagrass cultivars at 20 year average temperature for June 1 (24.3/18.9°C) in Lexington, Ky. The range for germination velocity in this study = 0 - 48. The higher the value the higher the germination velocity. Mean velocity calculated by modified Timson's index of germination and all data was arcsine transformed before statistical analysis. Bars with the same letter are not statistically different by F-protected Fisher's LSD (p>0.05).

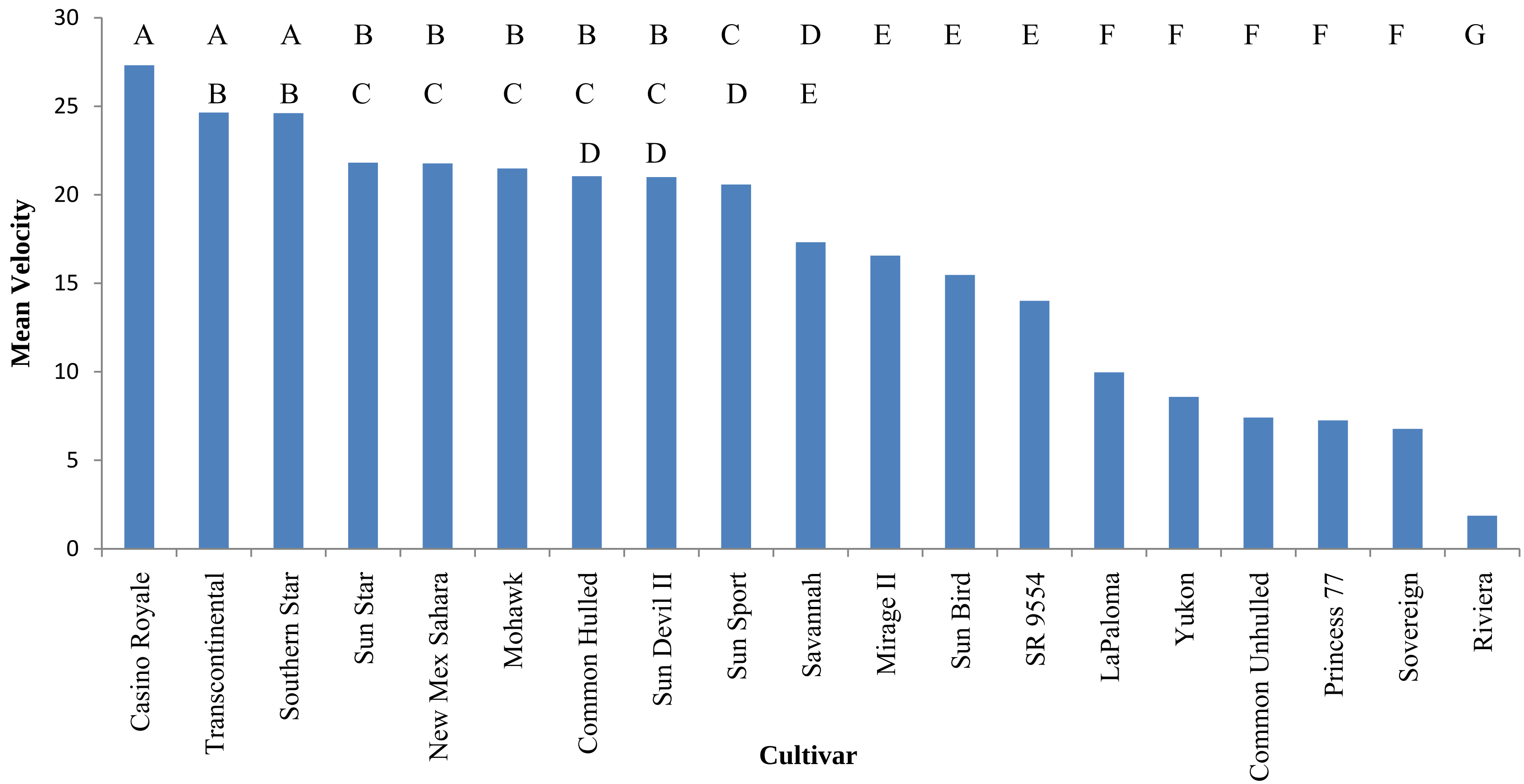


Figure 2.8. Mean germination velocity for nineteen bermudagrass cultivars at 20 year average temperature for June 15 (27.1/21.6°C) in Lexington, Ky. The range for germination velocity in this study = 0 - 48. The higher the value the higher the germination velocity. Mean velocity calculated by modified Timson's index of germination and all data was arcsine transformed before statistical analysis. Bars with the same letter are not statistically different by F-protected Fisher's LSD (p>0.05).

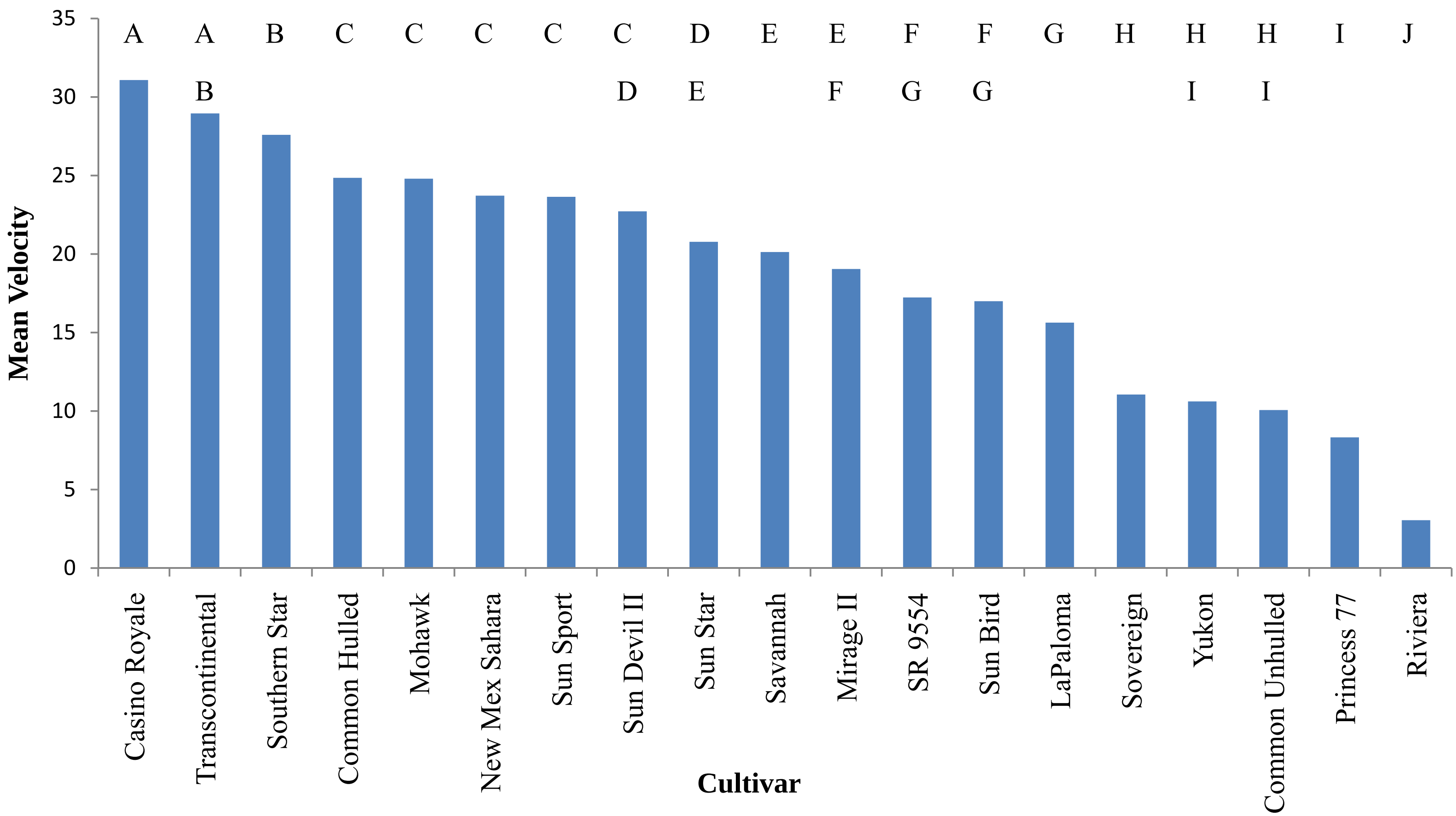


Figure 2.9. Mean germination velocity for nineteen bermudagrass cultivars at 20 year average day/night temperatures for July 1, 15 (28.3/22.8°C) in Lexington, Ky. The range for germination velocity in this study = 0 - 48. The higher the value the higher the germination velocity. Mean velocity calculated by modified Timson's index of germination index and all data was arcsine transformed before statistical analysis. Bars with the same letter are not statistically different by F-protected Fisher's LSD (p>0.05).

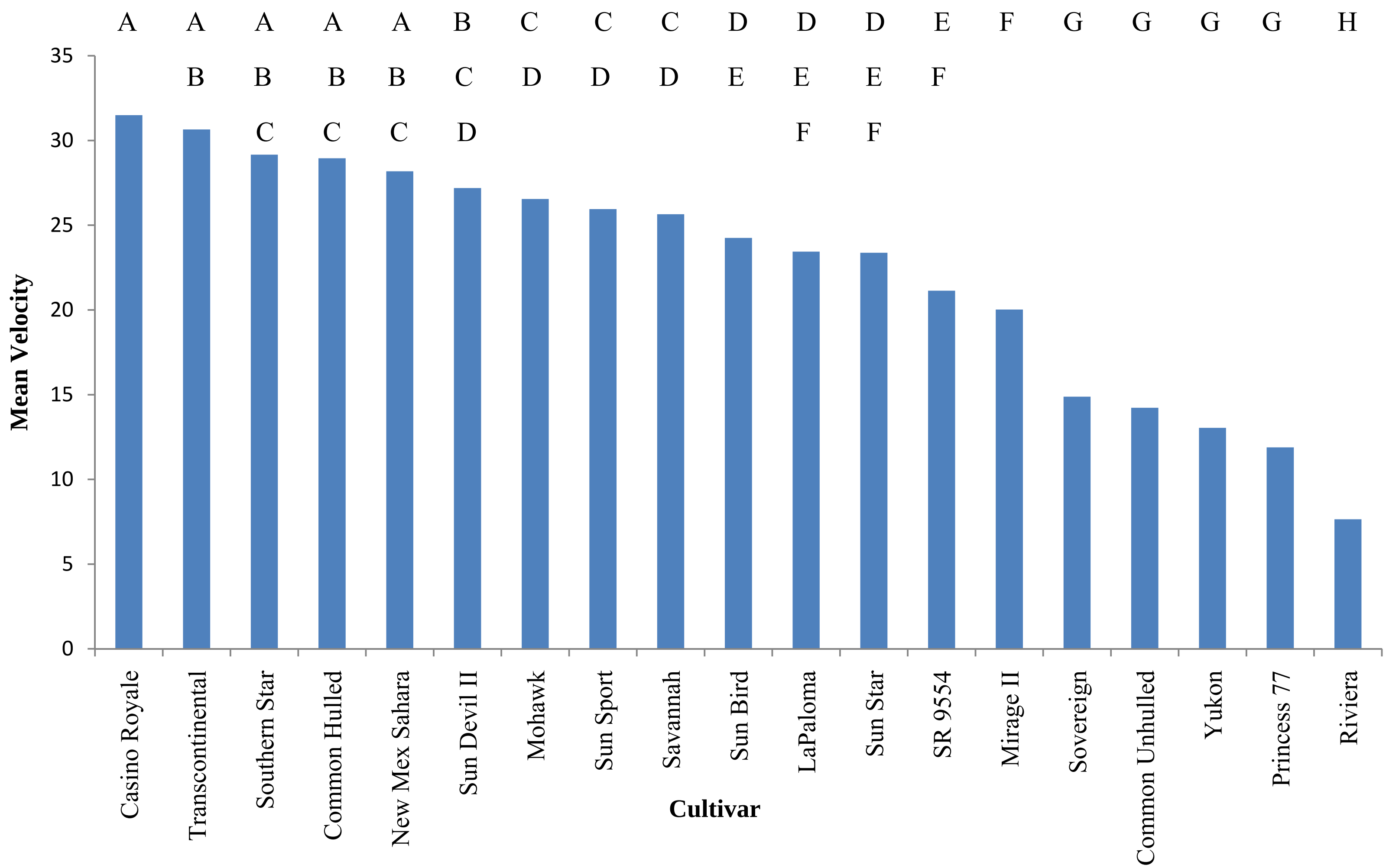


Figure 2.10. Mean germination velocity for nineteen bermudagrass cultivars at 20 year average day/night temperatures for August 1 (29.7/23.1°C) in Lexington, Ky. Scale 0 - 48. The higher the value the higher the germination velocity. Mean velocity calculated by modified Timson's index of germination and all data was arcsine transformed before statistical analysis. Bars with the same letter are not statistically different by F-protected Fisher's LSD (p>0.05).

Table 2.4. Analysis of variance for the main effect of cultivar for twenty year average day/night temperatures (21.5/16.3°C, 15 May; 24.3/18.9°C, 1 June; 27.1/21.6°C, 15 June; 28.3/22.8°C, 1 and 15 July; and 29.7/23.1°C, 1 Aug).

	Twenty Year Average Temperature Date									
	May 15		June 1		June 15		July 1 & 15		Aug. 1	
Source of Variation	F	Pr>F	F	Pr>F	F	Pr>F	F	Pr>F	F	Pr>F
Cultivar	51.12	<.0001	32.92	<.0001	29.60	<.0001	69.42	<.0001	26.70	<.0001
CV (%)	17.07		17.99		16.72		9.75		12.21	

Table 2.5. Mean germination velocity of 19 commercially available seeded bermudagrass cultivars across average temperature regimes for selected seeding dates. Mean velocity range = 0-48 with the higher the number representing faster germination velocity calculated by modified Timson's index. Mean velocity values within labeled with the same letter are not significantly different by F-protected Fisher's LSD (p>0.05).

Cultivar	21.5/16.3°C (May15)	24.3/18.9°C (June 1)	27.1/21.6°C (June 15)	28.3/22.8°C (July 1, 15)	29.7/23.1°C (Aug. 1)
	Mean velocity	Mean velocity	Mean velocity	Mean velocity	Mean velocity
A. Common – h	9.63 C,D,E	19.9 B,C,D	7.42 B,C,D	25.1 C	29.3 A,B,C
A. Common - u	2.1 H,I,J	8.2 G,H	7.4 F	10.1 H,I	14.2 G
Casino Royale	16.9 A	26.9 A	27.6 A	31.6 A	32.0 A
LaPaloma	3.9 G,H	9.6 G	9.9 F	15.6 G	23.7 D,E,F
Mirage II	7.5 F	11.4 F,G	16.6 E	19.1 E,F	20.1 F
Mohawk	11.2 C	20.8 B,C,D	21.6 B,C	25.1 C	26.8 C,D
New Mex Sahara	9.4 C,D,E,F	21.4 B,C	21.9 B,C	23.9 C	28.5 A,B,C
Princess77	2.4 H,I	4.9 H	7.2 F	8.3 I	11.9 G
Riviera	0.4 J	0.5 I	1.8 G	3.1 J	7.6 H
Savannah	8.8 D,E,J	15.4 E	17.4 D,E	20.2 E	25.9 C,D
Southern Star	13.1 B	21.9 B	24.8 A,B	27.9 B	29.6 A,B,C
Sovereign	1.9 I,J	4.6 H	6.7 F	11.1 H	14.9 G
SR 9554	5.2 G	11.1 G	14.1 E	17.3 F,G	21.3 E,F
Sun Bird	7.8 E,F	14.8 E,F	15.5 E	17.1 F,G	24.5 D,E
Sun Devil II	10.7 C	20.7 B,C,D	21.1 B,C,D	22.9 C,D	27.5 B,C,D
Sun Sport	10.5 C,D	17.4 D,E	20.7 C,D	23.8 C	26.2 C,D
Sun Star	9.9 C,D	17.8 C,D,E	20.9 B,C	22.0 D,E	23.5 D,E,F
Transcontinental	13.9 B	22.2 B	24.9 A,B	29.3 ,B	31.1 A,B
Yukon	1.3 I,J	4.8 H	8.6 F	10.6 H,I	13.1 G

Figures 2.11 through 2.29. Mean percent germination of 19 commercially available seeded bermudagrass cultivars germinated under twenty year average temperatures on selected dates (21.5/16.3°C,15 May; 24.3/18.9°C, 1 June; 27.1/21.6°C, 15 June; 28.3/22.8°C, 1 and 15 July; and 29.7/23.1°C, 1 Aug.).

Figure 2.11.

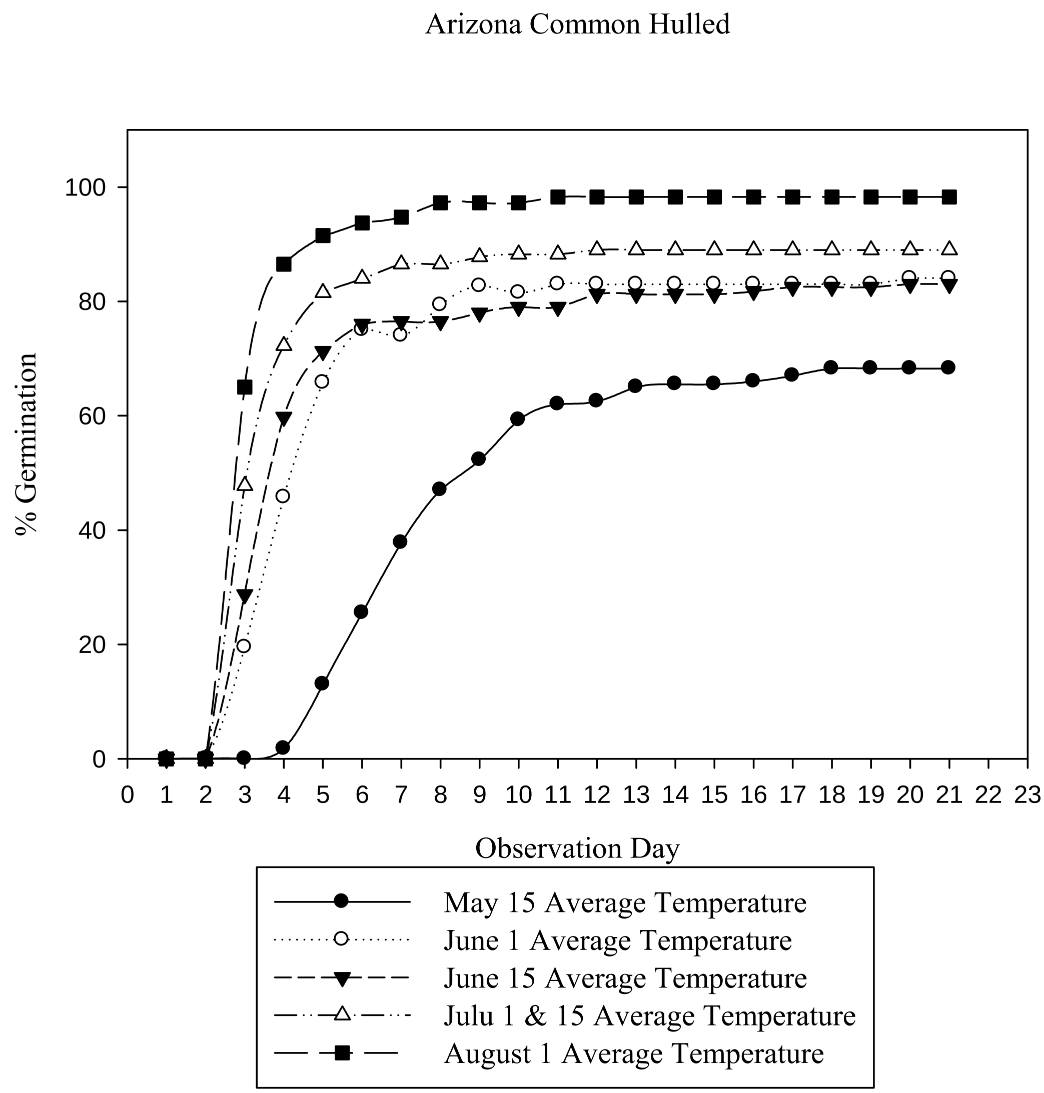


Figure 2.12.

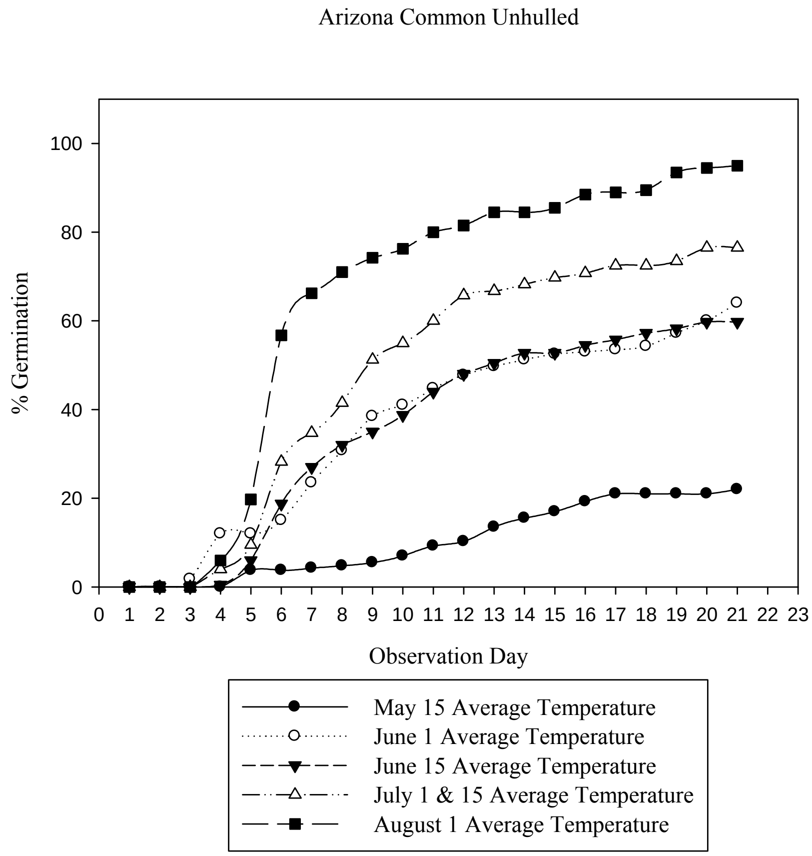


Figure 2.13.

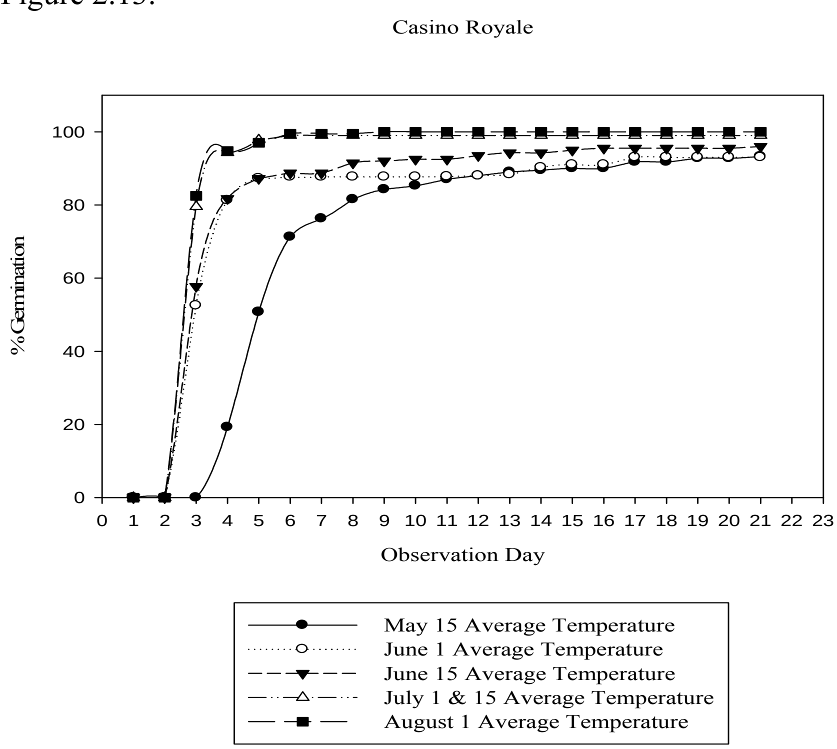


Figure 2.14.

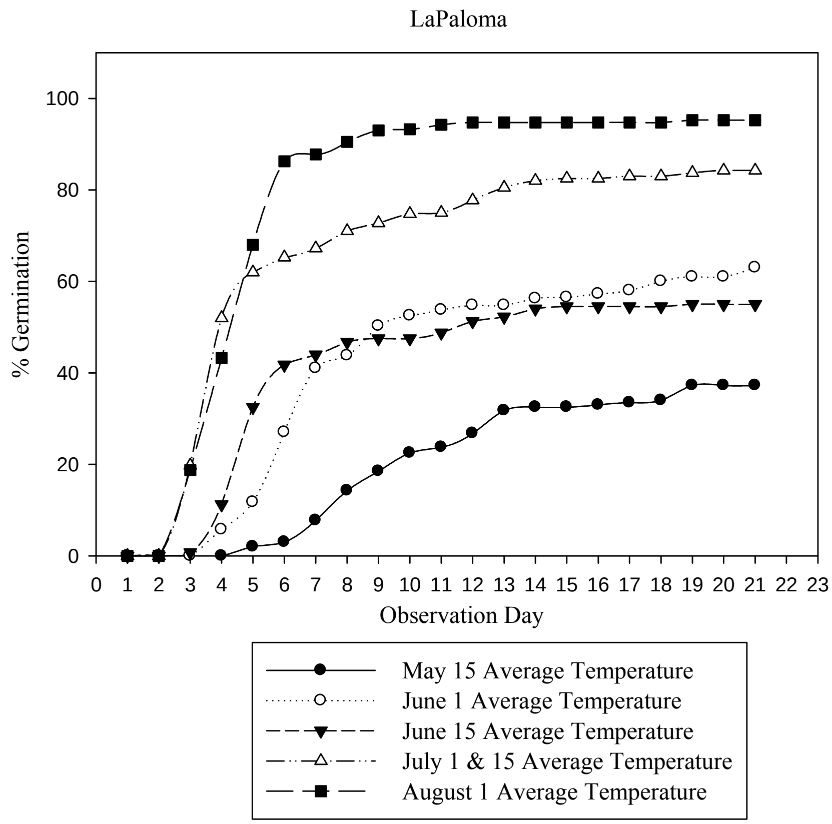


Figure 2.15.

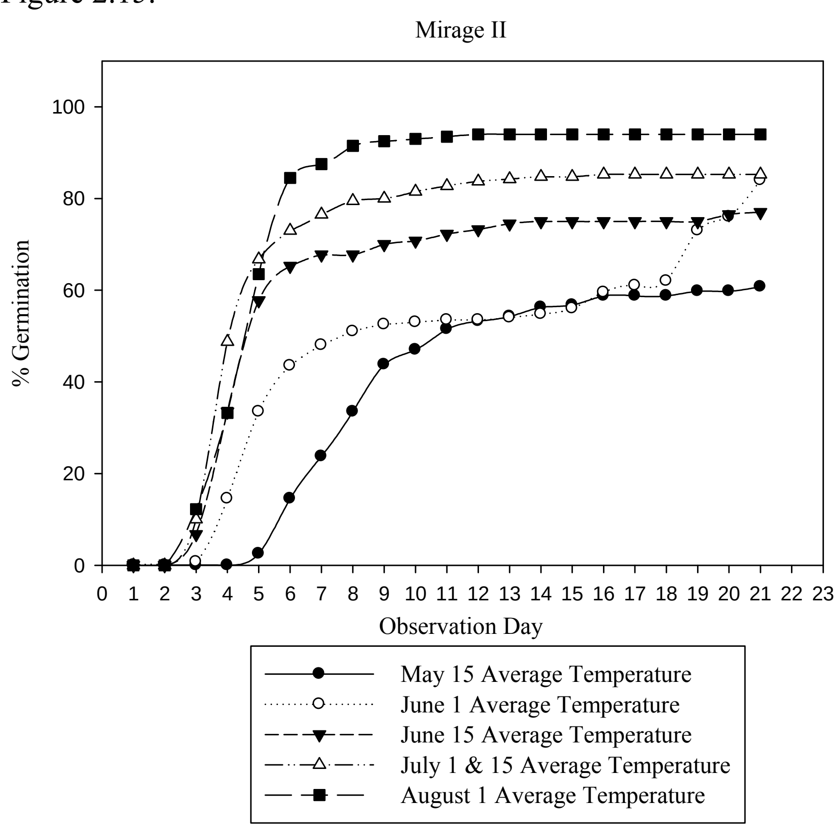


Figure 2.16.

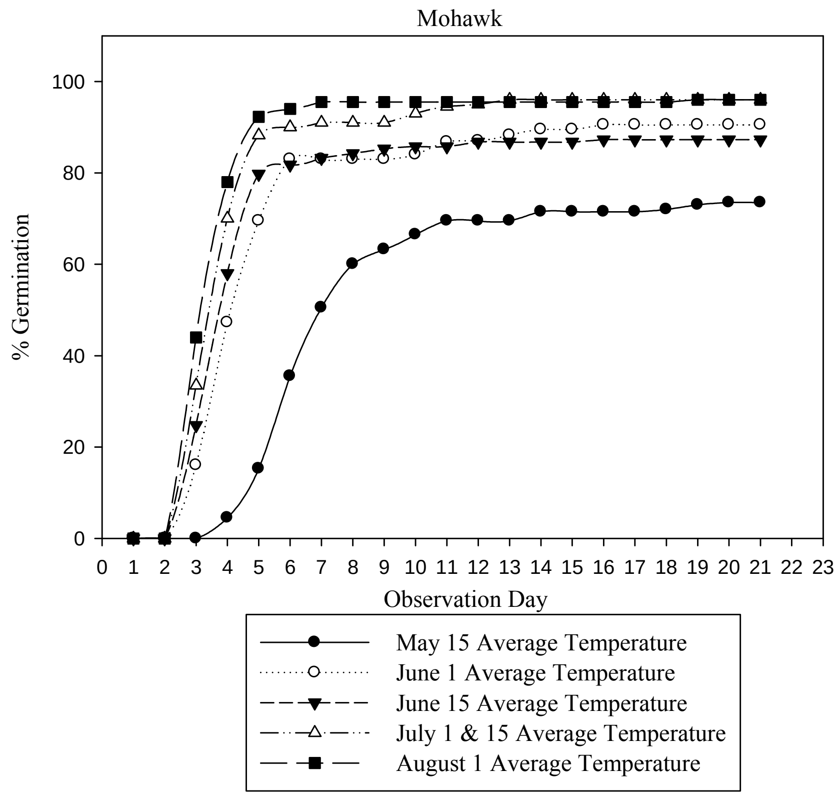


Figure 2.17.

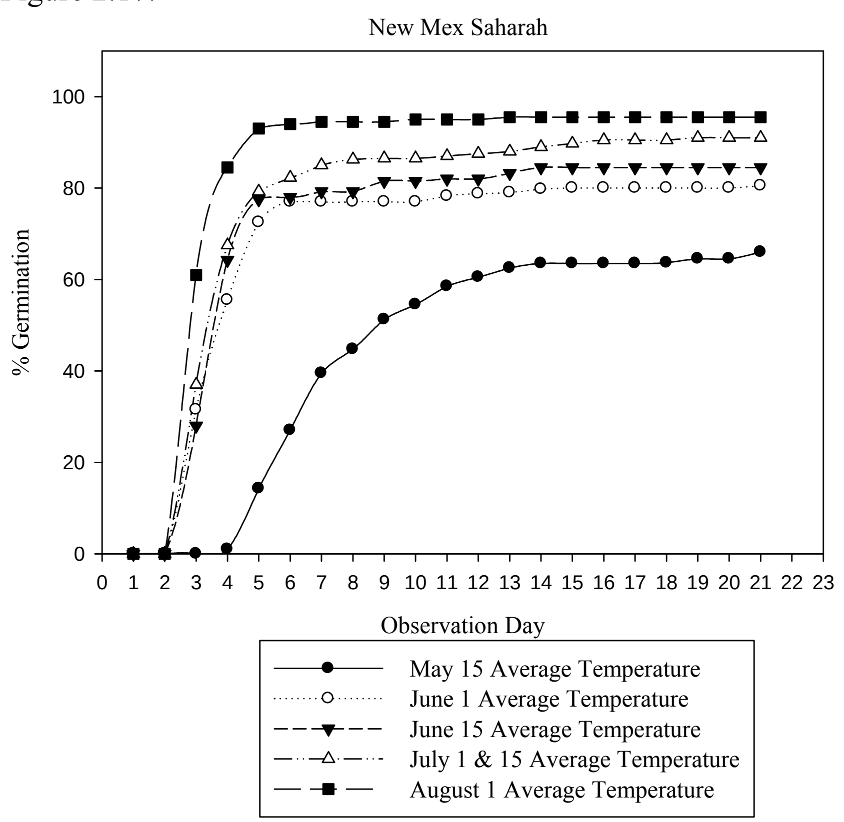


Figure 2.18.

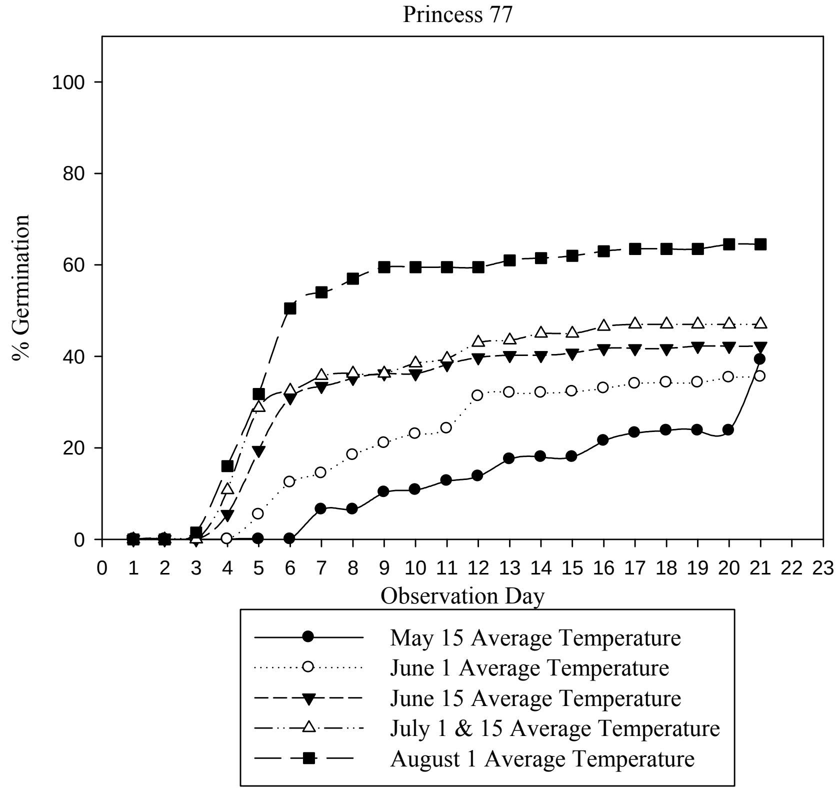


Figure 2.19.

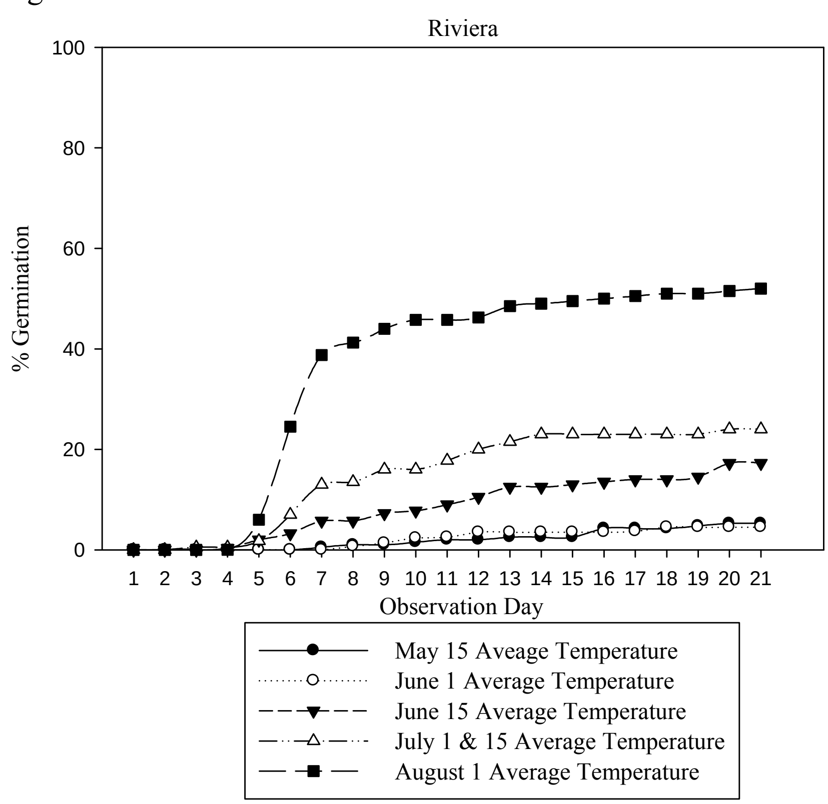


Figure 2.20.

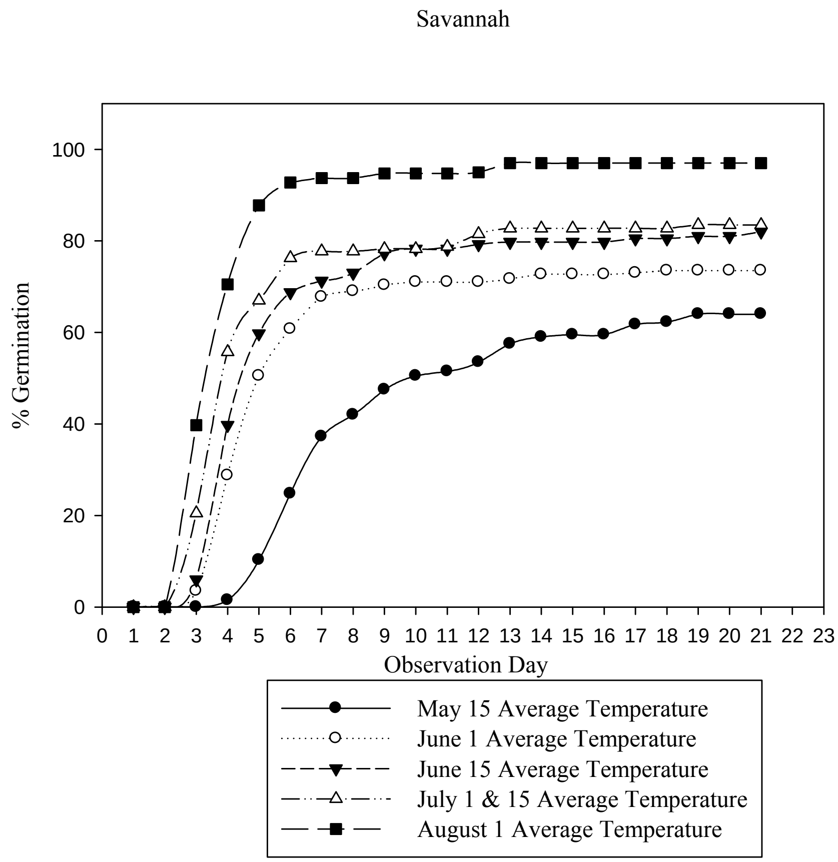


Figure 2.21.

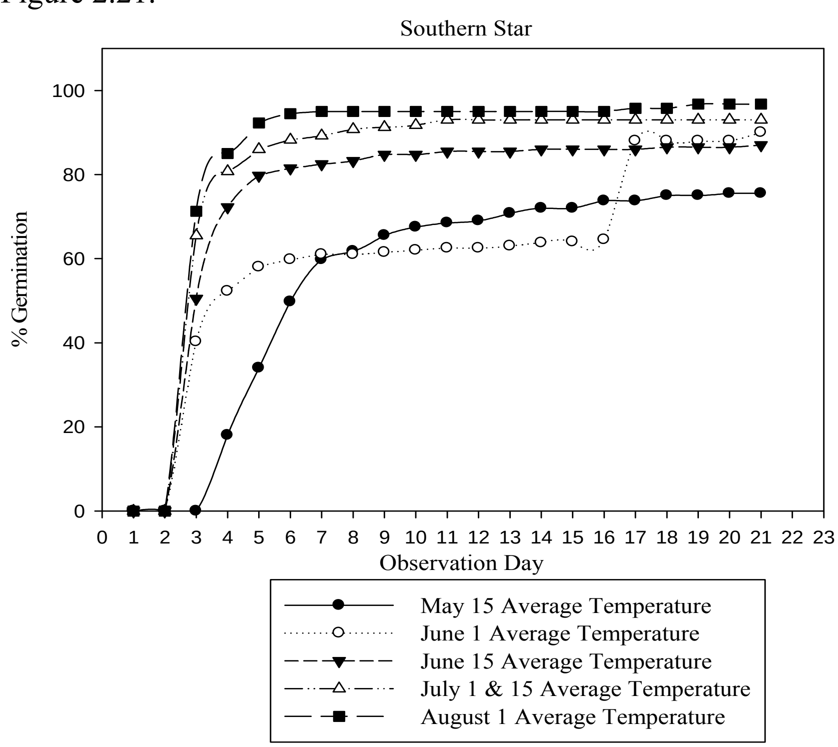


Figure 2.22.

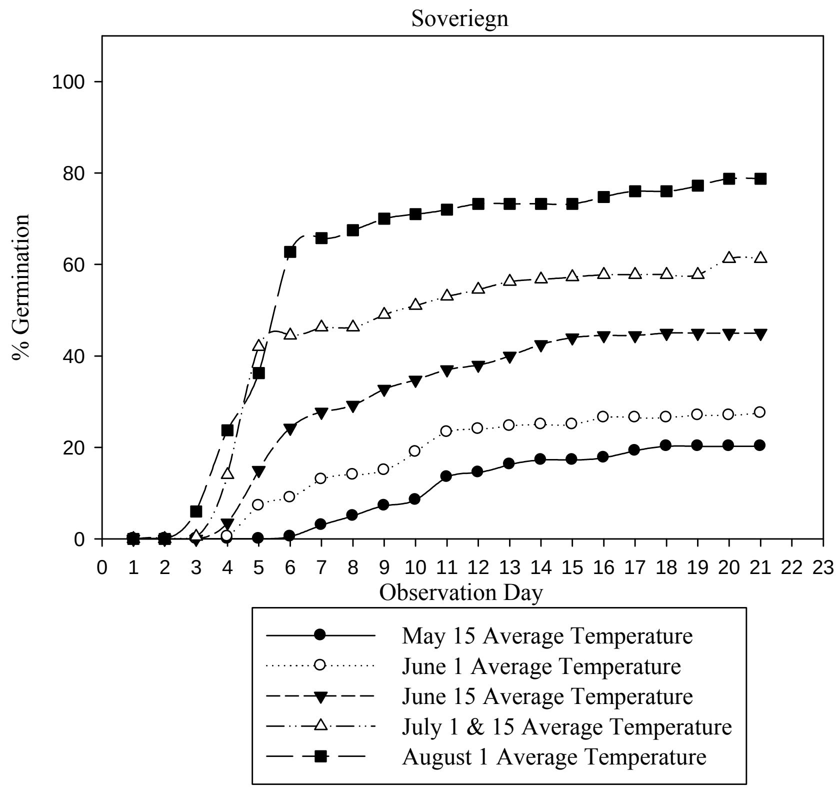


Figure 2.23.

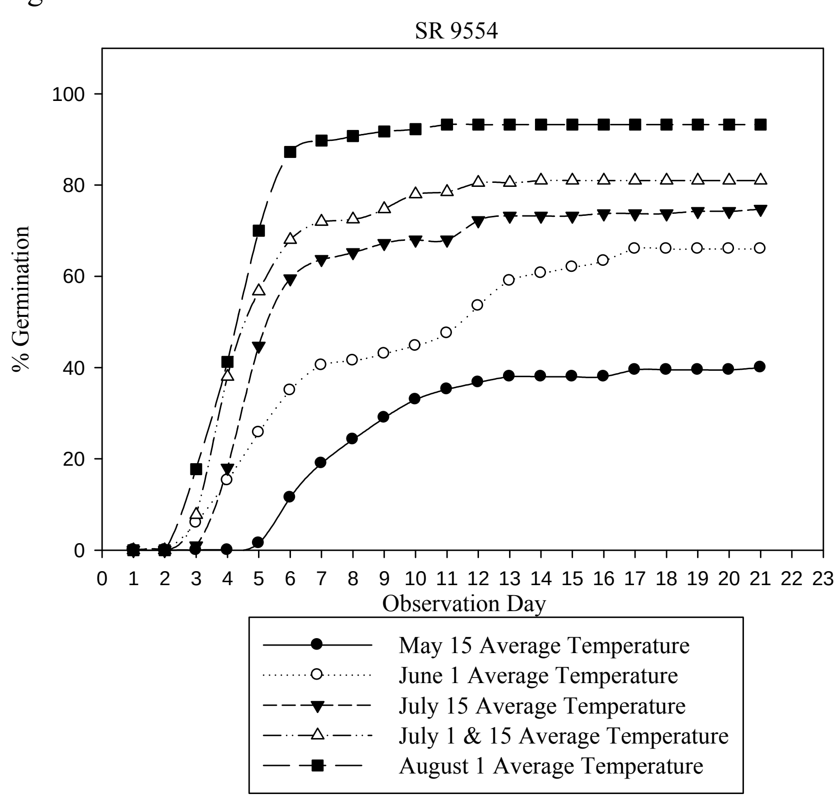


Figure 2.24.

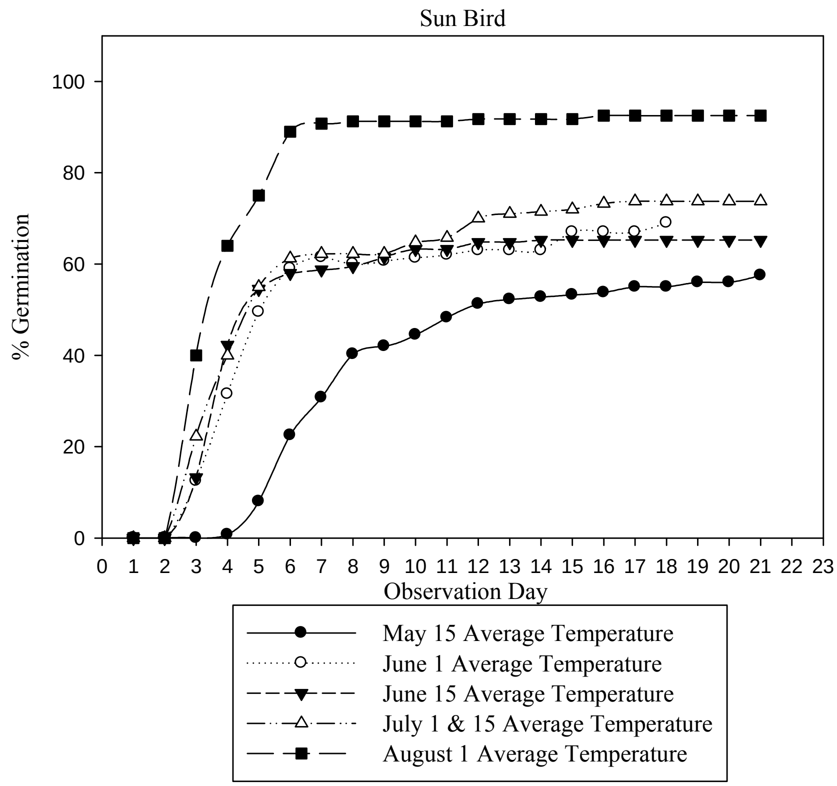


Figure 2.25.

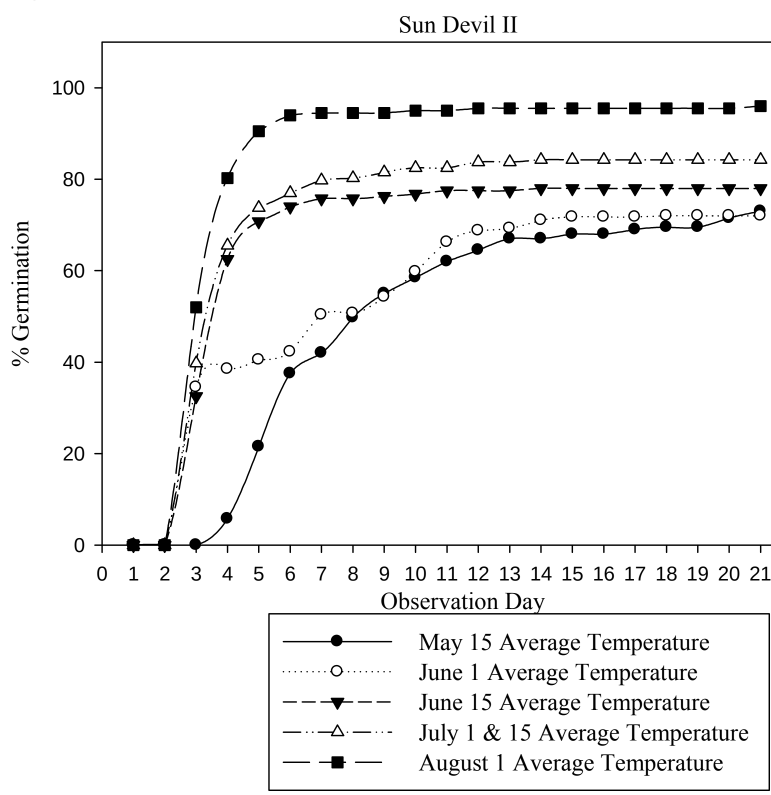


Figure 2.26.

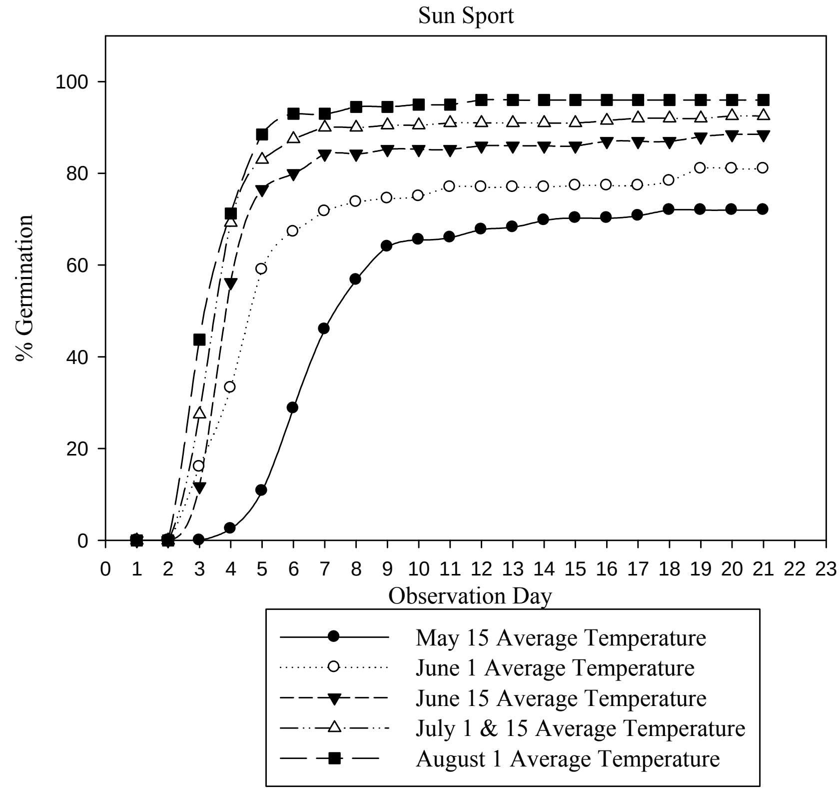


Figure 2.27.

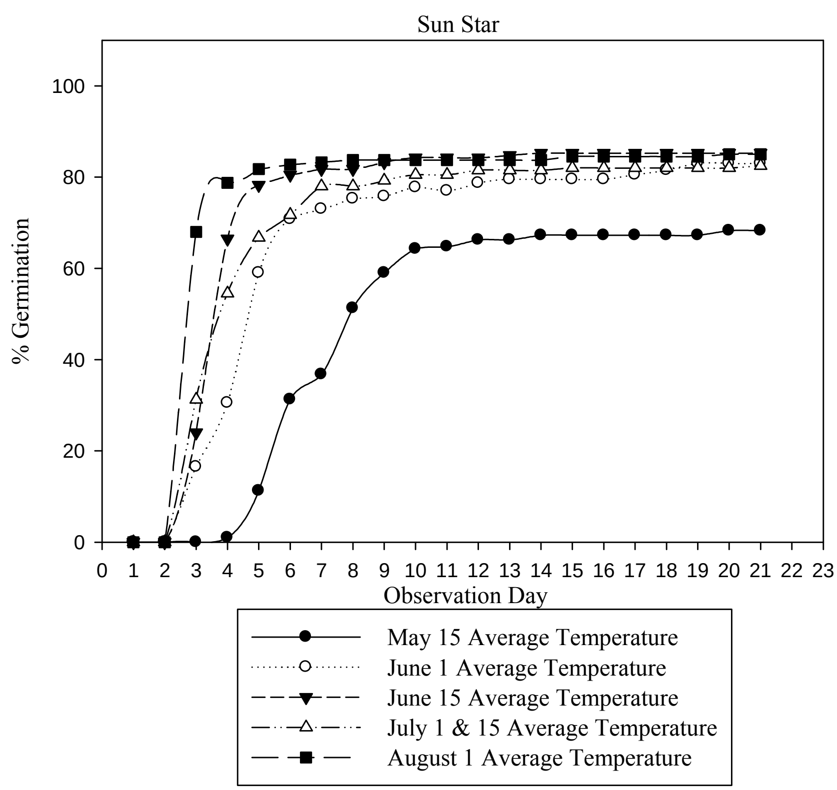


Figure 2.28.

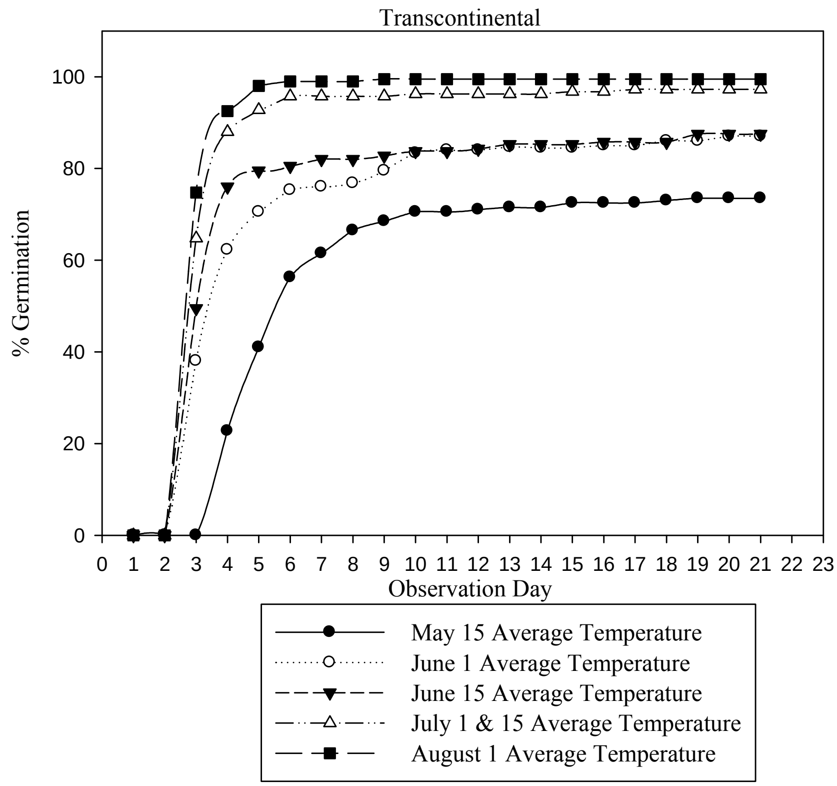
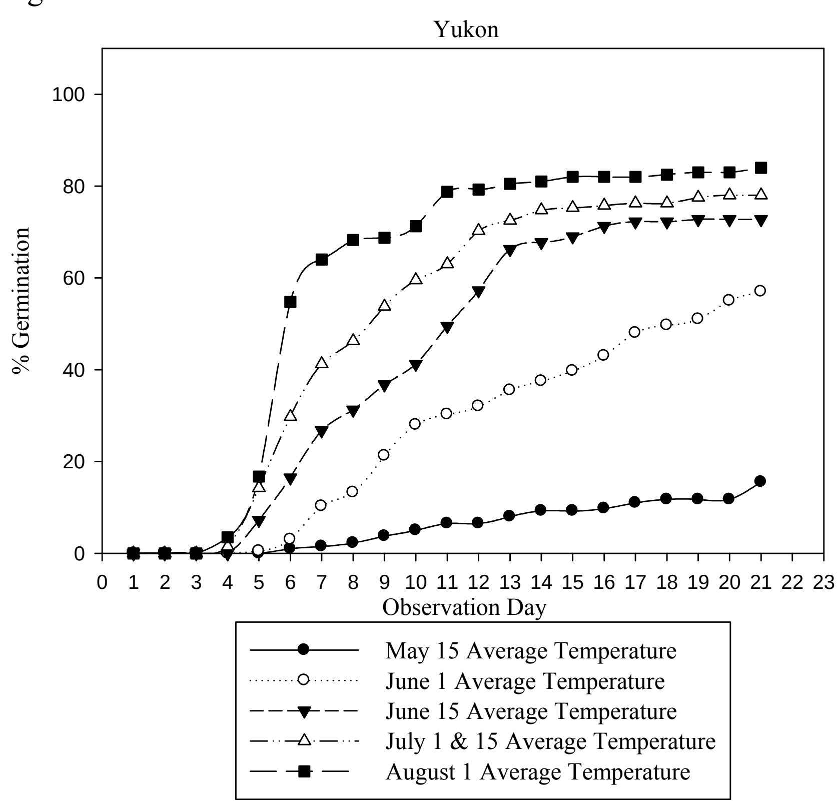


Figure 2.29.



As can be expected with almost all organisms, a fairly normal distribution was observed for the velocity of germination among the cultivars tested. For both years of the study, observations and analysis show two to three cultivars that complete the process quickest or slowest while the majority of the cultivars would be considered average in time to complete the germination process. Casino Royale was consistently the quickest or a statistical equivalent to the quickest to visibly complete germination in a field setting. Field observations noted some visible germination of Casino Royale in as few as 3 days and 2 days in a laboratory germination chamber at slightly higher temperatures than were obtained in the field.

Since its release in the late 1990s, Riviera has been known for its slow germination. In 2010, it was statistically the slowest and equivalent to Yukon with approximately 9 days elapsing before visible germination. In 2011 Riviera was not the slowest to visibly complete germination in the field. Arizona Common nhulled was statistically the slowest at 9 days with Riviera falling into the second slowest group at 7.5 days. Princess 77, which is very similar to Riviera phenotypically, apparently shares the same germination characteristics also. Princess 77 was not statistically different from Riviera in either 2010 or 2011 in a field setting.

It is interesting to note that the quickest cultivars to visibly complete germination in the field were not the same cultivars to complete plot cover first. Yukon would be the most consistent cultivar in that it was consistently the slowest or statistical equivalent to the slowest to visibly germinate and was also consistently the slowest to complete plot cover. In both 2010 and 2011, it required 83.5 and 69.5 days, respectively to complete plot cover. This wide variation in days between years may be attributable to poor ratings in two of four replications in 2010. Lack of performance appeared to be the result of fungal infection but was not investigated. Riviera, which was consistently one of the slowest to produce visible field germination, was either the fastest or close behind the fastest to complete plot cover for both years of the study. In 2010, Riviera required approximately 51 days, while Sovereign, which achieved the most rapid plot cover, reached complete cover in 47 days. In 2011 Riviera was the quickest by number of days (40.25), but was not statistically different form LaPaloma, Mirage II, Savannah, Southern Star, Sovereign, Sun Devil II, and Sun Sport which required 46.5, 44.25, 45.5, 46.75, 44.75, 47.0, and 45.5 days, respectively.

While the specific differences among the cultivars that cause these differences in visible field germination and seedling vigor is unclear, this study generally agrees with the findings of Patton et al.(2004) showing Riviera to possess very good vigor characteristics. While Riviera is always one of the slowest cultivars to germinate, once germination is complete it possesses enough seedling vigor to surpass many of the other cultivars and complete cover several days faster than many other cultivars.

Almost all commercially available cultivars of bermudagrass have coating applied and then are marketed as to the extra benefits provided by the coatings. This study found no differences with regard to germination velocity or percent total germination associated with the post-harvest seed coatings. This study agrees with Richardson et al., (2010) in that the coating provided no extra benefit to the processes of stand establishment. Richardson et al., (2010) evaluated coatings applied to seed of cool season species in varying soil conditions and concluded that only in sandy soils did the coatings seem to aid in the germination process. This study was conducted in a laboratory germination chamber which is certainly different from an actual field situation. Our analysis shows that in a setting where water was not limiting, that in many instances, the effects of the seed coating, though not statistically different, may have actually impeded the germination process.

This and other studies have shown no agronomical support for using seed coatings. However, this has not deterred their use as this is clearly normal in the industry today. Even with no studies to support their use in turfgrasses, coatings applied to bermudagrass seed do make applications easier. Bermudagrass seed is very small numbering one to two million seeds per pound. Seed coatings allow for easier handling and proper distribution. Also, coatings are usually brightly colored which make visual conformation of an appropriate application easier.

Seeding dates for bermudagrass have been well studied. With the release of many new cultivars over the past couple of decades, information concerning establishment and performance has lagged behind, i.e., not all commercially available cultivars have been evaluated. Turfgrass managers in transitional climatic zone are major consumers of seeded bermudagrasses. This study shows that in the upper transitional climatic zone, conventional seeding dates are not necessarily applicable to all of the commercially available cultivars of bermudagrass. While most of the cultivars obtain greater than eighty percent germination, this may not occur until the warmer temperatures of August. Many of the cultivars tested, such as Riviera, Princess 77, and Sovereign struggled to obtain, if they were able to do so, the eighty percent germination mark at the temperatures experienced during the normally recommended seeding dates of mid-May to mid-June.

The objectives of these studies were to quantify the differences in the germination and vigor characteristics of nineteen commercially available cultivars of seeded bermudagrass. We conclude that there are vast differences in these characteristics within the cultivars tested. Methods that have been accepted as standard (e.g., early June seeding date defined as optimal) are now called into question. Considering the many cultivars available today, genetic diversity likely contributes to the differences in performance characteristics. Temperature plays a definite and determining role in the ability of seeded bermudagrass cultivars to complete the germination process. In the upper transitional climatic zone, temperatures do not reach optimal levels for the germination for several of the cultivars until July. Riviera and Princess 77 which are two of the highest quality cultivars, have enormous difficulty completing germination in an upper transitional climatic zone environment at the normal recommended seeding date of June 1. Future research should investigate the physiological mechanisms among cultivars that are linked to temperature and impeding the completion of the germination process. Turfgrass managers should determine if the establishment time required for a specific intended use will coincide with the expected environmental conditions during establishment before choosing a cultivar.

Copyright © Michael Todd Deaton 2012

Chapter III

Thermal Modeling and Germination Characteristics of Two Seeded Bermudagrasses (*Cynodon dactylon* (L.) Pers.), cv. 'Riviera' and 'Casino Royale'

The grass species *Cynodon dactlyon* (L.) Pers. known as common bermudagrass generally does not exhibit seed dormancy. Baskin and Baskin (2001) classify this species as non-dormant, meaning that the seed possesses the ability to complete the process of germination upon release from the mother plant and does not require vernalization. Bermudagrass also possesses the characteristic of indeterminate flowering. This characteristic allows the plant to produce flowers and ultimately seed at any point during the active growing season.

Common bermudagrass has been used since the 1960's for seed production but lacked the desirable high quality characteristics of its vegetatively- propagated counterparts (Patton et al. 2008; Shaver et al. 2006; Karcher et al. 2004; Richardson et at. 2004). Until breeding improvements were made in the 'common' type bermudagrasses over the past two decades, sprigging was the most common means of propagation. New seeded cultivars released in the 1990's finally achieved equal or superior quality characteristics when compared to the interspecific hybrid cultivars that had long been the industry standards (Baltensperger and Klingenburg, 1994).

Seeded cultivars provided a substantially lower cost alternative compared to other means of stand establishment (Patton et al., 2004 a,b). In the early years of the 21st century, little information was available for seeded bermudagrass establishment and management. With the release of many new seeded cultivars, studies were quickly conducted to determine optimal seeding rates, dates, and fertility requirements (Shaver et al., 2006; Patton et al., 2004 (a, b); Karcher et al., 2004; Munshaw et al., 2002).

Consideration must be given to the seeding date and the amount of time the soil will be bare during bermudagrass establishment from seed. Annual grassy weeds such as crabgrass (*Digitaria spp. L.)* and goosegrass (*Eleusine indica L.)* germinate rapidly during the recommended window for seeding bermudagrass. These weeds can greatly increase the chances of stand failure if not addressed at the time of emergence. They also tend to germinate quicker than bermudagrass and thus will shade the bermudagrass seed and compete for vital radiation, soil moisture, and nutrients.

Seeding solely by calendar date causes other concerns that are related to temperature and germination of the desired species as well as weedy species. Weather data collected by the University of Kentucky Agricultural Weather Center shows significant variation in temperature among years for the same day of year. Intuitively, expected temperatures should be considered when planning establishment of bermudagrass by seed in order to maximize rapid germination.

Variability among seeded bermudagrass cultivars in temperature requirements to complete the germination process is an area that has not been well studied or documented. Studies by Patton et al. (2004 b), and Richardson et al. (2004) observed significant differences in visible germination time and stand establishment among cultivars. Patton et al. (2004 a) noted the use and utility of growing degree day (GDD) models to predict the germination of bermudagrass and zoysiagrass (*Zoysia japonica* Steud.). Patton's study estimated GDD accumulation with the equation: (Max. Temperature + Min. Temperature)/2 – Base Temperature (base temperature = 10°C) calculated daily from seeding to final rating date. Resulting GDD data indicated that Mirage bermudagrass requires >950 GDD to reach 95% cover, which could be accomplished in 30 to 60 days for sites in Kentucky and Indiana where the study was conducted.

Growing degree day or heat sum models can be used to predict germination at optimal moisture conditions. These models are based on thermal unit accumulation (temperatures over time) above a minimum base temperature at which the seed can progress toward the completion of germination (Bierhuizen and Wagenvoort, 1974; Wagenvoort and Bierhuizen, 1976). In the upper transition zone where most of the seeded bermudagrass applications are sports and golf turf, water and light are generally not limiting factors for the completion of germination. Therefore, assuming optimal moisture conditions, temperature is most likely the limiting factor for seed germination (Bierhuizen and Wagenvoort, 1974).

Over the years, heat sum models have been incorporated into more complex models to describe germination characteristics. Expanding on the long recognized cardinal temperatures (base, optimum, and ceiling) for germination introduced around 1860, hydrothermal time models have evolved to describe temperature and water thresholds for the germination process (Alvardo and Bradford, 2002). Modeling with weed species predicts seedling emergence patterns and is useful in weed management programs (Bradford, 2002).

The development and use of either thermal and/or hydrothermal models has been studied and documented for species such as potato (*Solanum tuberosum* L.) (Alvarado and Bradford, 2002) and tomato (*Lycopersicon esculentum* Mill.) (Cheng and Bradford, 1999). With the success of these models it is reasonable to think they could be applied to turfgrass species as well. However, studies of this nature for turfgrass species, especially bermudagrass, are limited or have not been attempted. Applications of thermal modeling for the upper transition zone would help characterize the optimum temperatures to achieve maximum germination of bermudagrass seeds.

Bradford (2002) noted that seeds in a given lot or population may have a similar base temperature, but there are possible exceptions. Models are based on the assumption that a common base temperature exists among the cultivars within a species. Delineating exceptions to the base temperature requires more elaborate and complex models to accurately describe the effects of temperature on the completion of germination (Bradford, 2002).

Within the species, cultivars of bermudagrass have been thought to be easy to establish due to quick germination compared to other warm season grasses (Philley and Krans, 1998). This continues to hold true for the majority of the commercially available seeded bermudagrasses. However, there are exceptions. Strong anecdotal evidence indicates that the cultivar Riviera can often be slow to germinate in the field. Slow germination is complicated by concurrent germination of weedy species, and sometimes also by subsequent over-management (e.g., over-irrigating) often due to concerns of the turf manager that germination should occur quicker. Riviera exhibits high turfgrass quality, superior traffic tolerance, winter hardiness, and resistance to winter kill which makes it appealing to most sports and golf turf managers, but it can often be one of the most difficult cultivars to establish from seed.

The objectives of this study were to build a thermal model and identify the germination characteristics of seeded bermudagrasses using Riviera and Casino Royale. These two cultivars were chosen based on previous studies that indicated these two cultivars represent the slowest and quickest germinating commercially available cultivars, respectively.

Materials & Methods

Germination Modeling

To obtain a true germination model for a species, data must be gathered in a controlled setting and then validated in either a greenhouse or field setting. This process will allow the researcher to confirm or disprove the accuracy of the observations obtained under controlled conditions in laboratory germination chambers.

Germination studies were conducted in the Turfgrass Science Laboratory on the University of Kentucky campus in 2011. An experiment was designed to evaluate two cultivars of seeded bermudagrass, Riviera and Casino Royale, which represented very slow and very fast germination, respectively. To define the cardinal temperatures that are necessary to construct a model, 50 seeds representing ten seed lots of Riviera and one seed lot of Casino Royale each with four replications were placed in 100 x 15mm Petri dishes (Fisher Scientific, Pittsburg, PA) on a double layer of CDB 3.25 blue blotter paper (Anchor Paper Co., Saint Paul, MN). Each Petri dish received 13 ml water, which allowed for free water in the dish without floating the seeds, and was placed in germination chamber models: (2) Hoffman Mfg., Albany OR. (SG8F), Conviron, Winnepeg Canada (model CMP 3244), Hoffman Mfg., Albany OR. (model SG2-22), Precision Scientific, India (model 805). Water was added as needed throughout the studies to maintain free water in each dish. Individual chambers were set at constant temperatures for an entire 24 hour period in five degree increments from 10-45 ^{o}C. White fluorescent lamps provided light in all chambers with a photon flux density ranging from 7 to 19 $\mu mols \cdot s^{-1} \cdot m^{-2}$. Thermal time calculations were made to determine the appropriate duration of tests for each temperature to ensure all seeds in each temperature were exposed to the same number of thermal units. The study ranged from 16 to 74 days depending on which temperature was evaluated.

Light, Temperature, and Fluridone

Three subsequent studies evaluated the effect of day length, varied day/night temperature regimes, and an ABA inhibitor (fluridone; 1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1H)-pyridinone) on the velocity and total percent germination of Riviera seeded bermudagrass. Approximately 50 seeds from three seed lots (produced in 2006, 2008, and 2010) were placed in 100 x 15mm Petri dishes (Fisher Scientific, Pittsburg, PA) on a double layer of CDB 3.25 blue blotter paper (Anchor Paper Co., Saint Paul, MN). Each Petri dish received 13 ml water which allowed for free water in the dish without floating the seeds. Water was added as needed throughout the studies to maintain free water in each dish. Four replications for the light and day/night temperature regime studies were randomly placed in germination chambers models: (2) SG8F (Hoffman Mfg., Albany OR.), model CMP 3244 (Conviron, Winnepeg Canada), model SG2-22 (Hoffman Mfg., Albany OR.), model 805 (Precision Scientific, India). The fluridone study used germination chamber model SG2-22 (Hoffman Mfg., Albany OR). White fluorescent lamps provided light in all chambers with a photon flux density ranging from 7 to 19 $\mu mols \cdot s^{-1} \cdot m^{-2}$. With the exception of the light study, each chamber was set to receive 8 hours of light and 16 hours of darkness throughout the twenty one day study.

The light study followed most of the AOSA standard protocols for germination testing with the exception of the simulated day length and potassium nitrate (KNO_3) solution. For this study, individual chambers were set for various day lengths consisting of 12, 14, and 16 hours of simulated day length. For the day/night temperature regime study, AOSA protocol was also used with the exception of temperature regime and KNO_3 solution. This study evaluated various temperature regimes consisting of 40/25, 35/20, ad 35/25°C day/night ranges and KNO_3 was not used.

A germination study was also conducted where the imbibition solution contained fluridone at a 50µM concentration. The fluridone solution was added to maintain free solution in the dishes throughout the study. A water check was used for statistical comparison for this study only. Standard AOSA protocol for bermudagrass was followed with the exception of adding the fluridone solution and not adding KNO_3.

Germination counts were made daily for radicle emergence for all studies. Seeds were counted as germinated and removed when the radicle was visible under a 1.75 X magnifying lens. For the fluridone study statistical analysis for speed or rate of germination was estimated using a modified Timson's index of germination velocity: $\Sigma G/t$, where G is the sum of the percentage of germination at 1-d intervals, and t is the total germination period (Khan and Unger, 1997). Total percent germination was also evaluated for the fluridone study. All statistical analyses were performed using F-protected Fisher's LSD in PROC GLM of SAS (SAS Inc. Cary, NC).

Results

Germination Modeling

At the conclusion of data collection, data revealed that Riviera would not complete the germination process in sufficient quantities to support a model (Table 3.1). For each lot containing approximately 200 seeds of Riviera, less than 3% germination was observed across and within all seed lots. This attempt at thermal modeling was strong and clear evidence of the fluctuating temperature requirement that was investigated further in following studies (day/night temperature regimes).

Casino Royale was studied under the exact same protocol as Riviera and was observed to complete the germination process adequately at constant temperatures (Table 3.1). Following the protocol for thermal modeling by Bradford (2002), Casino Royale germination data was analyzed in an attempt to characterize the seed lot germination characteristics. Results of the calculations were not applicable to thermal modeling due to the inconsistency of the germination patterns with this seed lot. Germination percentages for fractions of the seed lot did not correlate across constant thermal unit accumulation. This prevented an accurate definition of the base temperature for the seed lot and thus the species.

Table 3.1. Mean germination percentages of ten Riviera seed lots and one Casino Royale seed lot at 8 constant day/night temperatures. Each seed lot was exposed to equal thermal units by varying length of time in individual chambers. Germination percentages were calculated based on 200 seeds per seed lot.

Temp.	Seed Lot										
	S-1652-1R	S-1651-3R	S-1688-1R	S-1691-A	S-1689-1R	S-1607-1R	2009	2008	2007	2006	Casino Royale
10°C	0	0	0	0	0	0	0	0	0	0	0
15°C	0	0	0	0.5	0	0.5	0	0	0	0	20.5
20°C	0.125	0	0	0	0.125	0.125	0	0.125	0.125	0.125	41
25°C	0	0	0.125	0	0.625	0	0.25	0	0.5	0.375	33
30°C	0	0.25	0	0.125	0.125	0.125	0.125	0	0	0.25	61.5
35°C	0.125	0.625	0.125	0.5	0.5	0.25	0.625	0.375	0.375	1.75	83.5
40°C	0.25	0.25	0.25	1	0.625	1.125	0.875	1	0.75	2.25	82
45C	0	0	0	0	0	0	0	0	0	0	4

Light Study

The main effect of seed lots (produced in 2006, 2008, and 2010) was highly significant ($p<.0001$) (Table 3.2). There were no significant differences observed due to the main effect of day length ($p = 0.5753$). No significant interactions between day length by seed lot were observed ($p = 0.2318$) (Table 3.2). Figure 3.1 illustrates the highly significant differences observed due to the main effect of seed lot. The 2008 seed lot achieved 98.03% total germination while the 2010 and 2006 seed lots achieved 85.33% and 68.5% total germination, respectively. Figure 3.2 illustrates that day length had no significant effect on the mean percent germination across all three seed lots. Mean percent germination recorded was 83.75%, 82.42%, and 80.75% for the 16, 14 and 12 day length treatments, respectively.

Temperature Study

Since it was determined by the thermal modeling study that Riviera has a significant requirement for fluctuating temperatures, two additional fluctuating temperature regimes (40/25 and 35/25 ^{o}C, day/night temperatures) were evaluated along with the AOSA standard seed testing protocol temperature, 35/20 ^{o}C, day/night, for effects on total percent germination. The study used the same three seed lots as with the day length study and while the main effect of temperature regime was highly significant ($p<.0001$), no significant differences were observed due to the main effect of seed lot ($p = 0.2742$) (Table 3.3). Highly significant differences were observed for the main effect of temperature regime and seed lot x temperature regime interaction ($p<.0001$) (Table 3.3). Figure 3.3 illustrates the main effect of seed lot across temperature regimes.

Table 3.2. Analysis of variance for the main effect of seed lot (SL), day length (DL), and SL by DL interactions on the completion of germination of three seed lots of Riviera bermudagrass.

Source of Variation	F	Pr>f
SL	39.45	<.0001
DL	0.56	0.5753
SL x DL	1.49	0.2318
CV (%)		8.42

Figure 3.1. Mean percent germination of three seed lots of Riviera bermudagrass across three day length treatments. Bars with the same letter are not statistically different by F-protected Fisher's LSD (p>0.05).

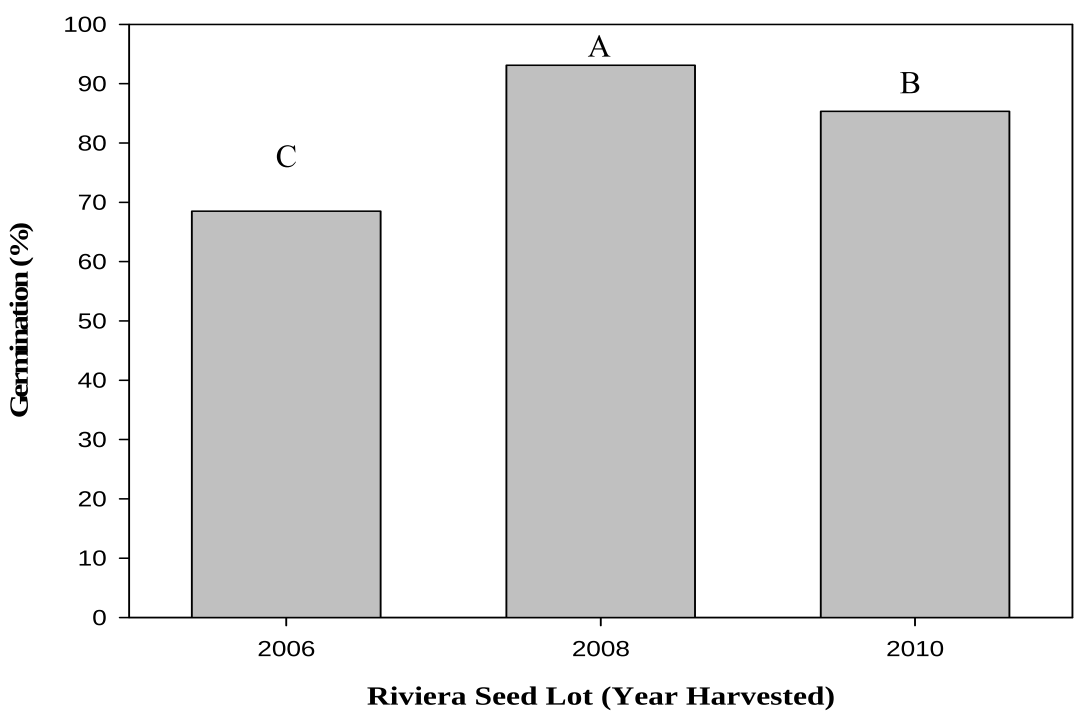


Figure 3.2. The main effects of three day lengths on the mean percent germination across three seed lots of Riviera bermudagrass. Bars with the same letter are not statistically different by F-protected Fisher's LSD (p>0.05).

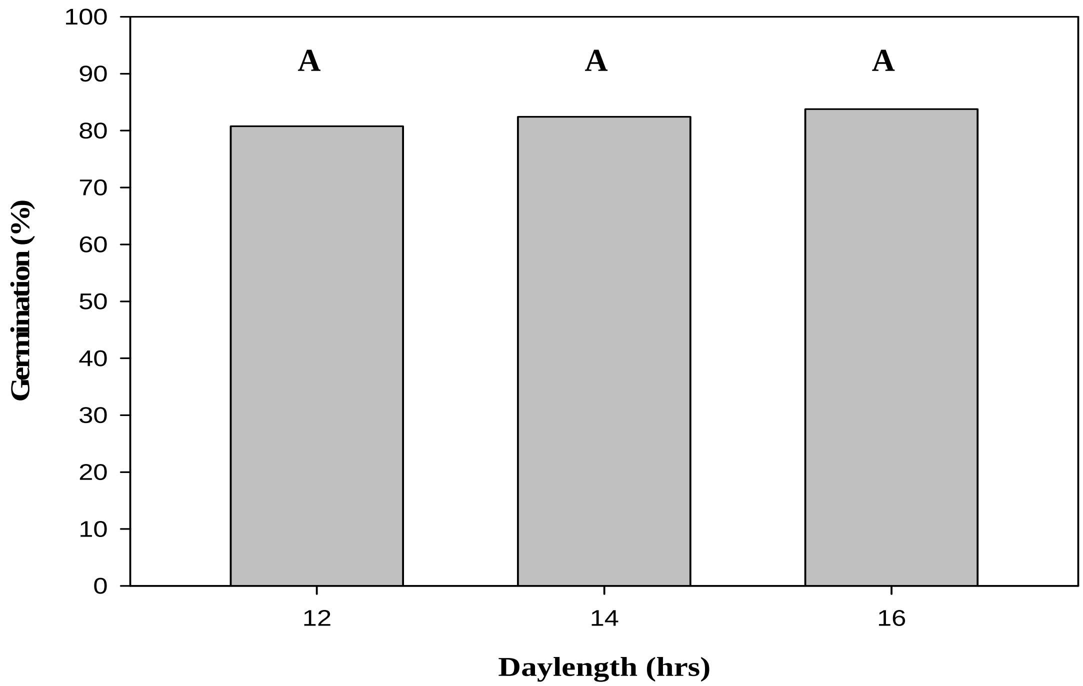


Table 3.3. Analysis of variance for the main effects of seed lot (SL), temperature regime (TR), and SL x TR interaction on the completion of germination of three seed lots of Riviera bermudagrass.

Source of variation	F	Pr<F
SL	1.36	0.2742
TR	765.42	<.0001
SL X TR	21.74	<.0001
CV (%)		15.06

Figure 3.3. Mean percent germination of three Riviera seed lots across three temperature regimes. Bars with the same letter are not statistically different by F-protected Fisher's LSD (p>0.05).

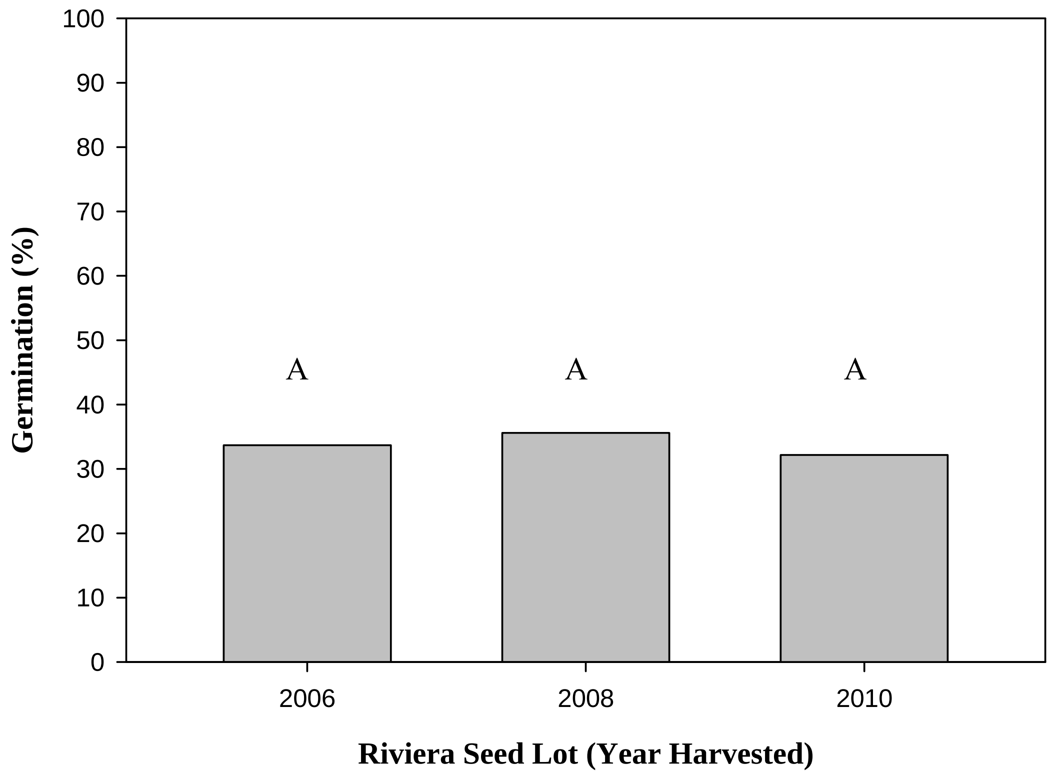


Figure 3.4 illustrates the highly significant ($p<.0001$) effects of temperature regimes across the three seed lots. Seed treated by the standard AOSA protocol temperature regime (35/20 ^{o}C day/night) achieved 80.75% total germination during the 21 day test period. No significant differences were observed between the two remaining temperature regimes which only achieved 10.83% and 9.83% total germination for 40/25 ^{o}C and 35/25 ^{o}C, respectively.

Fluridone Study

Fluridone, which is an ABA inhibitor, was evaluated for its effect on germination velocity and total percent germination of the same three seed lots of Riviera. The cultivar Casino Royale was also used in the study as a comparison due to its known rapid germination characteristics. Two temperature regimes were used in this study, 35^{o}C constant temperature and 35/20^{o}C day/night temperatures.

Under the constant 35^{o}C treatment, the main effect of fluridone was highly significant ($p<.0001$) across both cultivars and all seed lots for mean germination velocity. The main effects of cultivar/seed lots was also highly significant ($p<.0001$) (Table 3.4). Data in Table 3.5 indicate identical highly significant results for the 35/20 ^{o}C study.

To better illustrate the effects of fluridone seed treatments, statistical analysis was performed on mean germination velocity and total percent germination for Riviera among the three seed lots as well as total percent germination for Casino Royale within the two temperature regimes. For the 35^{o}C constant temperature germination velocity study, a

Figure 3.4. Mean percent germination across three seed lots of Riviera bermudagrass under three day/night temperature regimes. Day length and high temperature exposure was 8 h with the remaining 16 h in darkness at the low temperature. Bars with the same letter are not statistically different by Fisher's F-protected LSD (p>0.05).

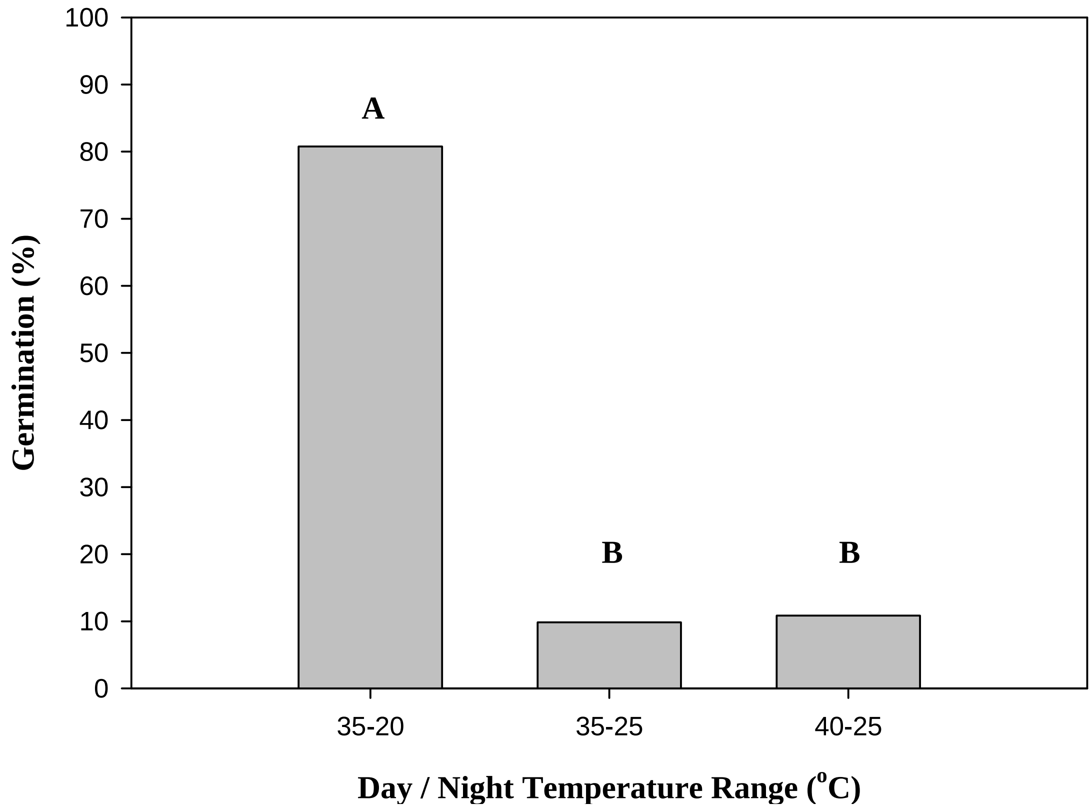


Table 3.4. Analysis of variance for the main effects of cultivar/seed lots of Casino Royale and Riviera bermudagrass, treatment with fluridone, and the cultivar/seed lot x fluridone treatment interaction on mean germination velocity. This study was conducted under 35^{o}C constant temperature.

Source of variation	F	Pr>F
Seed Lot	820.5	<.0001
Treatment	39.46	<.0001
Seed Lot x Treatment	0.59	0.6292
CV (%)		14.72

Table 3.5. Analysis of variance for the main effects of cultivar/seed lots of Casino Royale and Riviera bermudagrass, treatment with fluridone, and the cultivar/seed lot x fluridone treatment interaction on mean germination velocity. This study was conducted under 35/20^{o}C day/night temperatures.

Source of variation	F	Pr>F
Seed Lot	301.47	<.0001
Treatment	23.25	<.0001
Seed Lot x Treatment	2.22	0.1117
CV (%)		12.92

comparison of all three Riviera seed lots produced a highly significant ($p<.0001$) overall model. The main effects of seed lot and treatment (+/- fluridone) produced significant ($p = 0.0003$) and highly significant ($p<.0001$) differences (Table 3.6). Using a modified Timson's index for germination velocity ($\Sigma G/t$, where G is the sum of the percentage of germination at 1-d intervals, and t is the total germination period (Khan and Unger, 1997) (maximum for this study = 86 with the larger the number the faster the germination velocity) the 2006 seed lot was observed to have the largest germination velocity (Figure 3.5). The fluridone treatment increased the germination velocity ($p<0.0001$) (Figure 3.6).

Examination of the data for individual seed lots treated or left untreated with fluridone indicate significant differences, $p = 0.0038$ and $p = 0.0093$, in the mean germination velocity for the 2006 and 2008 lots, respectively (Figure 3.7). The 2010 seed lot produced a highly significant difference, $p<.0001$, in the mean germination velocity due to treatment with fluridone (Table 3.7).

Under the 35/20 ^{o}C temperature regime, the main effect of seed lot and treatment were significant ($p =0.0015$) and highly significant ($p<.0001$), respectively (Table 3.7). Among the seed lots there was no statistical difference between the 2008 and 2010 lots however both were statistically faster and statistically different for mean germination velocity when compared to the 2006 lot (Figure 3.8). Germination velocity of fluridone treated seeds across all three seed lots was significantly higher than untreated seeds, with index scores of 16.02 and 12.3, respectively (Figure 3.9). Statistical analyses of individual seed lots for mean germination velocity also produced significant differences.

Table 3.6. Analysis of variance for the main effects of three seed lots (SL) of Riviera bermudagrass, treatment with fluridone, and the SL x fluridone treatment interaction on germination velocity. This study was conducted under 35°C constant temperature.

Source of variation	F	Pr>F
Seed Lot	14.50	0.0003
Treatment	49.62	<.0001
Seed Lot x Treatment	1.53	0.2475
CV (%)		41.36

Figure 3.5. Mean germination velocity of three seed lots of Riviera bermudagrass across two fluridone treatments (+/-) at a constant temperature of 35°C. Bars with the same letter are not significantly different by Fisher's F-protected LSD (p>0.05).

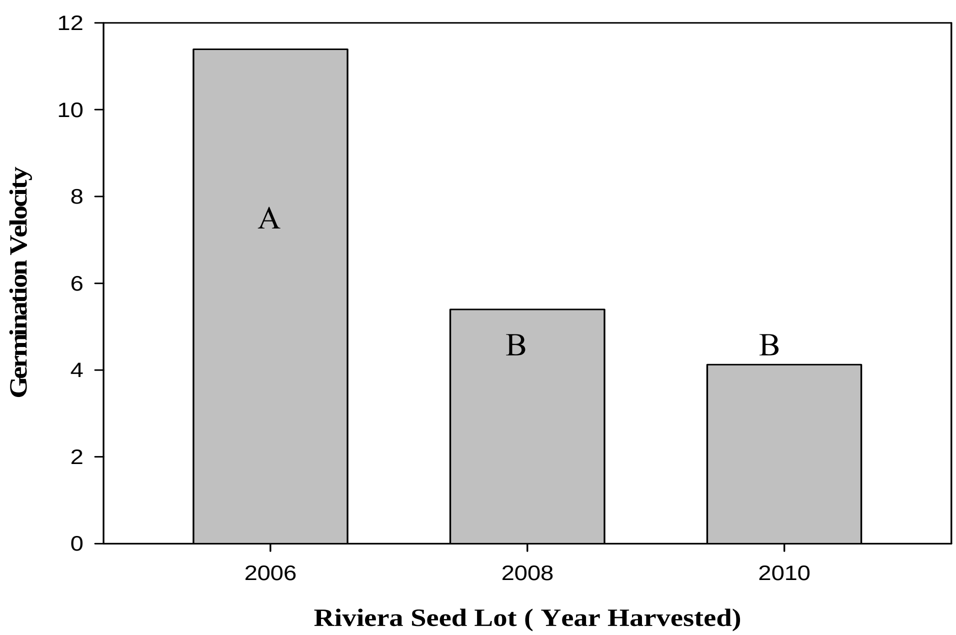


Figure 3.6. Mean germination velocity of seed treated or left untreated with fluridone. Data are across three seed lots of Riviera bermudagrass at a constant temperature of 35°C. Bars with the same letter are not significantly different by Fisher's F-protected LSD (p>0.05).

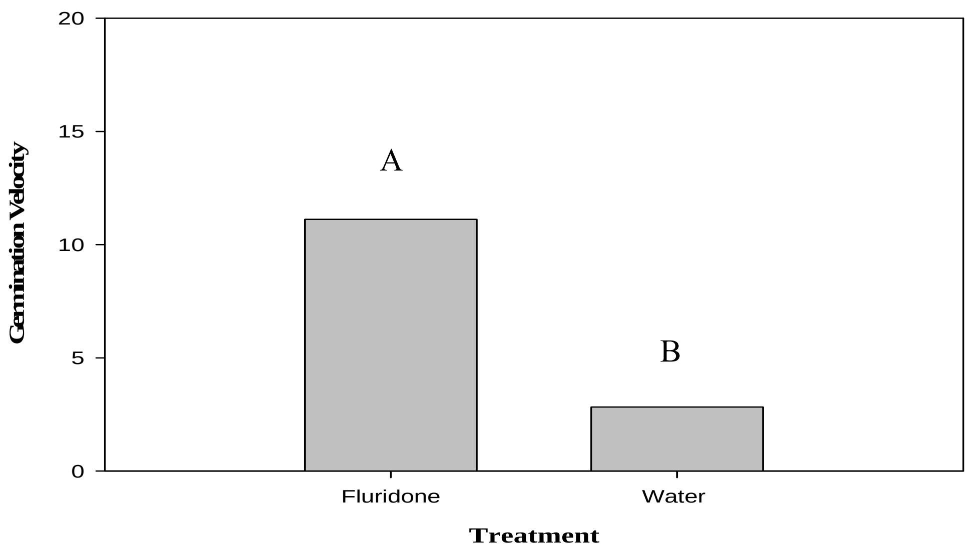


Figure 3.7. Mean germination velocity of three seed lots of Riviera bermudagrass seed treated or left untreated (water) with fluridone. The study was conducted at 35°C constant temperature. Significant differences are indicated within seed lot. Bars labeled with the same letter are not significantly different by Fisher's F-protected LSD (p>0.05).

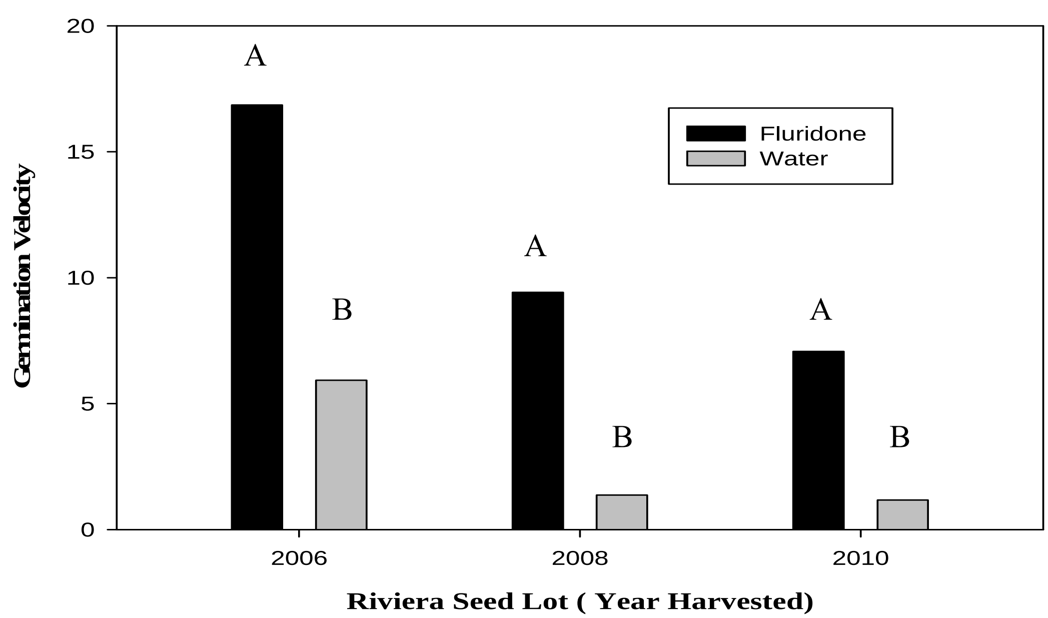


Table 3.7. Analysis of variance for main effect of seed lot, treatment (+/- fluridone), and seed lot x treatment interaction among three seed lots of Riviera bermudagrasses. This study was conducted under a 35°C/20°C day/night temperature regime.

Source of variation	F	Pr>f
Seed Lot	10.38	0.0015
Treatment	32.75	<.0001
Seed Lot x Treatment	0.42	0.6645
CV (%)		10.97

Figure 3.8. Mean germination velocity of three seed lots of Riviera bermudagrass across fluridone treatements (+/-). This study was conducted under a 35/20°C day/night temperature regime. Bars with the same letter are not significantly different by Fisher's F-protected LSD (p>0.05).

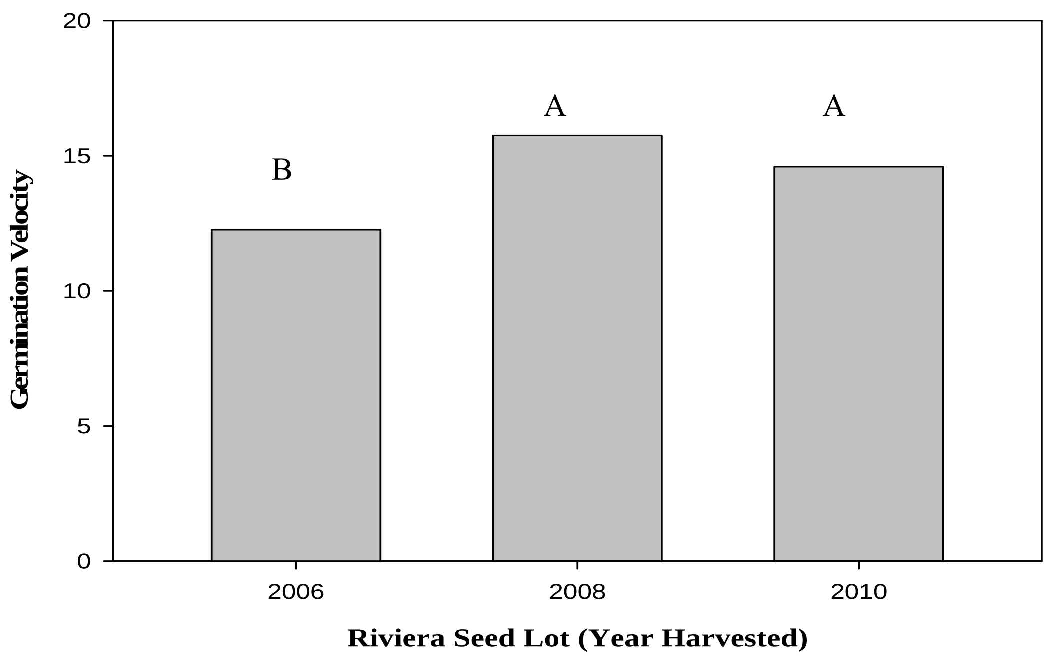


Figure 3.9. Mean germination velocity of seeds treated or left untreated (water) across three seed lots of Riviera bermudagrass. This study was conducted under a 35/20°C day/night temperature regime. Bars with the same letter are not significantly different by Fisher's F-protected LSD (p>0.05).

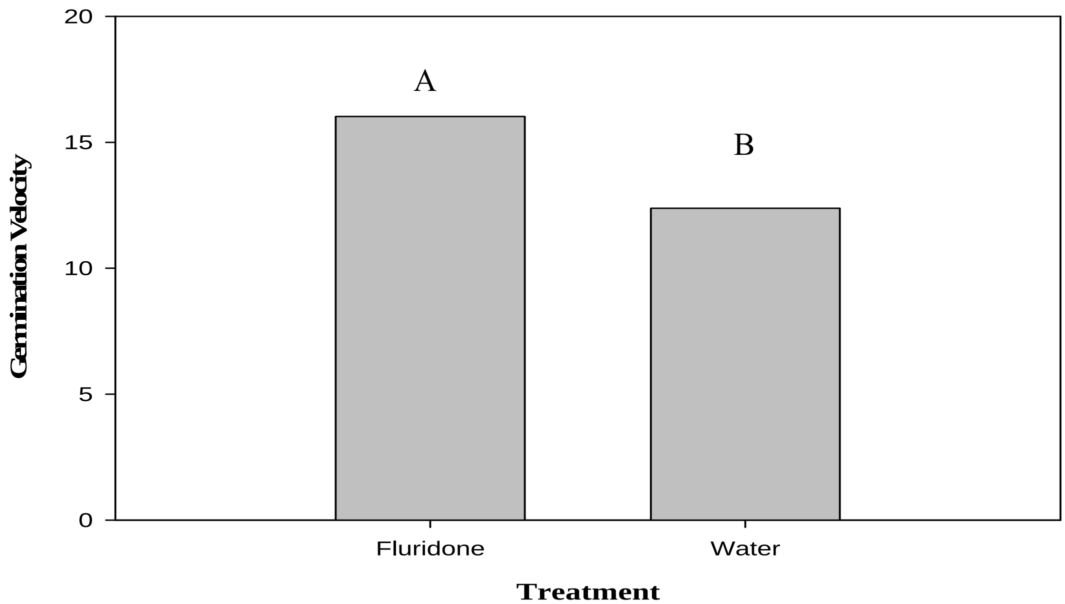


Figure 3.10, illustrates the differences in velocity index values within seed lots treated or left untreated with fluridone.

Fluridone was also evaluated for its effect on total percent germination of the same three seed lots of Riviera and one seed lot of Casino Royale bermudagrass under both temperature regimes (35^{o}C constant and 35/20^{o}C day/night temperatures). Among the three seed lots of Riviera, highly significant differences ($p<.0001$) were observed for the main effect of seed lot and fluridone treatment for fluctuating temperature and for the fluridone treatment at constant temperature. A significant difference ($p = 0.0036$) was observed for the main effect of seed lot at 35^{o}C constant temperature (Table 3.8). Figure 3.11 illustrates the significant main effect of seed lot on the total percent germination of the three Riviera seed lots across fluridone treatments (+/-) within the two temperature regimes. Figure 3.12 illustrates the main effect of treatment (+/- fluridone) on the total percent germination across the three Riviera seed lots.

Examination of the effects of fluridone on individual seed lots was important to distinguish the impact the molecule may have on total germination of various ages of seed and at constant and fluctuating temperatures. An analysis of variance was produced for each of the Riviera lots and for the single Casino Royale seed lot to illustrate the effects of fluridone (Table 3.9). The 35^{o}C constant temperature produced significant improvements ($p = 0.0017$ and $p = 0.0067$) in total germination for 2006 and 2008 lots respectively while producing highly significant ($p<.0001$) improvements for the 2010 lot of Riviera (Figure 3.13). Fluridone treated Casino Royale seed did not produce a statistical difference ($p = 0.1292$) but a slight increase in total germination was observed (Figure 3.13).

Figure 3.10. Mean germination velocity of three seed lots of Riviera bermudagrass seed treated or left untreated (water) with fluridone. The study was conducted at 35/20^{o}C day/night temperatures. Significant differences are indicated within seed lot. Bars labeled with the same letter are not significantly different by Fisher's F-protected LSD (p>0.05).

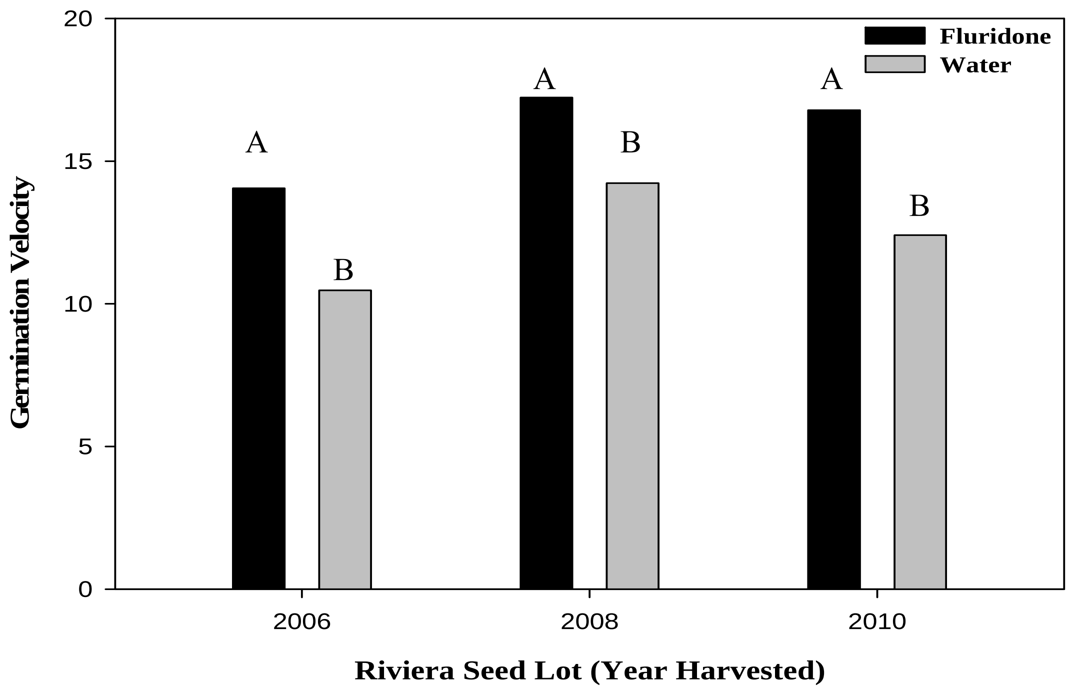


Table 3.8. Analysis of variance for the main effects of seed lot, treatment (+/- fluridone), and seed lot x treatment interaction on the total percent germination of three seed lots of Riviera bermudagrass germinated under 35°C constant temperatures or 35/20°C day/night temperatures.

35° C

Source of Variation	F	Pr>f
Seed Lot	8.38	0.0036
Treatment	68.05	<.0001
Seed Lot x Treatment	0.66	0.5292
CV (%)		38.02

35/20° C

Source of Variation	F	Pr>f
Seed Lot	46.59	<.0001
Treatment	33.40	<.0001
Seed Lot X Treatment	1.72	0.2121
CV (%)		5.53

Figure 3.11. Mean percent germination of three seed lots of Riviera bermudagrass across fluridone treatments (+/-) and germinated at 35°C constant temperature or 35/20°C day/night temperatures. Significant differences are illustrated within temperature regimes and bars with the same letter are not significantly different by Fisher's F-protected LSD (p>0.05).

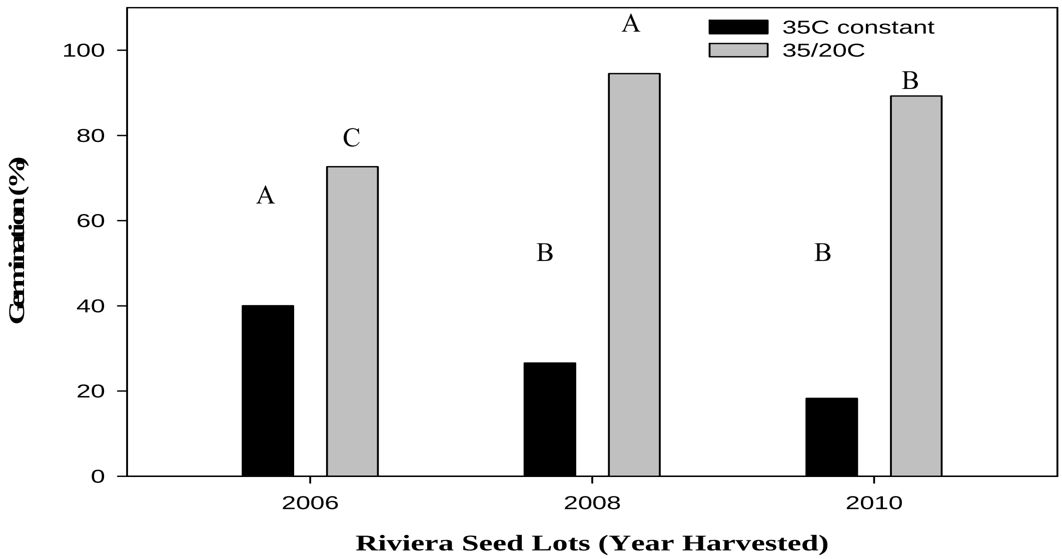


Figure 3.12. Mean percent germination of seeds treated or left untreated (water) with fluridone germinated in 35°C constant temperature or 35/20°C day/night temperatures. Data are across three seed lots of Riviera bermudagrass Significant differences are indicated within temperature regime and bars with the same letter are not significantly different by Fisher's F-protected LSD (p>0.05).

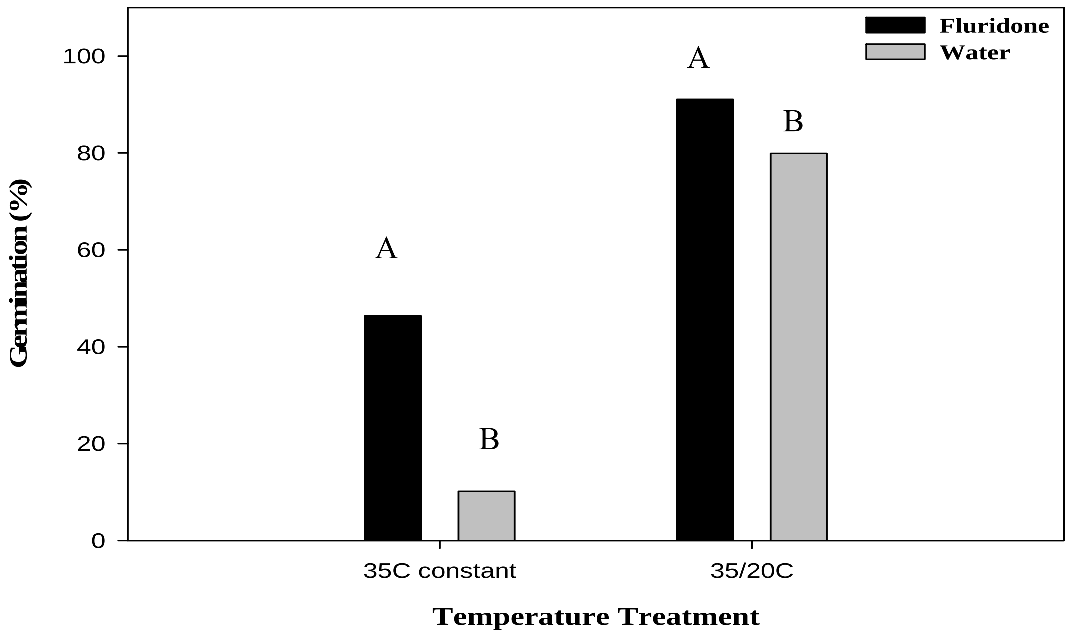
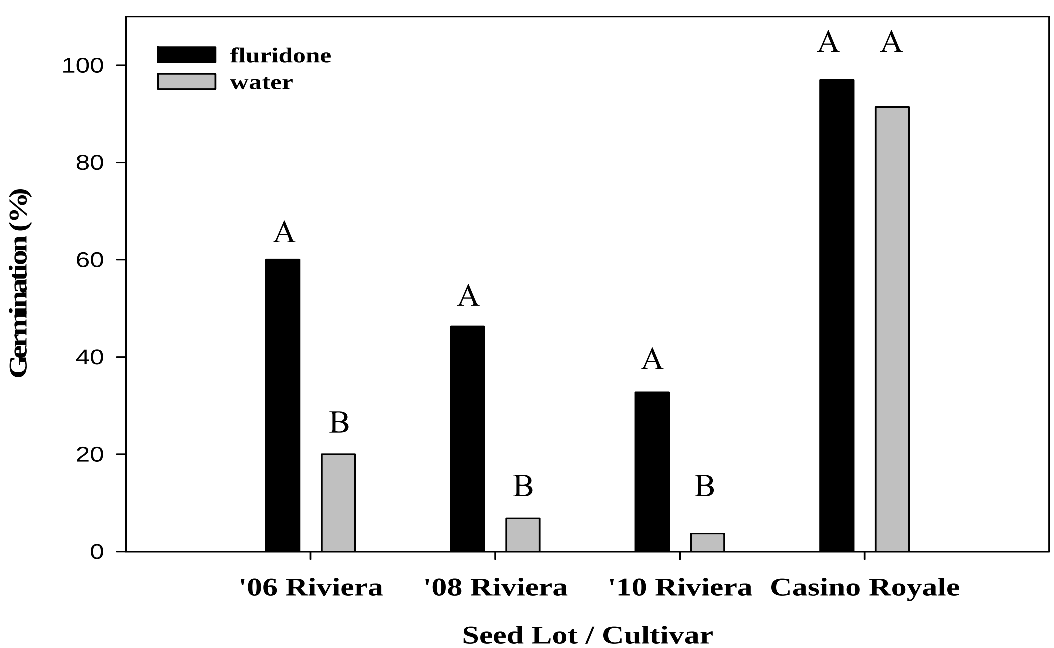


Table 3.9. Analysis of variance for the main effect of treatment (+/- fluridone) for two temperature regimes (35° C and 35/20° C) for three seed lots of Riviera and one seed lot of Casino Royale bermudagrass.

Source of Variation	Temp. regime	Cultivar	F	Pr>f	CV(%)
Treatment	35 C constant	2006Riv	28.86	0.0017	26.35
	35/20 C	2006Riv	5.89	0.0514	8.34
Treatment	35 C constant	2008Riv	16.41	0.0067	51.86
	35/20 C	2008Riv	20.53	0.0040	2.38
Treatment	35 C constant	2010Riv	208.62	<.0001	15.61
	35/20 C	2010Riv	22.23	0.0033	5.34
Treatment	35 C constant	Cas.Roy	3.09	0.1292	4.73
	35/20 C	Cas.Roy.	3.26	0.1211	4.35

Figure 3.13. Mean percent germination of three seeds lots of Riviera and one seed lot of Casino Royale bermudagrass treated or left untreated (water) with fluridone. This study was conducted at 35° C constant temperature. Bars within a seed lot/cultivar with the same letter are not significantly different by Fisher's F-protected LSD (p>0.05).



The fluctuating temperature study (35/20^{o}C day/night) study produced significant differences, p = 0.0514, p = 0.0040, and p = 0.0033 for the 2006, 2008, and 2010 lots of Riviera respectively (Figure 3.14). Casino Royale was not observed to have a statistical difference (p = .1211) in total percent germination but like the constant temperature study had a slight increase in total germination. Figures 3.15 and 3.16 illustrate the differences in total and daily percent germination for the three Riviera and one Casino Royale seed lots treated or left untreated with fluridone.

Discussion

This study initiated a concerted effort to define the causes responsible for the slow rate of completion of germination of Riviera bermudagrass. While many cultivars of bermudagrass complete the process fairly rapidly, their subsequent turfgrass quality is generally lacking in comparison to Riviera. The findings of this study agree with the conclusions of Patton et al. (2004b) and Richardson et al., (2004) that there are significant differences among the cultivars of bermudagrass in the process to complete germination and establishment. At least within the parameters of this study, it is clearly evident that Riviera is much slower to complete germination when compared to Casino Royale as well as several other commercially available cultivars.

Philey and Krans (1998) describe bermudagrass as a species that is generally easy and quick to establish. The time of their publication coincides with the approximate time Riviera was being developed (John Lamle, Johnston Seed Co., 2012 personal communication) developed and is probably the reason their general assumption does not completely hold true.

Figure 3.14. Mean percent germination of three seeds lots of Riviera and one seed lot of Casino Royale bermudagrass treated or left untreated (water) with fluridone. This study was conducted at 35/20^{o}C day/night temperatures. Bars within a seed lot/cultivar with the same letter are not significantly different by Fisher's F-protected LSD (p>0.05).

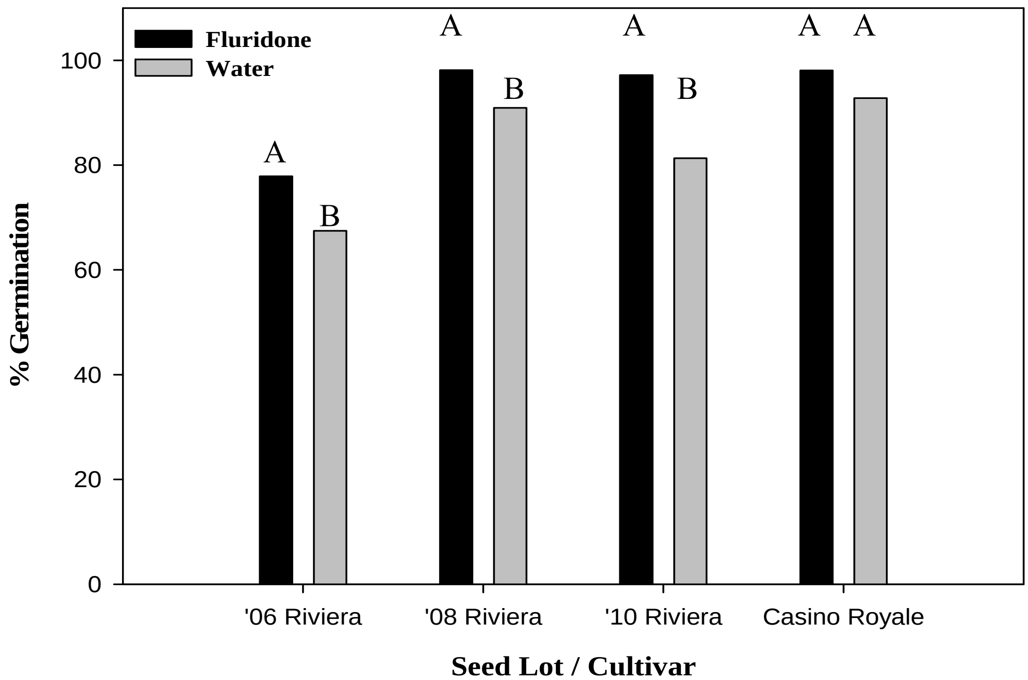


Figure 3.15. Daily percent germination of three seeds lots of Riviera and one seed lot of Casino Royale bermudagrass treated or left untreated (water) with fluridone. This study was conducted at 35° C constant temperature.

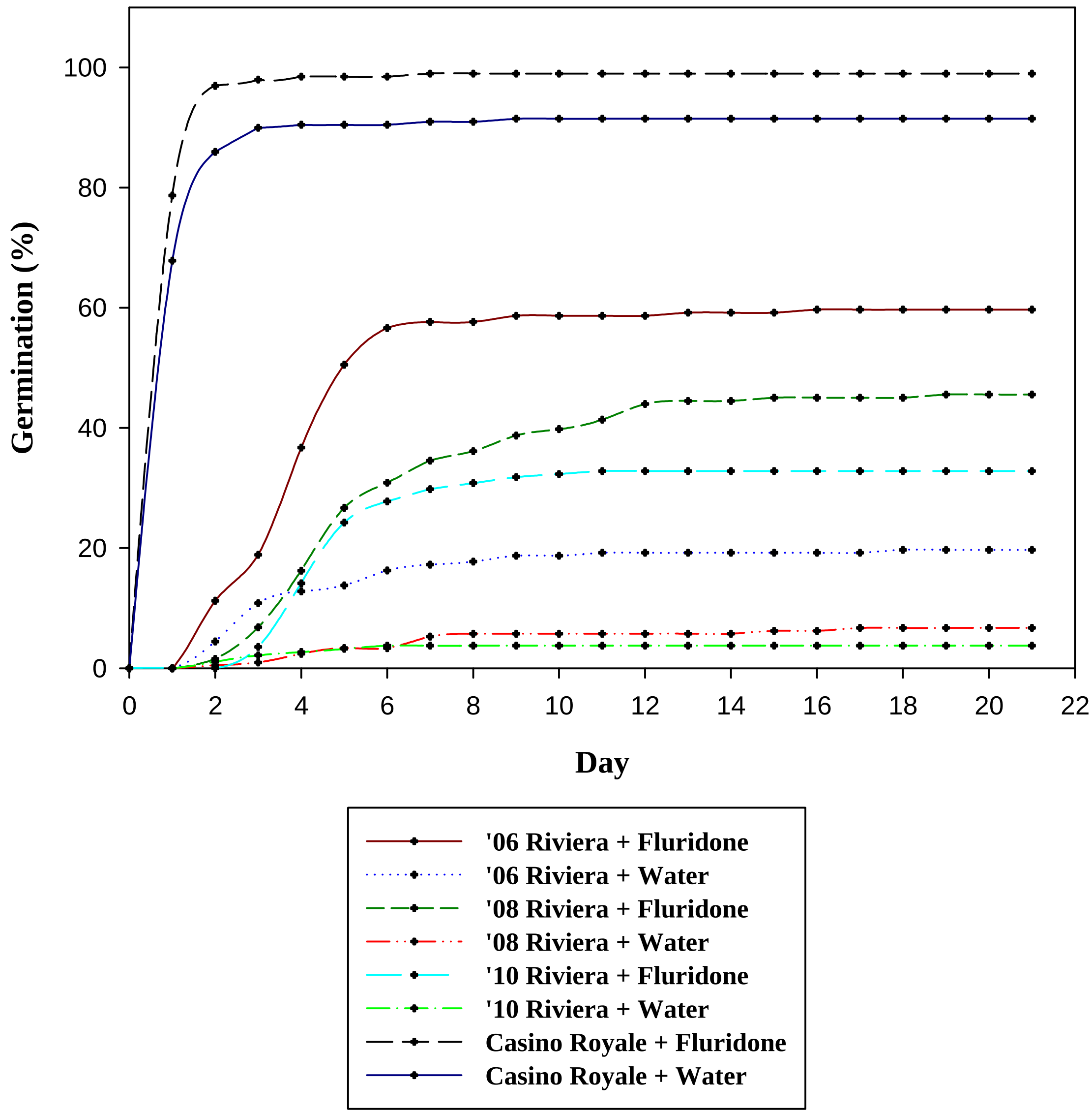
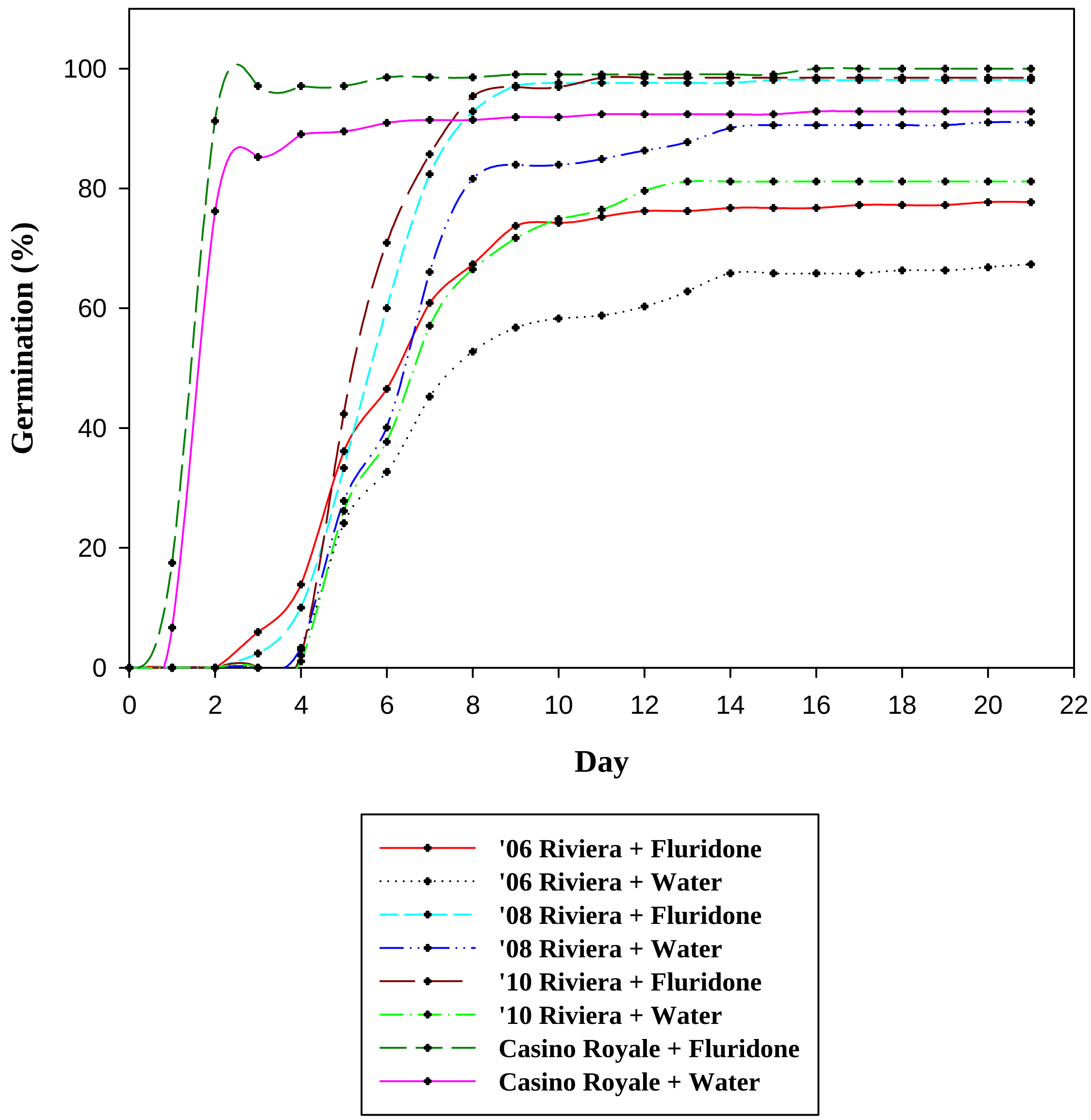


Figure 3.16. Daily percent germination of three seeds lots of Riviera and one seed lot of Casino Royale bermudagrass treated or left untreated (water) with fluridone. This study was conducted at 35/20°C day/night temperatures.



This study could not precisely define the causes of slow germination for Riviera relative to other bermudagrass cultivars. It does, however, agree well with the findings of Beirhuizen and Wagenvoort (1974) that temperature can be the most limiting factor in the germination process.

This study indicated that Riviera has a strict requirement for fluctuating temperatures. Inadequate germination was observed and modeling the characteristics for Riviera germination at constant temperatures was simply not possible. This information agrees with the work of Huarte et al., (2010), Wagenvoort and Bierhuizen, (1977), and Schull (1923) that many species have a fluctuating temperature requirement. This study and the previous work on modeling show that Riviera completes the germination process significantly better under strict fluctuating temperatures. However, Casino Royale will complete the germination process well at either constant or fluctuating temperatures.

This study agrees well with Wagenvoort and Bierhuizen, (1977) and Schull (1923) that fluctuating temperatures can enhance germination percentages. Our work indicates that not only fluctuating temperatures, but the range of the fluctuating temperatures can have a significant effect on germination. Riviera was shown to have greatly reduced germination percentages if the spread of the fluctuations was decreased. The exact reasoning and causes behind this phenomenon are still largely unknown.

Huarte and Bench-Arnold (2010) found that an ABA inhibitor, fluridone, had an effect on the germination process in *Cynara cardunculus* (L.) but that the inhibition of ABA was not the root cause for poor germination. This was relevant due to fluridone-treated seeds completing germination faster and to a greater percentage than non-treated seeds. They noted at least one other instance linking fluridone to shrinking the requirement for fluctuating temperatures. Although the current study can neither prove nor disprove the role of ABA in Riviera germination, the data produced definitely raises this possibility.

Lee et al., (2010) links the de novo production of ABA in seeds to species with slow germination characteristics. The production of ABA in the seed coat upon imbibition is a negative regulator of germination by preventing the production of GA. With additional ABA being produced in some species, the seed will not germinate until the ABA decreases and GA increases allowing production of alpha-amylase in the aluerone layer which begins the mobilization of food reserves for embryo growth. The addition of an ABA inhibitor has the possibility to reduce or stop the production of ABA in the seed which in theory should enable the seed to complete the germination process quicker.

As mentioned earlier, this study did not precisely define the causes reducing the germination velocity or percentage of Riviera. It does clearly indicate there are significant differences in germination velocity between Riviera and Casino Royale. Riviera has long been known in the turf industry to be difficult to establish in the upper transition zone. This characteristic has led to many establishment failures for professional turfgrass managers. This study has shown that Riviera is slow to germinate compared to Casino Royale and previous work has concluded the same compared to most other commercially available cultivars. This study indicates that Riviera has a strict fluctuating temperature requirement that simply may not be met under average field conditions in the upper transition zone.

Fluridone significantly enhanced the velocity and percentage of germination for Riviera. This was evident for both constant and fluctuating temperatures. Based on this study, future work should continue to investigate the causes of slow germination for Riviera. Future work should also include work with ABA inhibitors as a seed treatment to enhance the velocity and percentage of germination of Riviera. Riviera is a desirable cultivar for turf managers in the transition zone due to its superior quality and traffic tolerance characteristics. Improvements in the rate of germination which translates into faster establishment would be a significant improvement for the cultivar and greatly increase it use especially in the upper transition zone.

Copyright © Michael Todd Deaton 2012

Chapter IV

Simulated Traffic Tolerance of Newly Established, Commercially Available Cultivars of Seeded Bermudagrass (*Cynodon dactylon* (L.) Pers.)

How much traffic or wear can an athletic field or other turfgrass surface accommodate or tolerate? There is no one correct answer for this question, due to inherent variability among cultivars and environmental conditions from year to year (Powell, 2006).

Bermudagrass is most commonly the turf of choice for athletic fields. Reasons for this include anatomical characteristics that infer a greater level of tolerance to traffic stress versus cool season species (Thoms et al., 2011; Williams et al., 2010; Trenholm et al., 2000). Popularity and use of both common and hybrid bermudagrass (*Cynodon dactylon* (L.) Pers. and *C. dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davey, respectively) has led to numerous studies evaluating traffic tolerance among bermudagrass cultivars. Most of these previous studies made comparisons among just a few of the most widely used cultivars.

Until recently, the common seeded type of bermudagrass has lagged far behind the vegetative propagated interspecific hybrid bermudagrasses in overall quality (Patton et al. 2008; Shaver et al. 2006; Karcher et al. 2004; Richardson et at. 2004). Until the release of improved cultivars in the 1990s, seeded bermudagrass tended to have a coarse leaf with a more open type growth habit and lighter green color than the hybrids, such as the industry standard ‘Tifway’ (Baltensperger and Klingenburg, 1994).

As a result of breeding efforts and the release and production of cultivars such as Riviera in 2001 (Martin et al., 2007) a renewed interest in seeded bermudagrasses emerged (Richardson et al., 2008; Shaver et al., 2006). It was not until this time that seeded cultivars achieved equal or superior quality characteristics, traffic tolerance, and winter tolerance in the transition zone (Patton et al. 2008; Munshaw et al. 2001). The improved cultivars opened the door for seeded bermudagrass to be used in fine turf applications such as sports and golf turf (Patton et al. 2006).

Many factors may contribute to a species ability to withstand stresses imposed by excessive traffic. Bronson et al., (2005) categorized these factors into two major groups: morphological and anatomical. Tissues such as sclerenchyma and higher lignin content directly affect a species ability to withstand excessive traffic (Beard, 1973). Thick secondary walls composed of sclerenchyma provide structural support to plant parts that are no longer elongating (Taiz and Zeiger, 2006). Photosynthates are precursors to all plant compounds which include lignin that is used primarily for structural components in the cell wall (Beard, 1973). Shearman et. al, (2006) linked traffic tolerance with lignin content, sclerenchyma fibers, other cell wall components, and leaf width and tensil strength. Beard (1973) linked other factors such as stolons and rhizomes along with high verdure with increases a species' ability to withstand greater amounts of traffic stress.

Traffic stress has been characterized into two major components: wear stress and compaction (Thoms et al., 2011; Trappe et al., 2011; Vanini et al., 2007; Turgeon, 2005; Trenholm et al., 2000; Beard, 1973). Turfgrass wear is comprised of horizontal forces from tearing, tissue bruising and removal (Thoms et al., 2011; Trappe et al., 2011; Vanini et al., 2007). Soil compaction or soil displacement, which is primarily a vertical force, leads to lower oxygen levels in the soil, poor soil drainage, and greater soil strength (Thoms et al., 2011; Trappe et al., 2011; Vanini et al., 2007; Trenholm et al., 2000).

Vanini et al., (2007) described various configurations of traffic simulators that have been developed and used to study the effects of traffic stress on turfgrass. Designs have ranged from apparatuses that impose only wear stress to machines that impose wear stress and compaction together. Traffic simulators have been well documented in the literature since their arrival as a research tool in the late 1950's. Designs such as studded drum rollers did not produce horizontal stress as does wear imposed by humans. This prompted the development of the differential-slip wear machine (Canaway 1976).

Cockerham and Brinkman (1989) developed the Brinkman Traffic Simulator (BTS). The BTS simulates cleated athletic foot traffic which results in both wear and compaction. Several, more recent studies have questioned the rate of wear of the BTS, which lead to the development of the Cady Traffic simulator (CTS) (Vanini et al., 2007). The CTS is argued to produce more aggressive stress with fewer passes over the test area (Vanini et al., 2007). The work reported by Vanini et al., (2007) was conducted on a Kentucky Bluegrass (*Poa pratensis* L.) stand maintained at a 51 mm mowing height. Until a recent study by Thoms et al., (2011) comparisons of the machines were limited in the literature.

Thoms et al., (2011) notes the extensive use of the BTS and concurs that the BTS and CTS make the same number of cleat marks and differ mainly in the rate or aggressiveness of the applied stress. Younger (1961) stated the necessity of replicable treatments in traffic studies to produce reliable and creditable information. Based on several peer reviewed publications either machine has the ability to simulate and replicate wear stress and is suitable for studying traffic tolerance of turfgrass (Thoms et al., 2011; Vanini et al., 2007).

Increasing popularity of seeded bermudagrass in the transition zone has fueled a wide array of studies from seeding rates and dates to traffic tolerance. Traffic tolerance studies by Thoms et al., (2011); Trappe et al., (2011); Williams et al., (2010); Deaton et al., (2010), Bayrer (2006), and Trenholm et al., (2000) are some that have evaluated both seeded and vegetative bermudagrasses. These studies usually concentrated on the most popular cultivars that were available at the time of the study. The age of the turf stands in the aforementioned studies varied between months and years, or was simply not stated. The objective of this study was to evaluate a more comprehensive list of seeded bermudagrass cultivars with emphasis on newly established stands. In particular, stands that had been established at recommended seeding times for the upper transition zone and would be subjected to traffic that same autumn football season, as would be the case on most high school athletic fields.

Materials & Methods

Research was conducted in 2010 and 2011 at the A.J. Powell, Jr. Turfgrass Research Center located in Lexington, Kentucky. The soil was a Maury silt loam (fine, mixed mesic typic Paleudalf) with a pH of 6.3 and approximately 4% organic matter in the top 5 cm. The study was seeded at 12.2 kg ha^{-1} pure live seed (Munshaw et al., 2001) on 27 June 2010 and an adjacent site for the second year of the study was seeded 30 June 2011.

Experimental design was a randomized complete block design with four replications. Experimental units were 1.5 m^2. Nineteen commercially available cultivars were evaluated: 'Arizona Common' hulled, 'Arizona Common' unhulled, 'Casino Royale', 'LaPaloma', 'Mirage II', 'Mohawk', 'New Mex Sahara', 'Princess 77', 'Riviera', 'Savannah', 'Southern Star', 'Sovereign', 'SR 9554', 'Sun Bird', 'Sun Devil II', 'Sun Sport', 'Sun Star', 'Transcontinental', and 'Yukon'. These cultivars were chosen from more than 20 commercially available cultivars listed on the National Turfgrass Evaluation Program's website (NTEP, 2010). Nineteen cultivars were available to be procured through retail seed distributors.

Nitrogen in the form of urea (46-0-0) was applied at a rate of 24.4 kg ha^{-1} and lightly raked into the soil prior to seeding. Germination blankets were used to cover the plots to prevent cross contamination of the cultivars and enhance germination, and irrigation was applied as needed to maintain adequate moisture to allow the germination process to proceed uninhibited. At 10 d post seeding, all plots achieved a minimum germination of 10 %. At that time, covers were removed to control grassy weeds in the test areas in both years of the study. Monosodium acid methanearsonate (MSMA) was successfully applied at a rate of 3.18 L ha^{-1} on 14 and 29 July 2010 and 11, 15 July and 1 August 2011 to control crabgrass (*Digitaria spp.* L.) and goosegrass (*Eleusine indica* L.). Plots were maintained for the remainder of the growing season as athletic field turf using a reel type mower (model no. 2653A; Deere & Co., Moline, IL.) at 1.9 cm. with clippings returned 5 days wk^{-1} during active growth and 3 days wk^{-1} as growth slowed with cooling temperatures in autumn. Nitrogen in the form of urea (46-0-0) was applied twice monthly at a rate of 24.4 kg ha^{-1} through August and irrigation was applied as needed to prevent any visible drought stress.

Simulated traffic treatments began 8 September 2010 and 29 August 2011 coinciding with the local high school football season and ended 25 October 2010 and 30 September 2011. Traffic treatments were applied every Monday, Wednesday, and Friday regardless of the soil moisture status and weather conditions. Cockerham and Brinkman (1989) used an elaborate set of measurements from game play based on field use area, number of players, and number of cleats per shoe, etc. They calculated, quantified and linked the simulated wear rate of two passes with the BTS to the play wear rate received following one national football league game at the forty yard line. Two passes with the BTS in opposite directions were applied each treatment for a total of six passes per week to simulate a moderate to heavy level of traffic, or three events per week, indicative of many county high school athletic fields.

Visual estimation (0 to 100 scale, where 0=bare soil and 100=complete bermudagrass plot cover) of percent turfgrass cover (PTC) was recorded before the first treatment and continued one time weekly throughout the length of the study. For statistical analysis, data were analyzed using F-Protected Least Significant Difference (LSD) means separation ($p \leq 0.05$ at $\alpha = 0.05$), and PROC GLM of SAS© (SAS version 9.2; SAS Institute, Cary NC). PROC MIXED was used to determine the best fit equation in a backward stepwise procedure. The quadratic model was selected due to significance level and F value. Additionally, quadratic regression analysis describing the rate of decline (PTC) for each cultivar was calculated using PTC values over time using Sigma Plot 10.0 (Systat Software, San Jose, CA). Linear models generated in Sigma Plot 10.0 were used for slope comparisons and cultivar rankings for rate of decline were generated using Microsoft Excel 2007.

Results

There was a highly significant difference ($p=0.0025$) between years for final percent turfgrass cover (PTC) and rate of turfgrass cover decline ($p<0.0001$) over time. Therefore, results are presented separately for each year of the study. Environmental conditions with respect to precipitation were vastly different between 2010 and 2011. The BTS and humans will cause more severe damage to the turf as the level of moisture in the soil increases (Williams et al., 2010) and precipitation was much higher in 2011 especially in the month of September (Table 4.1). Williams et al. (2010) also noted the month of October as being critical with respect to traffic stress as bermudagrass growth begins to slow with cooler temperatures. Increased moisture in 2011 and the faster decline in PTC attributable to cooler temperatures was likely the cause of the significant difference between the study years.

2010

Significant differences ($p \leq .0.05$) were observed among cultivars for all but two dates (13 and 27 Sept.) in 2010 (Table 4.2). Without exception, Riviera maintained the highest PTC ratings followed closely but not significantly different from Princess 77 with a PTC rating at the final observation date of 91% and 85%, respectively. Likewise and without exception, Yukon and Casino Royale demonstrated the lowest traffic tolerance with a final PTC rating of 27% and 40%, respectively. Table 4.3 is a complete pairwise comparison of PTC on the last observation date among the nineteen cultivars tested, and indicates many significant differences. Correspondingly, the rate of decline was also highly significant ($p<0.0001$) (Table 4.4), especially among the strongest (Riviera) and weakest (Yukon) cultivars (Figure 4.1 Table 4.5). Figures 4.2 through 4.20

Table 4.1. Total precipitation, normal precipitation, and deviation from normal precipitation data collected at the University of Kentucky Agricultural Experiment Station in Lexington for the periods 1 July through 31 Oct. in 2010 and 2011.

Month	**Precipitation (mm)**	**Normal precipitation (mm)**	**Departure from normal precipitation (mm)**
------------------------------2010------------------------------			
July	123.35	122.08	+1.27
August	61.42	95.69	-34.27
September	32.49	78.93	-46.44
October	36.80	68.53	-31.73
------------------------------2011------------------------------			
July	86.80	122.08	-35.28
August	62.44	95.69	-33.25
September	150.00	78.93	+71.07
October	92.64	68.53	+24.11

Table 4.2. Analysis of variance for the main effect of cultivar in tolerance to simulated athletic traffic on seven observation dates in 2010.

	2010													
	13Sept.		20 Sept.		27 Sept.		4 Oct.		11 Oct.		18 Oct.		25 Oct.	
Sourc	F	Pr>F	F	Pr>F	F	Pr>F	F	Pr>F	F	Pr>F	F	Pr>F	F	Pr>F
Rep	0.90	0.4476	3.32	0.0265	0.92	0.4388	2.19	0.1002	0.98	0.4104	1.50	0.2259	0.93	0.4326
Cultivar	1.27	0.2472	3.33	0.0003	1.67	0.0753	1.88	0.0380	5.12	<.0001	4.57	<.0001	7.73	<.0001
CV(%)	6.18		5.61		7.41		9.11		11.81		15.05		18.58	

Table 4.3. P values from single degree of freedom f-tests of percent turf cover (PTC) ratings on the last observation date among 19 cultivars in 2010. CH (Arizona Common –hulled), CR (Casino Royale), CU (Arizona Common –unhulled), LaP (LaPaloma), MII (Mirage II), Mhk (Mohawk), NMS (New Mex Saharah), P77 (Princess 77), Riv (Riviera), Sav (Savannah), SB (Sun Bird), SDII (Sun Devil II), Sov (Sovereign), SoSt (Southern Star), SR 9554, SSp (Sun Sport), SSt (Sun Star), Trcl (Transcontenential), Yk (Yukon).

	CH	**CR**	**CU**	**LaP**	**MII**	**Mhk**	**NMS**	**P77**	**Riv**	**Sav**
CH	--	0.1796	0.8980	0.4281	0.1796	0.9337	0.4445	0.0002	<.0001	0.6459
CR	0.1796	--	0.2246	0.0331	0.0008	0.1542	0.5630	<.0001	<.0001	0.0719
CU	0.8980	0.2246	--	0.3573	0.0324	0.8327	0.5243	0.0001	<.0001	0.5569
LaP	0.4281	0.0331	0.3573	--	0.2214	0.4781	0.1198	0.0038	0.0004	0.7389
MII	0.1796	0.0008	0.0324	0.2214	--	0.0537	0.0056	0.0926	0.0182	0.1199
Mhk	0.9937	0.1542	0.8327	0.4781	0.0537	--	0.3966	0.0003	<.0001	0.7067
NMS	0.4445	0.5630	0.5243	0.1198	0.0056	0.3966	--	<.0001	<.0001	0.2212
P77	0.0002	<.0001	0.0001	0.0038	0.0926	0.0003	<.0001	--	0.4936	0.0013
Riv	<.0001	<.0001	<.0001	0.0004	0.0182	<.0001	<.0001	0.4936	--	<.0001
Sav	0.6459	0.0719	0.5569	0.7389	0.1199	0.7067	0.2212	0.0013	<.0001	--
SB	0.8528	0.2473	0.9542	0.3282	0.0281	0.7882	0.5624	0.0001	<.0001	0.5190
SDII	0.1790	0.0074	0.1411	0.5807	0.5021	0.2073	0.0353	0.0188	0.0025	0.3759
Sov	0.0220	0.0003	0.0157	0.1331	0.7796	0.0273	0.0023	0.1606	0.0371	0.0667
SoSt	0.9300	0.2907	0.9679	0.3787	0.0358	0.8642	0.4985	0.0002	<.0001	0.5842
SR 9554	0.6206	0.0665	0.5332	0.7660	0.1286	0.6804	0.2801	0.0014	0.0001	0.9716
SSp	0.3374	0.0217	0.2769	0.8673	0.2909	0.3808	0.0851	0.0063	0.0007	0.6188
SSt	0.0217	0.0003	0.0154	0.1315	0.7747	0.0269	0.0023	0.1625	0.0377	0.0658
Trcl	0.2862	0.0163	0.2324	0.7838	0.3426	0.3254	0.0675	0.0087	0.0010	0.5435
Yk	0.2756	0.8007	0.3359	0.0601	0.0020	0.2407	0.7444	<.0001	<.0001	0.1215

Table 4.3 (cont.). P values from single degree of freedom f-tests of percent turf cover (PTC) ratings on the last observation date among 19 cultivars in 2010. CH (Arizona Common –hulled), CR (Casino Royale), CU (Arizona Common –unhulled), LaP (LaPaloma), MII (Mirage II), Mhk (Mohawk), NMS (New Mex Saharah), P77 (Princess 77), Riv (Riviera), Sav (Savannah), SB (Sun Bird), SDII (Sun Devil II), Sov (Sovereign), SoSt (Southern Star), SR 9554, SSp (Sun Sport), SSt (Sun Star), Trcl (Transcontenential), Yk (Yukon).

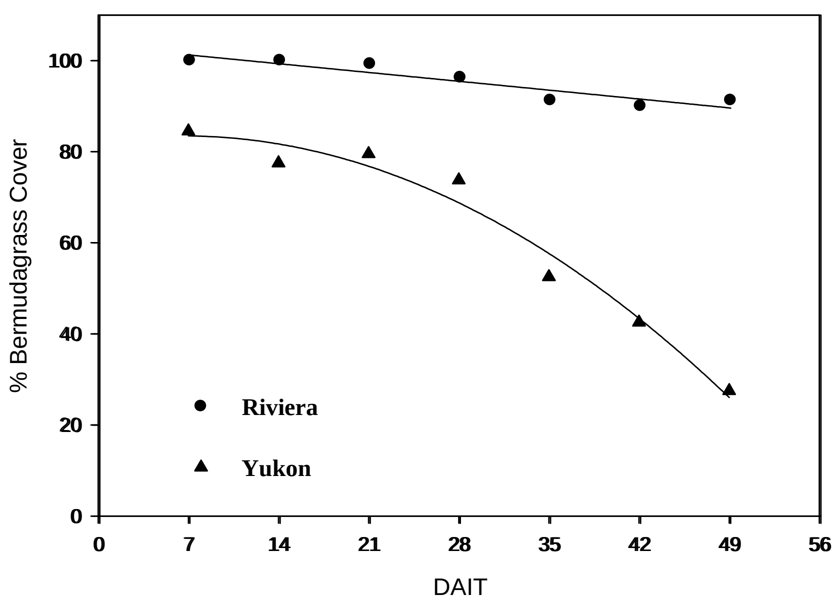
	SB	**SDII**	**Sov**	**SoSt**	**SR 9554**	**SSp**	**SSt**	**Trcl**	**Yk**
CH	0.8528	0.1790	0.0220	0.9300	0.6206	0.3374	0.0217	0.2862	0.2756
CR	0.2473	0.0074	0.0003	0.2097	0.0665	0.0217	0.0003	0.0163	0.8007
CU	0.9542	0.1411	0.0157	0.9679	0.5332	0.2769	0.0154	0.2324	0.3359
LaP	0.3282	0.5807	0.1331	0.3787	0.7660	0.8673	0.1315	0.7838	0.0601
MII	0.0281	0.5021	0.7796	0.0358	0.1286	0.2909	0.7747	0.3426	0.0020
Mhk	0.7882	0.2073	0.0273	0.8642	0.6804	0.3808	0.0269	0.3254	0.2407
NMS	0.5624	0.0353	0.0023	0.4985	0.2081	0.0851	0.0023	0.0675	0.7444
P77	0.0001	0.0188	0.1606	0.0002	0.0014	0.0063	0.1625	0.0087	<.0001
Riv	<.0001	0.0025	0.0371	<.0001	0.0001	0.0007	0.0377	0.0010	<.0001
Sav	0.5190	0.3759	0.0667	0.5842	0.9716	0.6188	0.0658	0.5435	0.1215
SB	--	0.1263	0.0134	0.9222	0.4962	0.2524	0.0131	0.2107	0.3654
SDII	0.1263	--	0.3417	0.1523	0.3954	0.7000	0.3385	0.7809	0.0152
Sov	0.0134	0.3417	--	0.0175	0.0722	0.1818	0.9949	0.2193	0.0008
SoSt	0.9222	0.1523	0.0175	--	0.5600	0.2950	0.0172	0.2485	0.3161
SR 9554	0.4962	0.3954	0.0722	0.5600	--	0.6421	0.0712	0.5674	0.1132
SSp	0.2524	0.7000	0.1818	0.2950	0.6421	--	0.1797	0.9146	0.0408
SSt	0.0131	0.3385	0.9949	0.0172	0.0712	0.1797	--	0.2169	0.0007
Trcl	0.2107	0.7809	0.2193	0.2485	0.5674	0.9146	0.2169	--	0.0314
Yk	0.3654	0.0152	0.0008	0.3161	0.1132	0.0408	0.0007	0.0314	--

Table 4.4. 2010 Analysis of variance for main effect of cultivar for decline over time in turf cover.

Source of variation	F	Pr>f
Rep	0.18	0.2768
Cultivar	4.91	<0.0001
CV(%)		-28.21

Figures 4.1 through 4.20. 2010 Regression graphs illustrating rates of decline resulting from simulated athletic traffic for 19 seeded bermudagrass cultivars. Treatments were applied 3 times per week beginning 8 Sept. 2010. Percent turf cover (PTC) ratings were recorded weekly for seven weeks beginning one week after the initiation of traffic treatments. PTC was rated on a 1 – 100 scale with 1 = bare soil and 100 = complete bermudagrass cover and is plotted against days after initial treatment (DAIT). Figure 46 compares the slowest rate of decline (Riviera) with the most rapid rate of decline (Yukon). Figures 45-65 illustrate each of the individual 19 cultivars tested.

Figure 4.1.



Riviera

rsqr = 0.5303
f(x) = 103.1429 - 0.2734x - 6.0739E-005

Yukon

rsqr = 0.6023
$f(x) = 82.1071 + 0.4150x - 0.0318x^2$

Table 4.5. Cultivar ranking for percent turfgrass cover decline due to repeated simulated traffic treatments with the Brinkman traffic simulator in 2010.

2010	
Cultivar	**Slope**
Riviera	-0.2768 a
Princess 77	-0.4196 a,b
Southern Star	-0.6939 b,c
Sun Sport	-0.6964 b,c
Mirage II	-0.7398 b,c,d
SR 9554	-0.9120 c,d,e
Sovereign	-0.9401 c,d,e,f
LaPaloma	-09554 c,d,e,f
Transcontinental	-0.9605 c,d,e,f
Sun Bird	-1.0434 c,d,e,f
Savannah	-1.0753 c,d,e,f,g
Arizona Common – hulled	-1.1186 d,e,f,g
Mohawk	-1.1314 d,e,f,g
Arizona Common – unhulled	-1.1760 e,f,g
Sun Devil II	-1.1760 e,f,g
Sun Star	-1.2003 g,f
New Mex Sahara	-1.3227 g,f
Casino Royale	-1.4286 f
Yukon	-1.4291f

Figure 4.2

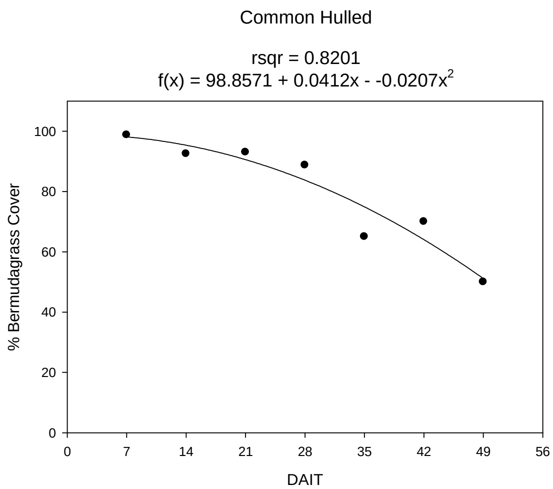


Figure 4.3

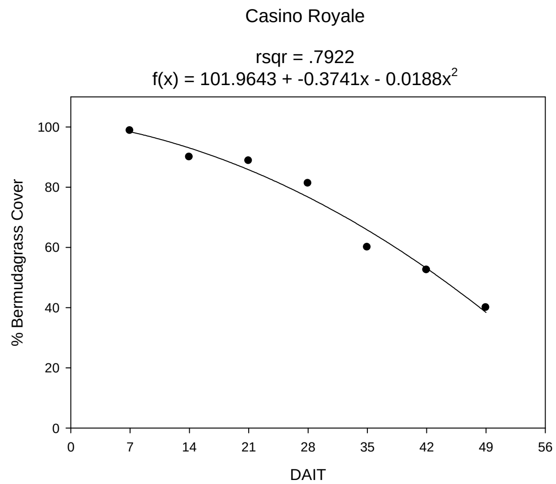


Figure 4.4

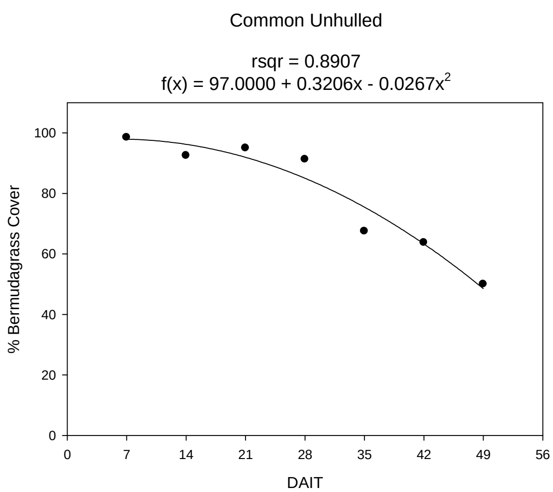


Figure 4.5

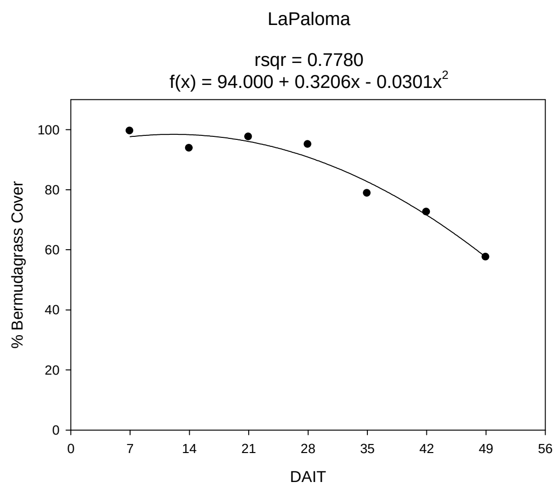


Figure 4.6

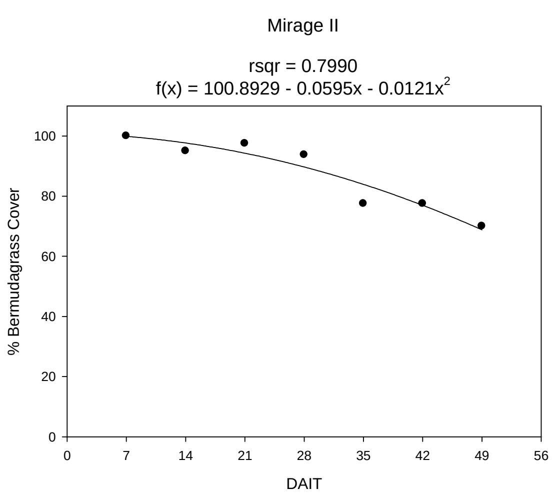


Figure 4.7

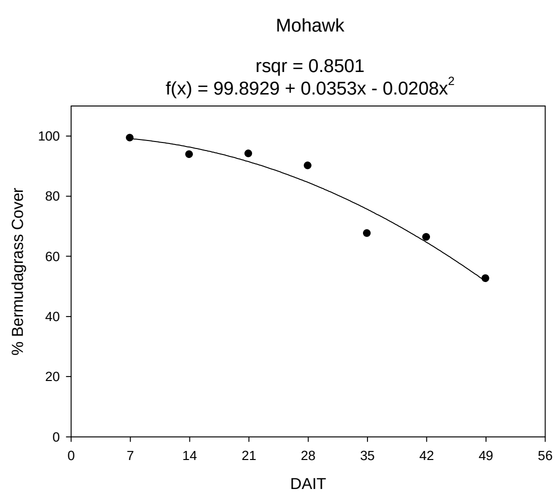


Figure 4.8

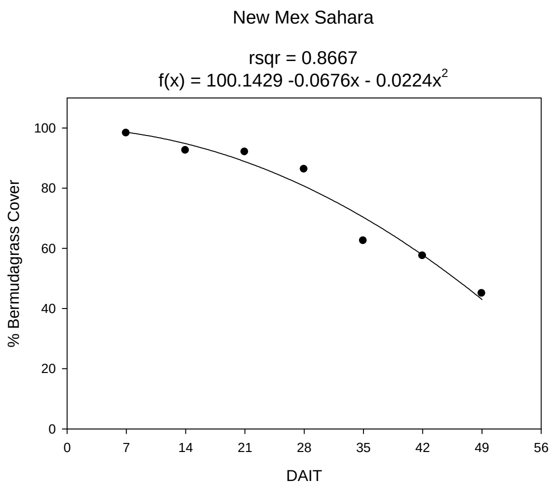


Figure 4.9

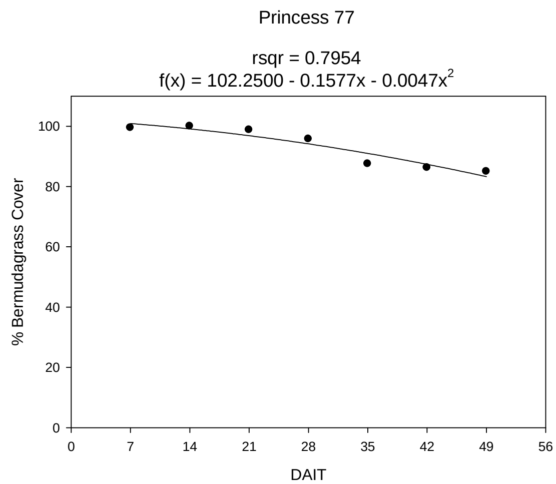


Figure 4.10

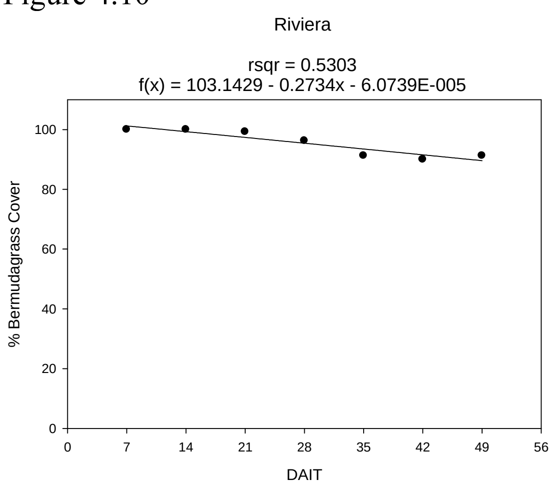


Figure 4.11

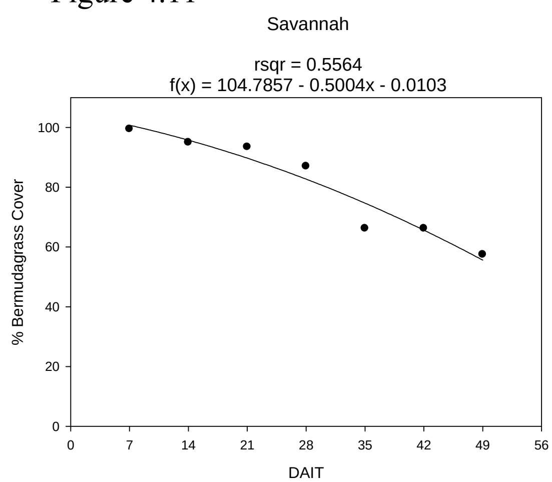


Figure 4.12

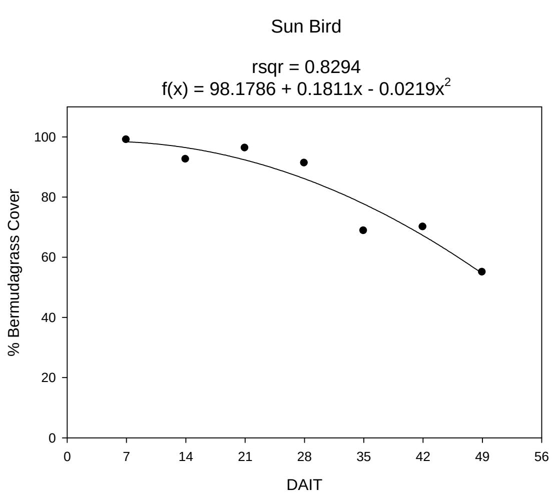


Figure 4.13

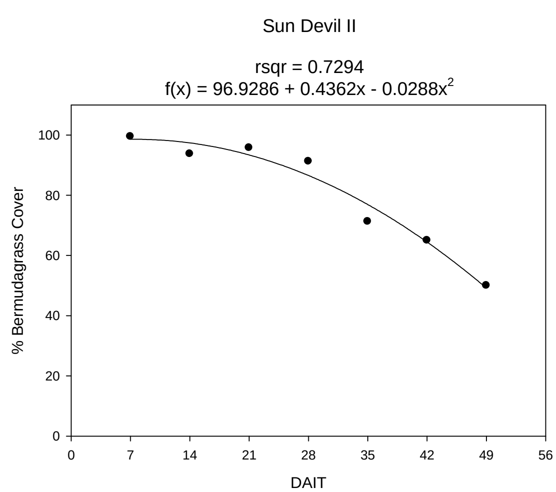


Figure 4.14

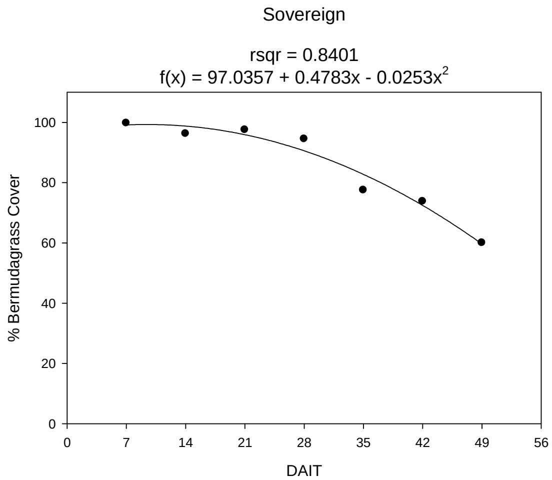


Figure 4.15

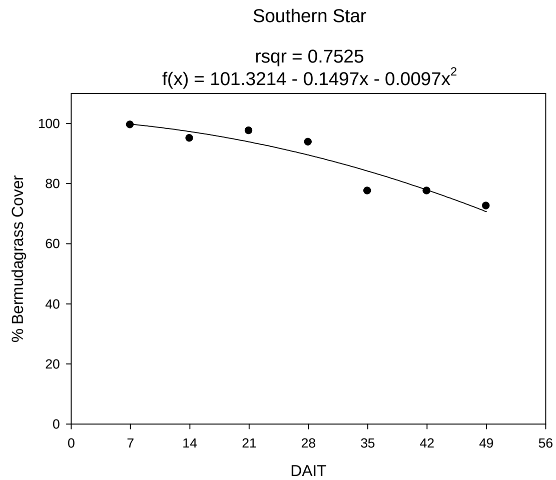


Figure 4.16

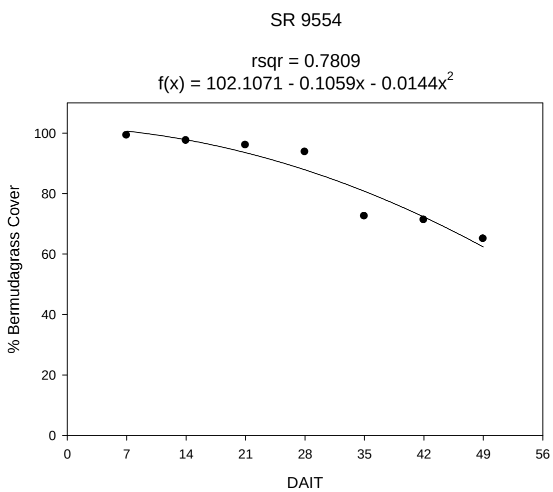


Figure 4.17

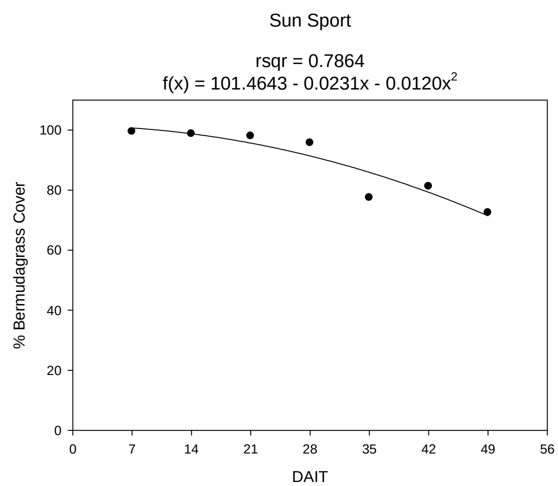


Figure 4.18

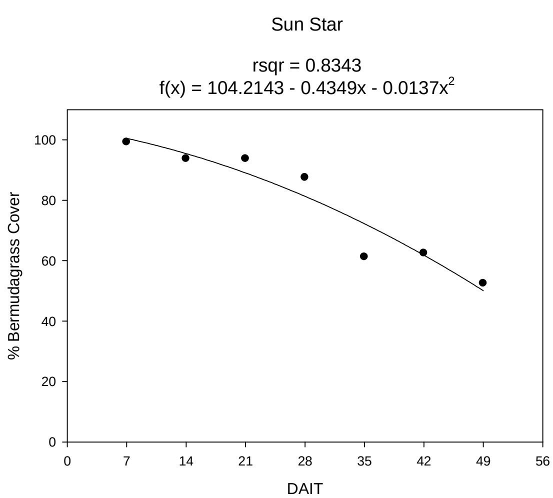


Figure 4.19

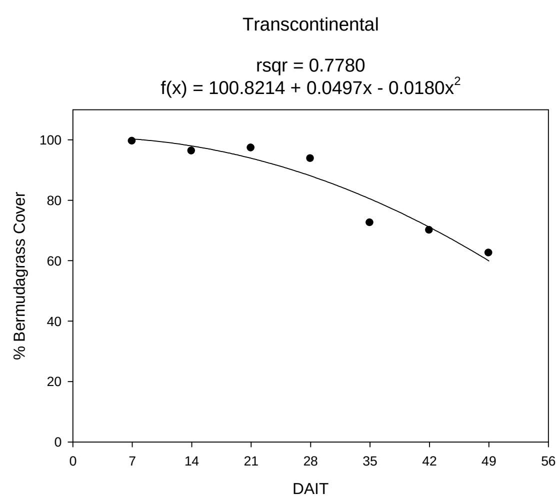
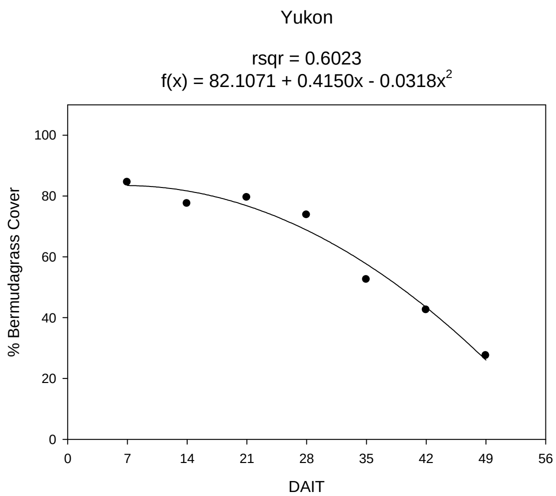


Figure 4.20


Yukon
rsqr = 0.6023
f(x) = 82.1071 + 0.4150x - 0.0318x2
% Bermudagrass Cover
DAIT
0
20
40
60
80
100
0
7
14
21
28
35
42
49
56

illustrate the rates of decline over time for each cultivar when exposed to a high level of simulated traffic.

2011

Highly significant differences (p≤.0001) were observed for all dates among cultivars for 2011 (Table 4.4). Without exception Riviera maintained the highest PTC rating with final a final rating of 73%. Similar to the results in 2010, Casino Royale ranked as one of the least tolerant to simulated traffic. Sun Star had the lowest final PTC rating of 14%. Table 4.6 presents a complete pairwise comparison of the nineteen cultivars tested and Table 4.7 indicates significant differences among cultivars with respect to rate of turfgrass cover decline over time due to traffic treatments. Regression lines for loss of cover over time shown in Figure 4.21 illustrates the difference in rate of decline among two standard cultivars tested Riviera and Yukon. Figures 4.21 through 4.40 illustrate individual cultivar traffic tolerance over time at a medium to high level of simulated traffic.

Discussion

We conclude that the commercially available seeded bermudagrass cultivars have significantly different tolerances to simulated athletic field traffic. Significant differences (p≤0.05) were observed for all except two observation dates throughout the two year study. These results agree well with previous studies completed by Bayrer (2006) and Williams et al., (2010), both of which tested bermudagrasses in autumn following establishment in summer of the same year.

While a traffic tolerance study of this magnitude has not been undertaken previously, many studies (Thoms et al., 2011; Trappe et al., 2011; Williams et al., 2010, Deaton and Williams, 2010;) that made comparisons among cultivars have been

Table 4.6. Analysis of variance for the main effect of cultivar in tolerance to simulated athletic traffic on seven observation dates in 2011.

	2011													
	19 Aug.		26 Aug.		2 Sept.		9 Sept.		16 Sept.		23 Sept.		30 Sept.	
Source	F	Pr>F	F	Pr>F	F	Pr>F	F	Pr>F	F	Pr>F	F	Pr>F	F	Pr>F
Rep	1.79	0.1604	0.60	0.6188	1.01	0.3970	1.38	0.2601	1.39	0.2602	1.27	0.2952	1.40	0.2525
Cultivar	42.99	<.0001	40.97	<.0001	24.79	<.0001	6.07	<.0001	6.08	<.0001	5.35	<.0001	5.18	<.0001
CV(%)	5.06		5.58		6.41		9.11		9.12		28.89		49.1	

Table 4.7. P values from single degree of freedom F-tests of percent turf cover (PTC) ratings on the last observation date among 19 cultivars in 2011. CH (Arizona Common –hulled), CR (Casino Royale), CU (Arizona Common –unhulled), LaP (LaPaloma), MII (Mirage II), Mhk (Mohawk), NMS (New Mex Saharah), P77 (Princess 77), Riv (Riviera), Sav (Savannah), SB (Sun Bird), SDII (Sun Devil II), Sov (Sovereign), SoSt (Southern Star), SR 9554, SSp (Sun Sport), SSt (Sun Star), Trcl (Transcontenential), Yk (Yukon).

2011	CH	CR	CU	LaP	MII	Mhk	NMS	P77	Riv	Sav
CH	--	0.4275	0.8366	0.9154	0.5094	0.4183	0.4955	0.0288	<.0001	0.1109
CR	0.4725	--	0.5569	0.3684	0.1465	0.9873	0.9109	0.0022	<.0001	0.0172
CU	0.8366	0.5569	--	0.7547	0.3866	0.5463	0.6344	0.0131	<.0001	0.0719
LaP	0.9154	0.3684	0.7547	--	0.5798	0.3600	0.4309	0.0299	<.0001	0.1366
MII	0.5094	0.1465	0.3866	0.5798	--	0.1421	0.1801	0.1049	0.0002	0.3492
Mhk	0.4183	0.9873	0.5463	0.3600	0.1421	--	0.8983	0.0021	<.0001	0.0165
NMS	0.4955	0.9109	0.6344	0.4309	0.1801	0.8983	--	0.0032	<.0001	0.0231
P77	0.0288	0.0022	0.0131	0.0299	0.1049	0.0021	0.0032	--	0.0313	0.4920
Riv	<.0001	<.0001	<.0001	<.0001	0.0002	<.0001	<.0001	0.0313	--	0.0046
Sav	0.1109	0.0172	0.0719	0.1366	0.3492	0.0165	0.0231	0.4920	0.0046	--
SB	0.1481	0.0254	0.0986	0.1801	0.4307	0.0244	0.0336	0.4035	0.0029	0.8821
SDII	0.7598	0.6256	0.9208	0.6804	0.3344	0.6144	0.7069	0.0099	<.0001	0.0577
Sov	0.0884	0.0127	0.0562	0.1100	0.2954	0.0122	0.0173	0.5641	0.0064	0.9212
SoSt	0.3331	0.8614	0.4461	0.2829	0.1040	08739	0.7745	0.0012	<.0001	0.0106
SR 9554	0.8799	0.5205	0.9560	0.7970	0.4175	0.5102	0.5956	0.0152	<.0001	0.0811
SSp	0.7917	0.5964	0.9539	0.7112	0.3557	0.5854	0.6762	0.0111	<.0001	0.0633
SSt	0.1631	0.0290	0.1096	0.1975	0.4617	0.0278	0.0382	0.3749	0.0024	0.8412
Trcl	0.7698	0.6164	0.9311	0.6900	0.3410	0.6052	0.6972	0.0103	<.0001	0.0594
Yk	<.0001	,.0001	<.0001	<.0001	0.0005	<.0001	<.0001	<.0001	<.0001	0.0107

Table 4.7 (cont.). P values from single degree of freedom F-tests of percent turf cover (PTC) ratings on the last observation date among 19 cultivars in 2011. CH (Arizona Common –hulled), CR (Casino Royale), CU (Arizona Common –unhulled), LaP (LaPaloma), MII (Mirage II), Mhk (Mohawk), NMS (New Mex Saharah), P77 (Princess 77), Riv (Riviera), Sav (Savannah), SB (Sun Bird), SDII (Sun Devil II), Sov (Sovereign), SoSt (Southern Star), SR 9554, SSp (Sun Sport), SSt (Sun Star), Trcl (Transcontenential), Yk (Yukon).

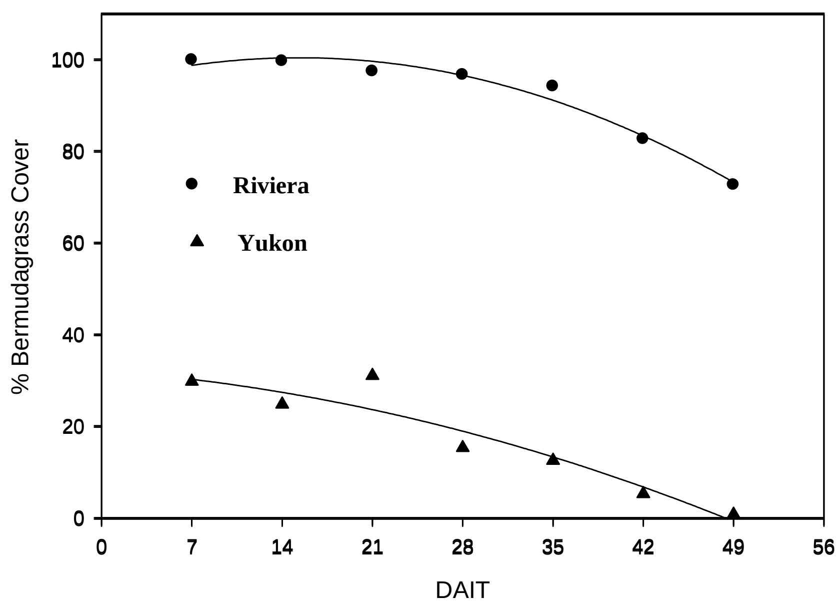
2011	**SB**	**SDII**	**Sov**	**SoSt**	**SR 9554**	**SSp**	**SSt**	**Trcl**	**Yk**
CH	0.1481	0.7598	0.0884	0.3331	0.8799	0.7917	0.1631	0.7698	<.0001
CR	0.0254	0.6256	0.0127	0.8614	0.5205	0.5964	0.0290	0.6164	<.0001
CU	0.0986	0.9208	0.0562	0.4461	0.9560	0.9539	0.1096	0.9311	<.0001
LaP	0.1801	0.6804	0.1100	0.2829	0.7970	0.7112	0.1975	0.6900	<.0001
MII	0.4307	0.3344	0.2954	0.1040	0.4175	0.3557	0.4617	0.3410	0.0005
Mhk	0.0244	0.6144	0.0122	0.8739	0.5102	0.5854	0.0278	0.6052	<.0001
NMS	0.0336	0.7069	0.0173	0.7745	0.5956	0.6762	0.0382	0.6972	<.0001
P77	0.4035	0.0099	0.5641	0.0012	0.0152	0.0111	0.3749	0.0103	<.0001
Riv	0.0029	<.0001	0.0064	<.0001	<.0001	<.0001	0.0024	<.0001	<.0001
Sav	0.8821	0.0577	0.9121	0.0106	0.0811	0.0633	0.8412	0.0594	0.0107
SB	--	0.0800	0.7958	0.0160	0.1103	0.0874	0.9586	0.0822	0.0070
SDII	0.0800	--	0.0446	0.5077	0.8771	0.9668	0.0893	0.9896	<.0001
Sov	0.7958	0.0446	--	0.0077	0.0637	0.0492	0.7560	0.0460	0.0146
SoSt	0.0160	0.5077	0.0077	--	0.4139	0.4814	0.0184	0.4993	<.0001
SR 9554	0.1103	0.8771	0.0637	0.4139	--	0.9100	0.1223	0.8874	<.0001
SSp	0.0874	0.9668	0.0492	0.4814	0.9100	--	0.0974	0.9771	<.0001
SSt	0.9586	0.0893	0.7560	0.0184	0.1223	0.0974	--	0.0918	0.0060
Trcl	0.0822	0.9896	0.0460	0.4993	0.8874	0.9771	0.0918	--	<.0001
Yk	0.0070	<.0001	0.0146	<.0001	<.0001	<.0001	0.0060	<.0001	--

Table 4.8. 2011 Analysis of variance for main effect of cultivar for decline over time in turf cover.

Source of variation	F	Pr>f
Rep	1.31	0.2804
Cultivar	4.67	<0.0001
CV(%)		-22.38

Figures 4.21 through 4.40. 2011 Regression graphs illustrating rates of decline resulting from simulated athletic traffic for 19 seeded bermudagrass cultivars. Treatments were applied 3 times per week beginning 28 Aug 2011. Percent turf cover (PTC) ratings were recorded weekly for seven weeks beginning one week after the start of traffic treatments. PTC was rated on a 1 – 100 scale with 1 = bare soil and 100 = complete bermudagrass cover and is plotted against days after initial treatment (DAIT). Figure 66 compares the slowest rate of decline (Riviera) with the most rapid rates of decline (Yukon). Figures 67-85 illustrate each of the individual 19 cultivars tested.

Figure 4.21



Riviera

rsqr = 06139

$f(x) = 94.6429 + 0.7330x - 0.0239x^2$

Yukon

rsqr = 0.4090

$f(x) = 32.3571 - 0.2066x - 0.0095x^2$

Table 4.9. 2011 Cultivar ranking for percent turfgrass cover decline due to repeated simulated traffic treatments with the Brinkman traffic simulator.

2011	
Cultivar	**Slope**
Riviera	-0.6071 a
Princess 77	-0.9464 a,b
Sun Sport	-1.2704 b,c
Sun Bird	-1.3520 b,c,d
Sun Devil II	-1.3571 b,c,d
Southern Star	-1.3839 b,c,d
Mirage II	-1.5332 c,d,e
Sovereign	-1.7283 c,d,e,
LaPaloma	-1.7334 c,d,e
Arizona Common – hulled	-1.7538 c,d,e
Transcontinental	-1.7959 d,e
Savannah	-1.8074 d,e
Arizona Common – unhulled	-1.8482 d,e
SR 9554	-1.8520 d,e
New Mex Sahara	-1.9209 e
Mohawk	-2.0038 e
Casino Royale	-2.0153 e
Sun Star	-2.0166 e
Yukon*	

*Yukon omitted from this rating due to unsatisfactory establishment prior to start of simulated traffic treatments.

Figure 4.22

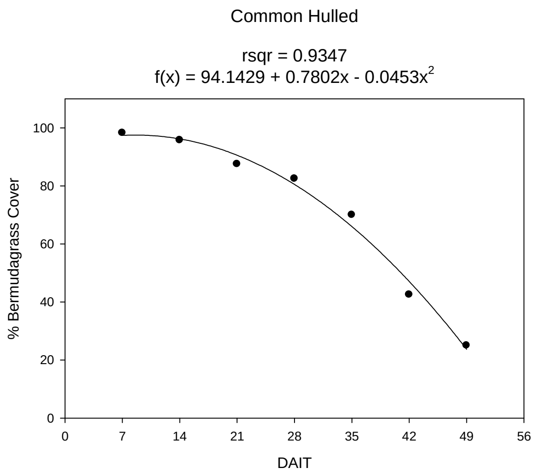


Figure 4.23

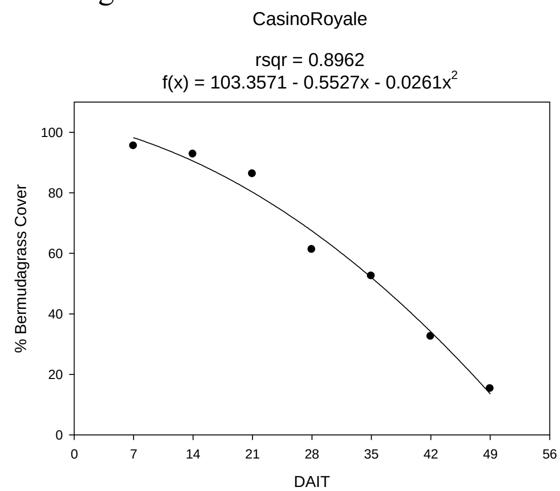


Figure 4.24

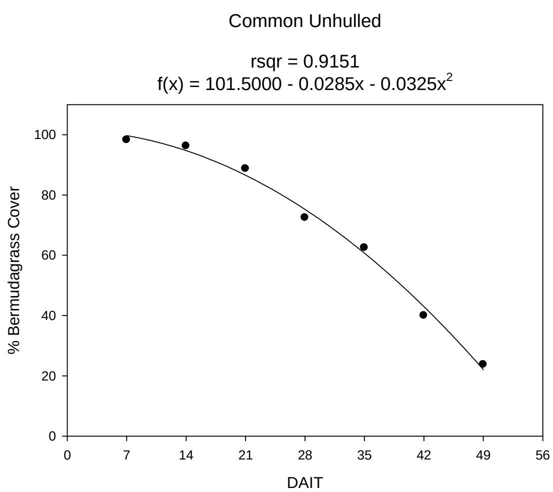


Figure 4.25

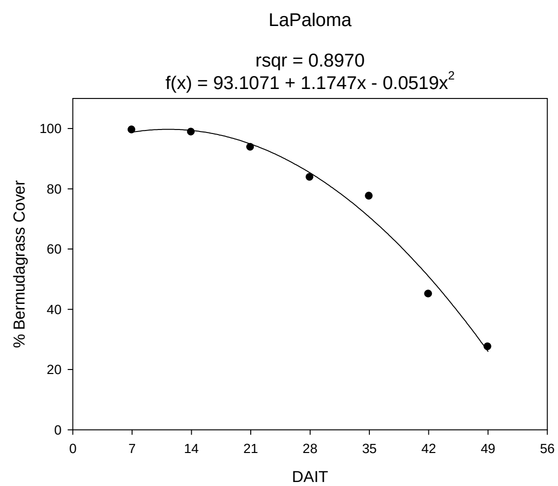


Figure 4.26

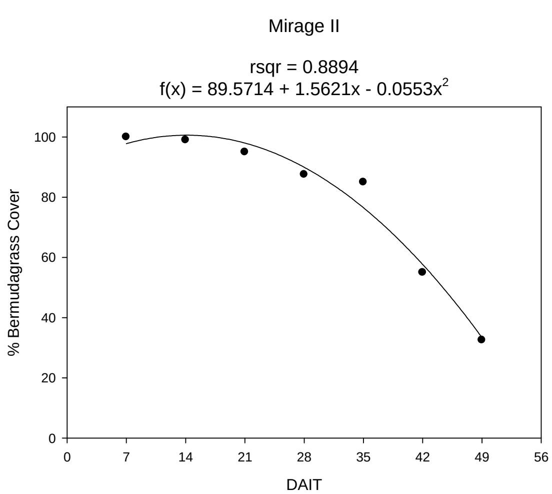


Figure 4.27

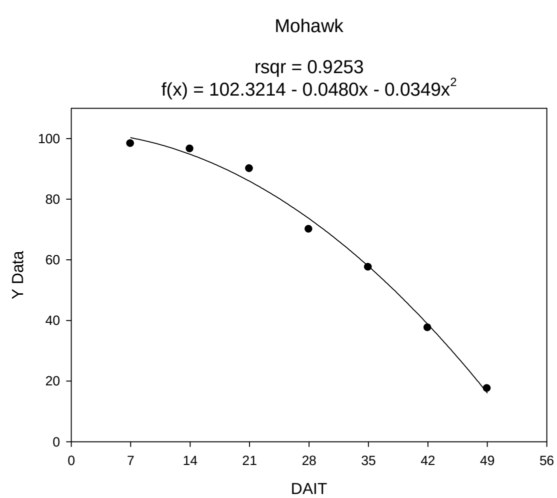


Figure 4.28

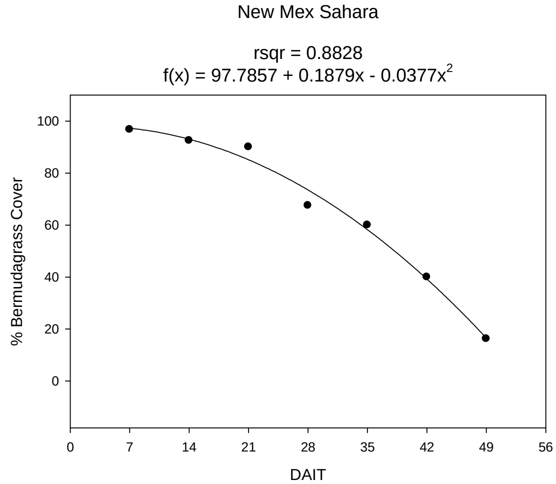


Figure 4.29

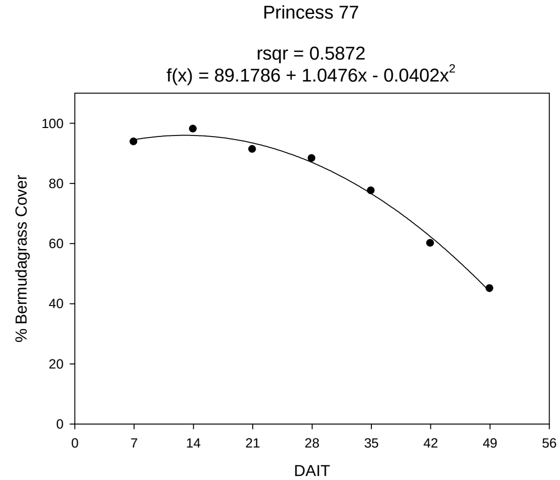


Figure 4.30

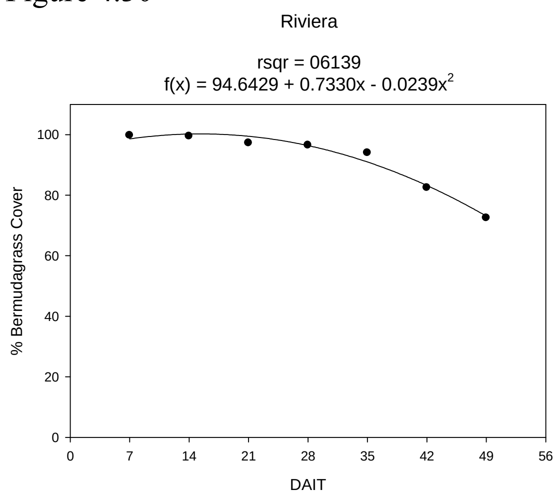


Figure 4.31

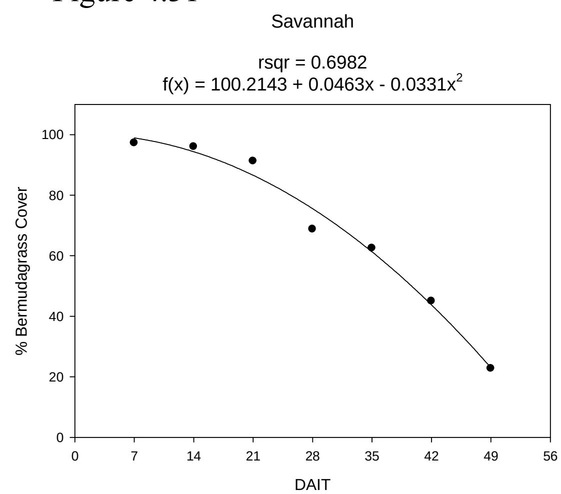


Figure 4.32

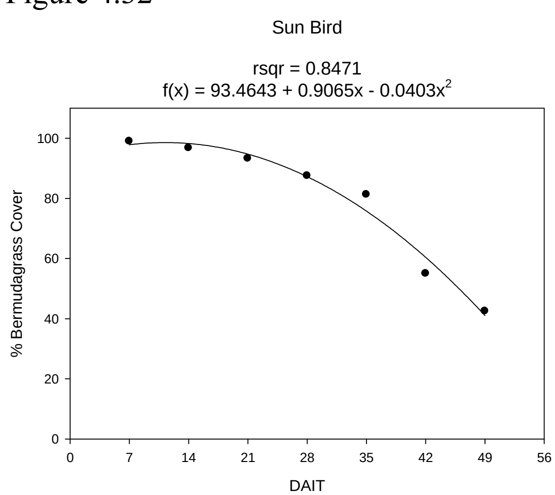


Figure 4.33

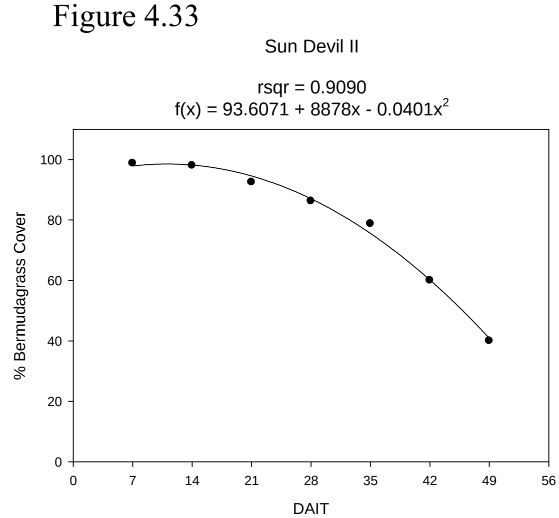


Figure 4.34

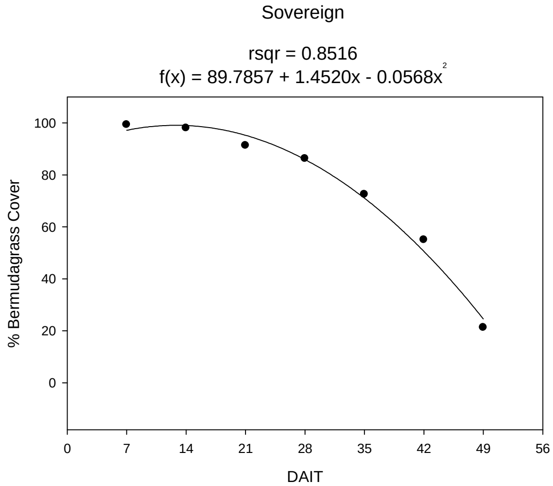


Figure 4.35

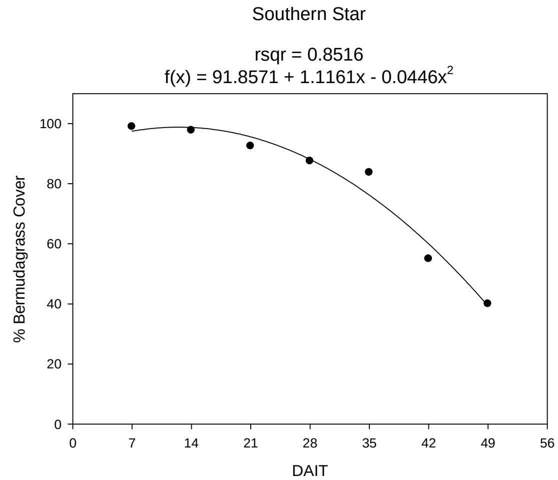


Figure 4.36

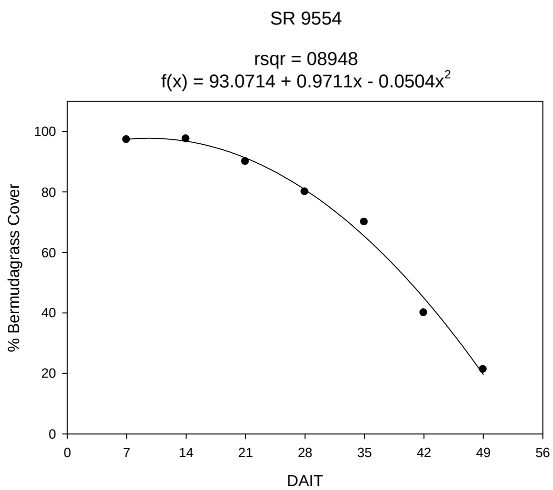


Figure 4.37

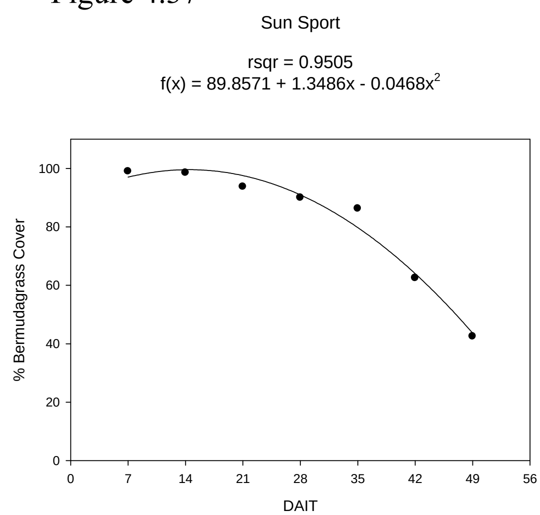


Figure 4.38

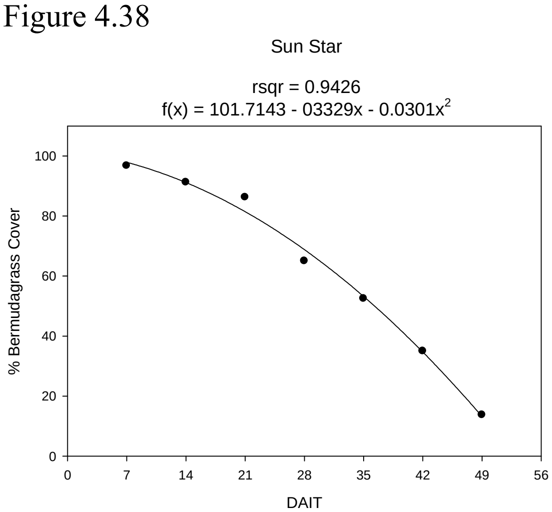


Figure 4.39

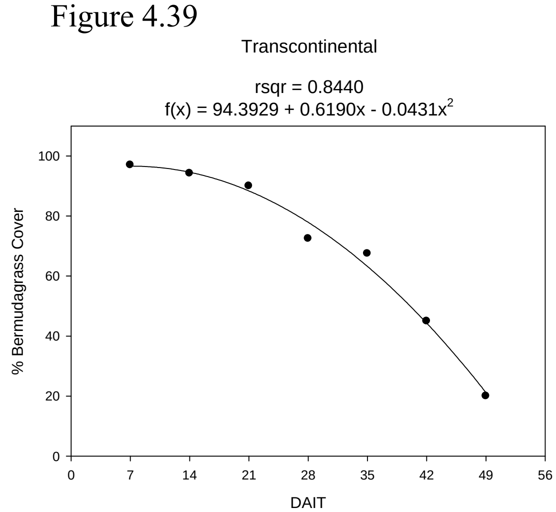
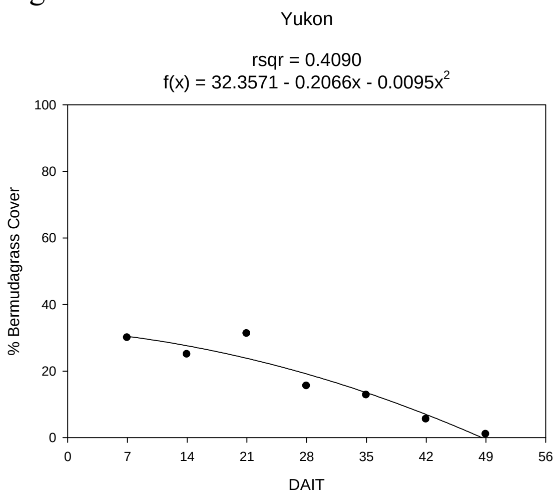


Figure 4.40



completed. In most of the studies that included seeded bermudagrass cultivars, Riviera, was evaluated. This study agrees with previous work that has shown Riviera to have equal or superior traffic tolerance among the cultivars tested including hybrid cultivars.

For both years of this study Riviera maintained higher PTC than all other cultivars. In both years of the study, Yukon had the lowest PTC ratings along with Casino Royale and Sun Star.

In 2011, Yukon received very low ratings due to poor establishment and subsequent difficulty in obtaining complete plot cover in two of four replications. Excessive moisture due to periodic heavy rain events also contributed to the quick disappearance of the poorly established Yukon. In contrast, Riviera, under the exact same environmental conditions, performed exceptionally well overall with only slightly lower final PTC ratings between study years; 91% and 73% for 2010 and 2011, respectively.

Large and highly significant differences (P<0.001) differences exist among seeded bermudagrass cultivars in their tolerance to simulated athletic traffic. Anatomical and morphological differences among cultivars contribute to traffic tolerance (Brosnan et al., 2005). Williams et al., (2010) reported that the cultivars with higher tiller densities and fine leaf texture tolerated stresses imposed by traffic better than those with more open growth characteristics and coarse leaf texture. This study agrees well with these findings with Riviera and Princess 77 having a tight, more closed growth habit and fine leaf texture compared to cultivars such as Yukon and Casino Royale which exhibit more open growth and a coarser leaf texture.

Turfgrass mangers should consider traffic tolerance among other characteristics when choosing cultivars for high traffic situations. Future research should continue to evaluate newly released cultivars for tolerance to athletic field traffic stresses.

Copyright © Michael Todd Deaton 2012

Chapter V

Conclusions

Seeding bermudagrass (*Cynodon dactylon* (L). Pers.) is a form of propagation for the species that has been used for applications from agriculture to home lawns since the 1940's. At that time there was very little genetic diversity among commercially available cultivars. Around the 1960s Arizona "Common" bermudagrass was beginning to be used more heavily for home lawn situations and seed production. Prior to this time bermudagrass was propagated vegetatively either by sprigging or sodding. Seeded cultivars provided a much more cost effective alternative compared to any form of vegetative establishment.

Common, non-hybrid bermudagrass has limitations, especially in fine turf applications such as golf and sports turf. It lacks many of the desirable quality characteristics that are available with many of the developed interspecific hybrid varieties such as the cultivars that have been developed in Tifton, Georgia. Course leaf texture, light green color, and poor winter hardiness are some of the limitations that made common bermudagrass less desirable compared cool season grasses in the transitional climatic zone.

It was not until the later years of the twentieth century with the release of seeded cultivars such as Mirage that the seeded cultivars began to achieve the quality nearer that of the interspecific hybrid cultivars. The release of these new seeded cultivars sparked the interest of breeders and prompted resurgence in breeding efforts for seeded cultivars. It was not until the late 1990's with the release of Riviera bermudagrass that seeded cultivars reached the quality of hybrid cultivars. Riviera had been shown to equal or surpass the hybrid cultivars in quality. It also possesses excellent winter hardiness and disease resistance which make it a very popular choice for fine turf applications in the transition zone. These two characteristics along with superior quality were even more important in the upper transition zone where the growing season for bermudagrass is the shortest and the climate is the coldest.

Riviera has all of the desirable qualities for fine turf but is not without its own limitations. Turfgrass managers, especially in the upper transition zone, were finding that it was extremely difficult to germinate and therefore establish successfully. To date, very little effort has been given to addressing the root causes of this problem which are largely unknown. Managers who seeded Riviera would depend on normal recommended seeding dates and in many cases experience establishment failures. This is a costly mistake and results in additional expenses, time, and in many cases settling for an alternative cultivar with lower quality and traffic tolerance.

This study focused on investigating the cause or causes of poor Riviera germination. A specific physiological cause was not delineated. However, this study revealed some unusual and interesting characteristics that quantified the poor germination characteristics of Riviera. The conclusion that Riviera may be difficult to establish is no longer based on anecdotal evidence.

Many of the commercially available cultivars available today provide quick germination. This study quantified field germination characteristics for nineteen commercially available cultivars and found that the large majority of the cultivars completed the germination process within a five to seven day range. As with most living organisms, a normal distribution is observed across cultivars with a few having quicker and a few having slower germination than the majority. Field studies also quantified that even with Riviera being the slowest to complete the germination process; it possesses enough seedling vigor to be one of the quickest to complete 100% plot cover or stand establishment. From a turfgrass manager's perspective, if they can achieve good germination, quick stand establishment will follow. However, this study proves that adequate and rapid germination is not always a simple matter of planting by calendar dates.

In fine turf applications light and water are not usually a limiting factor for the germination process. Most golf courses and sports turf venues have automatic irrigation to provide ample moisture for the germination process and grow-in period. This leaves temperature to be the likely culprit for the germination problems associated with Riviera. This study evaluated the effects of temperature on Riviera germination and concluded for the upper transition zone it was indeed the limiting factor. This geographical region can and does achieve adequate temperatures to germinate bermudagrass. Most of the available cultivars will germinate well in normal early June temperatures. Riviera and Princess 77 are two of the exceptions, and Riviera has been shown to require much warmer temperatures to achieve good (80% or higher) germination. In a research setting where field plots are small enough to be covered with germination blankets, good germination of Riviera can be observed at early June temperatures also. This is not an economically feasible option for most field managers with multiple acres that would require covering to enhance germination. Riviera seed was shown by this study to produce optimal germination at a temperature range of 35^{o} C day and 20^{o} C night temperatures. Slight deviations from these temperatures were shown to dramatically reduce the percentage of germination. These temperatures are approximately ten to fifteen degrees above normal day time high temperatures experienced in Lexington, Kentucky and for many other areas in the upper transition zone at recommended seeding dates.

The physiological reasons that induce these strict temperature requirements for Riviera are unknown. Many other species also have temperature requirements similar to Riviera and the causes are also unknown.

In work with other species, ABA inhibitors have been shown to increase the overall velocity and total percentage of seeds germinated. The exact causes of these increases are not well known.. Theories include unknown mechanisms that decrease the fluctuating temperature requirement to reducing de novo ABA production in the seed coat. This study found both faster germination rates and higher germination percentages when an ABA inhibitor was used as a seed treatment. Fluridone, the ABA inhibitor used in this study, enhanced the germination process both at fluctuating temperatures and at constant temperatures for Riviera bermudagrass.

Cultivars within a species are generally thought to have similar germination characteristics which allow the species to be modeled either by degree days, hydrothermal, or thermal methods. These models allow characterization of the germination characteristics as a species. The bermudagrass cultivars tested, Riviera and Casino Royale, could not be fit to the model due to inadequate or irregular germination under standard modeling protocols.

Riviera is a cultivar that was shown under constant temperatures to achieve very poor germination percentages which prohibited normal thermal modeling. As shown, the strict fluctuating temperature requirement of Riviera prevented the modeling process under constant temperatures. This study also has shown that Riviera can achieve significantly greater percentages of germination under constant temperatures when fluridone is used as treatment in the imbibition solution. This is evidence that fluridone has an effect on the requirement for fluctuating temperatures as shown in previous work in other species. Germination at fluctuating temperatures was also shown to significantly increase velocity and percent germination of Riviera. Fluridone in the imbibition solution at optimal germination temperatures would indicate the possibility of an effect on de novo ABA production in the seed allowing the germination process to progress much quicker.

Riviera has been shown by this study to be unique in many aspects of germination within the species. The difficulties in completion of the germination process have been shown to be heavily related to temperature and with probably some connection to ABA. Although this study was unable to pinpoint the exact cause behind the temperature requirements of Riviera, it raises many questions for further research.

Modifications to recommended seeding dates have to be made when considering the establishment of Riviera. Cooler temperatures at normal recommended seeding dates will greatly reduce the velocity and percentage of germinating seed and will allow grassy weed competition to further decrease the chances of successful establishment. As shown by this study, seed grown under temperatures expected in July and early August produced significantly higher germination velocities and percentages. For most turf applications in the upper transition zone the later dates create a possibility of a time disparagement. As shown by this study, most of the cultivars tested reached complete cover well in advance of the start of the high school football season. Special note should be taken in the performance of Riviera. With visible germination taking up to ten days in Lexington with a planting date of approximately July 1, Riviera was either the quickest or statistically equivalent to the quickest cultivar to complete cover. It was also equivalent to or superior in traffic tolerance as a newly established stand maintaining greater than 70% cover with moderate to heavy simulated traffic applied in normal and wetter than normal moisture conditions.

Rivera's popularity stems from it superior quality and traffic tolerance. Many more professional turf managers would prefer to establish it for playing surfaces if the probability of successful establishment was greater. This study poses many new questions as to the causes and potential solutions to the poor germination characteristics of Riviera. Future research should concentrate heavily on a short term solution as well as having some long term goals. Fluridone was shown to have significant positive effects on the velocity and germination of Riviera. The exact application method whether applied as a post seeding treatment before irrigating or the possibility of incorporating the molecule in the post-harvest seed coating need to be addressed. Defining the concentration and application protocol would have significant positive effects for field managers establishing Riviera playing surfaces in the upper transition zone.

Long term research should investigate the levels of ABA in the seed to determine if fluridone is inhibiting de novo production or if inhibiting ABA by some unknown mechanism is altering the fluctuating temperature requirement of the seed. If the mechanism can be identified it may be possible for breeders to manipulate crosses to eliminate this problem while retaining the desirable characteristics.

Copyright © Michael Todd Deaton 2012

References

Ahring, R.M., W.W. Huffine, C.M. Taliaferro, and R.D. Morrison. 1975. Stand Establishment of Bermudagrass from Seed. Agronomy Journal (67): 229-232.

Alvarado, V. and K.J. Bradford. 2002. A Hydrothermal Time Model Explains the Cardinal Temperatures for Seed Germination. Plant, Cell, and Enviroment (25): 1061-1069.

AOSA. 1998. Association of Official Seed Analysts. National Association of State Departments of Agriculture. Washington, D.C.

Baltensperger, A.A., and J.P. Klingenberg. 1994. Introducing New Seed-Propagated F_1 Hybrid (2-clone synthetic) Bermudagrass. USGA Green Section Record (32) (6): 14-19.

Baskin, C. C. and J. M. Baskin, 2001. Seeds Ecology, Biogeography, and Evolution of Dormancy and Germination. Academic Press, *An Imprint of Elsevier*, San Diego, Ca.

Bayrer, T. 2006. Wear Tolerance of Seeded and Vegetatively Propagated Bermudagrass Under Simulated Athletic Traffic. Thesis. http://lib.uky.edu/ETD/ukypssc2006t00397/Thesis.pdf.

Beard, J.B. Turfgrass: Science and Culture. New York: Prentice Hall, 1973.

Bennett, M. A. 2008. Seed Germination II – Factors Affecting Seed Germiantion. International Seed Physiology, HCS 3631.

Bewley, J. D., 1997. Seed Germination and Dormancy. The Plant Cell (9): 1055-1066.

Bierhuizen, J.F. and W.A. Wagenvoort, 1974. Some Aspects of Seed Germination in Vegetables. 1. The Determination and Application of Heat Sums and Minimum Temperature for Germination. Scientia Horticulturae, 2(1974) 213-219.

Bixbi-Brosi, A. 2011. Biological control of the black cutworm, *Agrotis ipsilon* Lepidoptera: Noctuidae) and endophyte mediated tritrophic interactions in Turfgrass. Dissertation. University of Kentucky Doctoral Dissertations. Paper 183. hppt://uknowledge.uky.edu/gradschool_diss/183.

Bradford, K. J. 2002. Applications of Hydrothermal Time to Quantify and Modeling Seed Germiantion and Dormancy. Weed Science, 50:248-260.

Busey, P. 2012. Bermudagrass. Online: http://www.floridaturf.com/bermuda/origins.htm. Accessed: 18 July 2012.

Canaway, P.M. 1976. A diff erential-slip wear machine (D.S.1) for the artificial simulation of turfgrass wear. J. Sports Turf Res. Inst. 52:92–99.

Cheng, Z and K.J. Bradford, 1999. Hydrothermal Time Analysis of Tomato Seed Germination Responses to Priming Treatments. Journal of Experimental Botany 50: 89-99.

Cockerham, S.T., and D.J. Brinkman, 1989. A Simulator for Cleated-Shoe Sports Traffic on Turfgrass Research Plots. California Turfgrass Culture 39 (3 & 4): 9 – 10.

Deaton, M. T. and D. W. Williams, 2010. Overseeding and Trinexapac-ethyl Effects on Tolerance to Simulated Traffic of Four Bermudagrass Cultivars Grown as a Sand-based Athletic Field. HortTechnology 20(4): 724-729.

Greipsson, S, 1999. Seed Coating Improves Establishment of Surface Seeded *Poa Pratensis* used in Revegetation. Seed Science and Techology, 27: 1029-1032.

Huarte, H. R. and R. L. Benech-Arnold, 2010. Hormonal Nature of Seed Responses to Fluctuating Temperatures in *Cynara cardunculus* (L.). Seed Science Research 20: 39-45.

Karcher, D. E., M.D. Richardson, J.W. Landreth, and J.H. McCalla, 2005. Recovery of Bermudagrass Varieties from Divot Injury. Online. Applied Turfgrass Science doi: 10.1094/ATS-2005-0117-01-RS.

Lee, K. P., U. Piskurewicz, V. Tureckova, M. Strnad, and L. Lopez-Molina, 2010. A Seed Coat Bedding Assay shows that RGL2-depentent Release of Abscisic Acid by the Endosperm Controls Embryo Growth in *Arabidopsis* Dormant Seeds. PNAS, Nov. Vol. 107 (44): 19108-19113.

Leinauer, B., M. Serena, and D. Singh, 2010. Seed Coating and Seeding Rate Effects on Turfgrass Germination and Establishment. HortTechnology 20(1): 179-185.

Lush, W.M., 1990. Turf Growth and Performance Evaluation Based on Turf Biomass and Tiller Density. Agronomy Journal 82:505-511.

Martin, D. L., Y. Wu, J. A. Anderson, M. P. Anderson, G. E. Bell, and N. R. Walker. 2007. Bermudagrass Cultivars with High Quality and Improved Cold Hardiness. USGA Turfgrass and Environmental Research Online 6(17):1-8.

Morris, K.N. 2010. National Turfgrass Evaluation Program. 2007 National Bermudagrass Test. NTEP No. 11-4. USDA, Beltsville, MD.

Munshaw, G. C. and D. W. Williams. 2002. Enhancing Stolon Production of Seeded Bermudagrass. GCM, Feb. 2002.

Munshaw, G. C., D. W. Williams, and P. L. Cornelius. 2001. Management Strategies During the Establishment Year Enhance Production and Fitness of Seeded Bermudagrass Stolons. Crop Science 41:1558-1564.

Nonogaki, H., G. W. Bassel, and J. D. Bewley. 2010. Germination Still a Mystery. Plant Science. Doi:10.1016/j.plantsci.2010.02.010.

Patton, A. J., M. D. Richardson, D. E. Karcher, J. W. Boyd, Z. J. Reicher, J. D. Fry, J. S. McElroy, and G. C. Munshaw. 2008. A Guide to Establishing Seeded Bermudagrass in the Transition Zone. Online. Applied Turfgrass Science. doi: 10.1094/ATS-2008-0122-01-MD.

Patton, A. J., G. A. Hardebeck, D. W. Williams, and Z. J. Reicher. 2004(a).Establishment of Bermudagrass and Zoysiagrass by Seed. Crop Science 44:2160-2167.

Patton, A. J., D. W. Williams, and Z. J. Reicher. 2004(b). Establishing Seeded Bermudagrass. GCM. Dec. 2004. pp. 73-77.

Philley, H. W. and J. V. Krans. 1998. Turf Performance of Seeded Bermudagrass Cultivars. GCM. Nov. 1998. pp. 62-66.

Powell, A.J. 2006. Sports Turf Traffic – How much is too much? (Online) http://www.uky.edu/Ag/ukturf/Athletic%20Field%20Pubs/sports%20turf%20traffic.pdf. Accessed 23 February 09.

Richardson, M.D. and K.W. Hignight. 2010. Seedling Emergence of Tall Fescue and Kentucky Bluegrass, as Affected by Two Seed Coating Techniques. HortTechnology 20(2):415-417.

Richardson, M.D., D.E. Karcher, P. Berger, and J.W. Boyd. 2004. Utilizing Improved Seeded Bermudagrass on Transition Zone Sports Fields. ActaHort. 661, ISHS. 1st IC on Turfgrass:369-374.

SAS Inc. 2008. SAS System for Windows v.9.2. SAS Institute, Cary North Carolina.

Shull, C.A. 1923. Physiology of Germination. Botanical Gazette, Vol. 76, No. 4, pp. 427-428.

Scott, J.M., C.J. Mitchell, and G.J. Blair. 1985. Effect of Nutrient Seed Coating on the Emergence and Early Growth of Perennial Ryegrass. Australian J. of Agri. Res. 36:221-231.

Scott, D. 1975. Effects of Seed Coating on Establishment. New England J. of Agri. Res. 18:59-67.

Shaver, B.R., M.D. Richardson, J.H. McCalla, D.E. Karcher, and P.J. Berger. 2006. Dormant Seeding of Bermudagrass Cultivars in a Transition-Zone Environment. Crop Sci. 46:1787-1792.

Shearman R.C. 2006. Fifty Years of Splendor in the Grass. Crop Sci. 46:2218–2229.

Systat Software, Inc. 2006. Sigma Plot for Windows. Version 10.0 Build 10.01.25 San Jose, CA.

Tiaz, L. and E. Zeiger. 2006. Plant Physiology, Fourth Edition. Sinauer Associates, Inc. Sunderland, Massachusetts.

Thoms, A. W., J. C. Sorochan, J. T. Brosnan, and T. J. Samples. 2011. Perennial Ryegrass (*Lolium perenne* L.) and Grooming Affect Bermudagrass Traffic Tolerance. Crop Sci. 51:2204-2211.

Trappe, J. M., D. E. Karcher, M. D. Richardson, and A. J. Patton. 2011. Shade and Traffic Tolerance Varies for Bermudagrass and Zoysiagrass Cultivars. Crop Sci. 51:870-877.

Trenholm, L.E., R.N. Carrow, and R.R. Duncan. 2000. Mechanisms of Wear Tolerance in Seashore Paspalum and Bermudagrass. Crop Sci. 40:1350-1357.

Turgeon, A.J. 2005. Turfgrass Management, 7th Edition. Pearson Prentice Hall, Pearson Education Inc. Upper Saddle River, New Jersey.

University of Kentucky Agricultural Weather Center. wwwagwxx.ca.uky.edu. Accessed 18 July 2012.

Unruh, J.B., R.E. Gaussoin, and S.C. Wiest. 1996. Basal Growth Temperatures and Growth Rate Constants of Warm-Season Turfgrass Species. Crop Sci. 36:997-999.

USDA, 1948. Grass Yearbook Of Agriculture 1948, United States Department of Agriculture, U.S. Government Printing Office – Washington 1948. Pgs 663 & 664.

Vanini, J.T., J.J. Henderson, J.C. Sorochan, and J.N. Rogers, III. 2007. Evaluating Traffic Stress by the Brinkman Traffic Simulator and Cady Traffic Simulator on a Kentucky Bluegrass Stand. Crop Sci. 47:782-784.

Vartha, E.W. and P.T.P. Clifford. 1973. Effects of Seed Coating on Establishment and Survival of Grasses, Surface-Sown on Tussock Grasslands. New Zealand J. of Exp. Agri. 1:39-43.

Wagenvoort, W.A. and J.F. Bierhuizen. 1976. Some Aspects of Seed Germination in Vegetables. II. The Effect of Temperature Fluctuations, Depth of Sowing, Seed Size and Cultivar, on Heat Sum and Minimum Temperature for Germintion. Scientia Horticulturae 6:259-270.

Williams, D. W., P. B. Burrus, and K. L. Cropper. 2010. Seeded Bermudagrass Tolerance to Simulated Athletic Field Traffic as Affected by Cultivars and Trinexapac-ethyl. HortTechology 20(3):533-538.

Yerramsetty, P.N., M.P. Anderson, and C.M. Taliaferro. 2005. DNA Fingerprinting of Seeded Bermudagrass Cultivars. Crop Sci. 45:772-777.

Youngner, V.B. 1961. Accelerated wear tests on turfgrasses. Agron. J. 53:217-218.

VITA

Michael Todd Deaton

BIRTHPLACE:

Lexington, Kentucky: 26 March 1968

EDUCATION:

M.S., Crop Science, University of Kentcuky, Completed: May 2007

Thesis: *Trinexapac-ethyl and Overseeding Effects on Shear Strength and Tolerance to Simulated Traffic of Four Bermudagrass Cultivars Grown on a Sand-Based System*

B.S., Agronomy, University of Kentucky, Completed May 1992

POSITIONS HELD:

- Graduate Research Assistant, Turfgrass Science, University of Kentucky, Department of Plant & Soil Science, May 2012 – July 2012
- Graduate Teaching Assistant, University of Kentucky, Department of Plant & Soil Sceince, Jan. 2012 – May 2012
- Graduate Research Assistant, Turfgrass Science, University of Kentucky, Department of Plant & Soil Science, May 2007 – Dec. 2011
- General Manager, Burley Belt Lawn Service, Inc., London, Kentucky

PUBLICATIONS:

<u>Refereed</u>

Deaton, M. T. and D. W. Williams, 2010. Overseeding and Trinexapac-ethyl Effects on Tolerance to Simulated Traffic of Four Bermudagrass Cultivars Grown as a Sand-based Athletic Field. HortTechnology 20(4): 724-729.

RESEARCH PRESENTATIONS:

Invited Presentations

Deaton, M.T. 2011 Advanced Turf Solutions Annual Meeting. Louisville, KY.

Diagnosing and cultural control of turfgrass diseases.

Offered Oral Presentations

Deaton, M.T. and D.W. Williams. *Overseeding and Trinexapac-ethyl effects on tolerance to simulated traffic of four bermudagrass cultivars grown on a sand-based system.* 2009 Tri-society (ASA, CSSA, SSSA) Annual meetings, Pittsburg, Pennsylvania.

Extension Presentations

Deaton, M. T. 2012 University of Kentukcy Turfgrass Field Day, Lexington, KY.

Research Update on warm season grasses from the University of Kentucky

Deaton, M. T. 2011 Kentucky Turfgrass Council Annual Meeting, Florence IN.

Research Update: *Seeded bermudagrass germination study.*

Deaton, M. T. 2011 University of Kentucky Turfgrass Field Day, Lexington, KY.

Comparisions of mean germination time and time to complete coverage on nineteen commercially available seeded bermudgrass cultivars.

Deaton, M. T. 2011 Kentucky Turfgrass Council Short Course, Louisville, KY. *Field diagnosis of common Kentucky turfgrass diseases.*

Deaton, M. T. 2011 Kentucky Turfgrass Council Short Course, Louisville KY.

Successful turf establishment from seed.

Deaton, M. T. 2010 Kentucky Turfgrass Council Annual Meeting, Bowling Green, KY. Research Update: *Temperature effects on the completion of germination of nineteen commercially available seeded bermudagrass cultivars.*

Deaton, M. T. 2010 Kentucky Turfgrass Council Annual Meeting, Bowling Green, KY. *Diagnosis and cultural control of turfgrass diseases.*

Deaton, M. T. 2010 University of Kentucky Turfgrass Field Day, Lexington, KY. *Comparisions of mean germination time and time to complete coverage of nineteen commercially available seeded bermudagrass cultivars.*

Deaton, M. T. 2009 Kentucky Turfgrass Council Annual Meeting, Bowling Green, KY. Research Update from the University of Kentucky.

Deaton, M. T. 2009 University of Kentucky Field Day, Lexington, KY. *Overseeding and Trinexapac-ethyl effects on tolerance to simulated traffic and shear strength of four bermudagrass cultivars grown on a sand-based system.*

Deaton, M. T. 2009 Kentucky Turfgrass Council Short Course, Louisville KY. *Diagnosing and cultural control of Kentucky turfgrass diseases.*

Deaton, M. T. 2008 Kentucky Turfgrass Council Annual Meeting, Bowling Green, KY. Research Update from the University of Kentucky.

Deaton, M. T. 2008 University of Kentucky Field Day, Lexington, KY. *Overseeding and Trinexapac-ethyl effects on tolerance to simulated traffic and shear strength of four bermudagrass cultivars grown on a sand-based system.*

Deaton, M. T. 2008 Kentucky Turfgrass Council Short Course, Louisville, KY. *Turfgrass renovation following drought or pest damage.*

Deaton, M. T. 2007 Kentucky Turfgrass Council Annual Meeting, Bowling Green, KY. Research Update from the University of Kentucky.

TEACHING:

Plant, Soils, and People: A Science Perspective (PLS 104), taught recitation sections

PROFESSIONAL MEMBERSHIP

1) Crop Science Society of America, member since 2007
2) Kentucky Turfgrass Council, member since 2007