ABSTRACT

HOYLE, JARED ADAM. Effect of Mowing Height in Turfgrass Systems on Pest Incidence. (Under the direction of Fred H. Yelverton.)

Field experiments were conducted to 1) determine if discrepancies occur between multiple methods for estimating large crabgrass cover to determine the most precise, accurate, and efficient method, 2) determine the effect of mowing height on large crabgrass incidence in common bermudagrass, 3) determine the effect of mowing height on large crabgrass and brown patch incidence in tall fescue, and 4) determine the effect of mowing height on common bermudagrass encroachment in tall fescue. All experiments were conducted at two locations in North Carolina. Mowing heights for experiments included 2.5, 5.1, 7.6, and 10.2 cm for tall fescue and 1.3, 2.5, 3.8, and 5.1 cm for common bermudagrass. Evaluation methods for estimating large crabgrass cover consisted of Visual Ratings (VR), Line Intersect Analysis (LIA), and Digital Image Analysis (DIA). All methods were compared to VR, the standard and accepted method of data collection. It was found in two separate field experiments that there were no differences among the three rating methods.

No effect of mowing height on large crabgrass incidence in common bermudagrass was found at 5 months after initiation (MAI).

Increasing tall fescue mowing heights resulted in reduced large crabgrass incidence and increased brown patch incidence. The presence of brown patch did not affect large crabgrass incidence. As mowing height increased, percent crabgrass cover at

6 MAI decreased. With increasing mowing heights percent brown patch cover increased in tall fescue.

Immediately following installation of common bermudagrass in tall fescue, mowing height treatments of 2.5, 5.1, 7.6, and 10.2 cm were initiated. Research determined that with increasing mowing heights in tall fescue, the percent of common bermudagrass cover was significantly reduced, especially after one year of growth.

These results show that VR may be more widely accepted in weed control studies in turfgrass systems. The mowing height of common bermudagrass will not suppress large crabgrass. A mowing height of 7.6 cm in tall fescue can reduce large crabgrass populations, decreasing dependence on pre-emergence herbicides, and keeping brown patch infestations below a common threshold of 5% brown patch cover. To prevent spread of common bermudagrass in tall fescue after contamination a mowing height of 7.6 or 10.2 cm is recommended.

Effect of Mowing Height in Turfgrass Systems on Pest Incidence

by
Jared Adam Hoyle

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements of the Degree of
Master of Science

Crop Science

Raleigh, North Carolina

2009

APPROVED BY:

Dr. Lane Tredway

Dr. Grady L Miller

Dr. Fred H Yelverton
Chair of Advisory Committee

DEDICATION

This thesis is dedicated to my father, mother, and brothers.

With their support and love they helped me achieve one of my life goals.

John Hoyle

Judy Hoyle

Jonathan Hoyle

Jason Hoyle

Justin Hoyle

BIOGRAPHY

I was born in Kernersville, North Carolina in 1984 where I spent my pre-college life. I grew up on a family farm where I was able to spend time outdoors enjoying mother-nature with my brothers. As a young boy, I enjoyed playing sports including soccer and baseball that I carried out through my life. I also enjoy hunting and fishing with my family and friends. It was during this time that I developed a passion for landscaping and turfgrass.

I begin my college career at North Carolina State in the Fall of 2002. During the Summer of 2005 I completed the North Carolina Nurserymen Internship at the J.C. Raulston Arboretum. In December 2006 I graduated with honors and received a B.S. in Horticulture Science with concentration in Horticulture Science Technology. Upon graduation I immediately began in January 2007 at North Carolina State University pursuing a M.S. degree in Crop Science under the direction of Dr. Fred H. Yelverton as a Graduate Research Assistant. Upon graduation I plan to continue my education and pursue a PhD.

ACKNOWLEDGEMENTS

There are many individuals I would like to thank for their support in helping me succeed in my graduate studies. First, I would like to thank my family and friends for helping me believe in myself so I could achieve this accomplishment. Even though all of them were not always present, their morale inspired me day after day. I would like to thank my brothers Jonathan, Jason, and Justin for always being there to congratulate me for any accomplishments I received. I would also like to thank my father and mother, John and Judy, for always being my rock to lean on when I needed support. Also, thanks to Sam Powell and Tim Davies for their friendship and support through my college career.

I would like to professionally express my gratitude to Dr. Fred H Yelverton for giving me the opportunity to pursue a Master's Degree and for the guidance that he gave during my career here. I would also like to thank Dr. Grady Miller and Dr. Lane Tredway for their professional help and guidance as well.

Lastly, I would like to thank fellow graduate students and Research Technicians for their assistance and support over the past several years; Travis Gannon, Leon Warren, Adam Hixson, Gerald Henry, Kyle Briscoe, and Mark Brotherton.

TABLE OF CONTENTS

Page
LIST OF TABLES……………………………………………………………………vi
LIST OF FIGURES…………………………………………………………………viii

CHAPTER 1

Estimating Large Crabgrass (*Digitaria sanguinalis*) Cover by Multiple Collection Methods..1
Abstract..1
Introduction..3
Materials and Methods..7
Results and Discussion..11
Sources of Materials 17
Acknowledgments 18
Literature Cited 19

CHAPTER 2

Effect of Mowing Height on Large Crabgrass (*Digitaria sanguinalis*) and Brown Patch (*Rhizoctonia solani*) Incidence in Turfgrass Systems 38
Abstract 38
Introduction 39
Materials and Methods 43
Results and Discussion 47
Sources of Materials 52
Acknowledgements 52
Literature Cited 53

CHAPTER 3

Effect of Mowing Height on Common Bermudagrass (*Cynodon dactylon*) Encroachment in Tall Fescue (*Lolium arundinaceum*) 61
Abstract 61
Introduction 62
Materials and Methods 65
Results and Discussion 66
Sources of Materials 72
Acknowledgments 72
Literature Cited 73

LIST OF TABLES

CHAPTER 1

Table 1. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2007. 22

Table 2. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2008. 23

Table 3. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2007 at Raleigh, NC. 24

Table 4. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2007 at Jackson Springs, NC. 26

Table 5. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2008 at Raleigh, NC. 28

Table 6. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2008 at Jackson Springs, NC. 30

CHAPTER 2

Table 1. Effect of mowing height on large crabgrass incidence in common bermudagrass pooled over Jackson Springs, NC and Raleigh, NC, 5 months after initiation..56

Table 2. Effect of mowing height on large crabgrass incidence in tall fescue pooled over Jackson Springs, NC and Raleigh, NC; 2007 and 2008, 6 months after initiation...57

Table 3. Effect of mowing height on large crabgrass incidence in tall fescue at Jackson Springs, NC and Raleigh, NC, 6 months after incitation; 2007-2008. 58

Table 4. Effect of mowing height on brown patch incidence in tall fescue pooled over fungicide treatments, 6 months after initiation.. 59

Table 5. Effect of mowing height and fungicide application on brown patch incidence in tall fescue pooled over locations and years, 6 months after initiation. 60

CHAPTER 3

Table 1. Effect of mowing height on bermudagrass encroachment in tall fescue over multiple weeks after incitation; 2007. 74

Table 2. Effect of mowing height on bermudagrass encroachment in tall fescue over multiple weeks after incitation; 2008. 75

Table 3. Effect of mowing height on bermudagrass encroachment in tall fescue over multiple weeks after incitation; 2007-2008. 76

LIST OF FIGURES

CHAPTER 1

Figure 1. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2007, for the effect of mowing height on crabgrass incidence. 32

Figure 2. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2008, for the effect of mowing height on crabgrass incidence. 33

Figure 3. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2007 at Raleigh, NC, for the effect of various pre-emergence herbicides on crabgrass incidence. 34

Figure 4. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2007 at Jackson Springs, NC, for the effect of various pre-emergence herbicides on crabgrass incidence. 35

Figure 5. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2008 at Raleigh, NC, for the effect of various pre-emergence herbicides on crabgrass incidence. 36

Figure 6. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2008 at Jackson Springs, NC, for the effect of various pre-emergence herbicides on crabgrass incidence. 37

CHAPTER 3

Figure 1. Plot layout for common bermudagrass installation in tall fescue.......................77

CHAPTER 1

Estimating Large Crabgrass (*Digitaria sangunalis*) Cover by Multiple Collection Methods.[1]

J. A. Hoyle, F. H. Yelverton, G. L. Miller, and L. Tredway[2]

Herbicide efficacy research trials in turfgrass systems commonly report data based on visual estimates. There has been much interest recently in determining how accurate and consistent visual estimates relative to other techniques. Other popular evaluation methodology includes line intersect analysis (LIA) and digital imaging analysis (DIA). Two separate field experiments were conducted during 2007 and 2008 at two locations. Both experiments were preformed to determine if rating methods differed in estimating large crabgrass in tall fescue. Large crabgrass populations were manipulated by either mowing height or by various pre-emergence herbicides for large

____

[1] Received for publication ________________ and in approved form ____________.

[2] Graduate Research Assistant[a], Professor[a], Professor[a] and Associate Professor[b], respectively. North Carolina Sate University, [a]Department of Crop Science, Box 7620, Raleigh, NC 27695-7620. [b]Department of Pathology, Box 7616, Raleigh, NC 27695-7620.

crabgrass germination and growth. Evaluated tall fescue mowing heights included 2.5, 5.1, 7.6 or 10.2 cm, which were initiated once soil temperatures reached an optimum (12.8° C) for crabgrass emergence. Visual ratings (VR), DIA and LIA were used to determine percent crabgrass cover for all experiments in mid-September at each location. No significant differences were noted between VR and DIA and VR and LIA for all experiments. Regression analysis of VR values against DIA or LIA values was also conducted. For all mowing height experiments of VR versus DIA expressed r^2 value of 0.99 and VR versus LIA, $r^2 = 0.99$, indicated rating methods were highly correlated. For the pre-emergence herbicide study on large crabgrass similar results were observed. Hence, no significant differences were detected between VR and DIA and VR and LIA. These data support the claim that VR is a reliable evaluation method when determining weed control efficacy.

Nomenclature: large crabgrass, *Digitaria sanguinalis* (L.) Scop; tall fescue, *Lolium arundinacuem* Schreb.

Key Words: rating methods, subjective data, qualitative data, quantitative data

Abbreviations: VR, visual rating; DIA, digital image analysis; LIA, line intersect analysis; RAL, Raleigh; JAC Jackson Springs, WAIT; weeks after initial treatment, fb; followed by.

INTRODUCTION

Weed populations can have a negative impact on any agronomic crop. Understanding these populations and how they can be controlled is essential in turfgrass management. Every year in the turfgrass industry new problems arise in weed science. This leads to an increasing demand for multiple experiments to be conducted with in the same growing season. With the increase in research experiments, data collection must be both accurate and efficient to satisfy all parties involved. Therefore, objective visual ratings (VR) have become more common and accepted. In turfgrass establishment studies, VR can be conducted in a short period of time allowing for frequent estimates relative to DIA or LIA. VR is considered to be a subjective rating (Skogley and Sawyer 1992; Richardson et al. 2001). Subjective or qualitative data acquisition requires less time, permits large sample size, and requires minimal equipment expenditure (Horst et al. 1984). Evaluators can reduce the frequency of data collection in a trade off for what is to be considered more quantitative data (Skogley and Sawyer 1992; Richardson et al. 2001). Quantitative data are usually more precise than the subjective visual ratings, however the time and cost requirements of quantitative data acquisition often limit its use (Richardson et al. 2001) as well as logistical and economical considerations (Horst et al. 1984).

Visual evaluation is routinely used in assessing turfgrass cultivars (Horst et al. 1984). These VR are collected by trained evaluators and allow for frequent assessments throughout the entire growing season (Morris 2002). Visual evaluations are routinely used to assess performance characteristics of turfgrass cultivars in field plantings (Horst et al. 1984). Visual assessments using numerical scales are the most common means of evaluating color in turfgrass cultivars (Landschoot and Mancino 2000). Horst et al. (1984) conducted a field study where 10 trained evaluators rated quality and density in multiple cultivars of Kentucky bluegrass (*Poa pratensis* L.) and tall fescue (*Lolium arundinacuem* Schreb.) Results from this study showed there is more variation between the evaluators than were in turfgrass cultivars. Although research has shown subjective data of turfgrass plots are inadequate in most situations, they have continued to be used for the past 15 yr (Richardson et al. 2001).

Conventional methods for measuring ground cover include point analysis and LIA (Oosting 1956; Cook and Stubbendieck 1986; ITT 1996), which are labor intensive (Booth 2005). Using LIA to estimate ground cover and ecological plant distribution (Laycock and Canaway 1980; Kershaw 1973) works essentially the same for measuring weed cover in turf. This method involves setting up a grid system over the entire plot or quadrant and counting the number or types of plants found at each intersection (Richardson et al. 2001). The number then is divided by the total number of intersections and multiplied by 100 to get a percent of desired plant species for that specific area. The spacing of intersects, size of the grid, and time allocated for counting can all determine the precision of the resulting data. Subsequently the amount of time and labor required for data collection of this quantitative data can limit the scope of the research (Richardson et al. 2001).

Recently, new inventions have emerged using digital images to support qualitative data with quantitative data. DIA has been successfully used to study nitrogen differences by color in corn (*Zea mays* L.) (Ewing and Horton 1999) and soybean (*Glycine max* L. [Merr.]) canopy coverage (Purcell 2000). This supportive approach has developed even further to determine fractional cover of senescence and green vegetation in rangeland (Laiberte et al. 2007). In the turfgrass field, Shaver et al. (2006) used DIA to determine turfgrass cover when studying dormant seeding bermudagrass (*Cynodon dactylon* (L.) Pers.) cultivars in a transition-zone environment. Digital image analysis was also used to determine the recovery of bermudagrass varieties (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy) and zoysiagrass varieties (*Zoysia japonica* Steud., *Z. matrella* (L.) Merr, and *Z. tenuifolia* Wild.) from divot injury (Karcher et al. 2005a, Karcher et al. 2005b) and differences in winter injury and freeze tolerance in zoysiagrass (*Zoysia* spp.) species and genotypes (Patton and Reicher 2007). Digital image analysis has also been use to quantify turfgrass color in zoysiagrass (*Zoysia japonica* Steud.) and creeping bentgrass (*Agrostis palustris* Huds.) (Karcher and Richardson 2003).

Technological advances in DIA have used computer programs to analyze the digital images by quantifying green-leaf area in large batches of digital images (Booth et al. 2005). The "VegMeasure" software program developed at Oregon State University (Louhaichi et al. 2001; Johnson et al. 2003) was used by Booth et al. (2005) to compare methods of measuring ground cover. It was found there was no difference between digital imaging software (VegMeasure) and a digital grid overlay (similar to LIA) in determining percent green cover. Other computer programs have been used to quantify wavelengths and analyze data through statistical software, as Ewing and Hortin (1999) did to quantify color images of corn crop. Purcell (2000) and Richardson et al. (2001) used a commercially available software program, Sigma Scan (v. 5.0, SPSS, Inc., Chicago IL 60611) to determine the portion of ground area covered by soybean (*Glycine max* L. [Merr.]), bermudagrass (*Cynodon dactylon* (L.) Pers.), and zoysiagrass (*Zoysia japonica* Steudel). Research conducted by Butler et al. (2004) in digital photography using Sigma Scan, resulted in a more effective tool than visual estimates for assessment of spring dead spot incidence in bermudagrass (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy). Richardson et al (2001) determined that DIA was an effective tool for measuring turfgrass cover and was significantly different from other rating methods of LIA and VR tested on the same plots.

Our hypothesis is that DIA, LIA, and VR can all be used to evaluate weed incidence in turfgrass. The objective of this research is to determine if there are differences among DIA, LIA, and VR for estimating percent crabgrass cover in weed control experiments involving different mowing heights or application of various pre-emergence herbicides.

MATERIALS AND METHODS

Mowing Height Study. Experiments were conducted to determine if multiple ratings methods differed in determining the effect of mowing height on crabgrass incidence in tall fescue. Field experiments were initiated in RAL at Lake Wheeler Field Labs and in JAC at Sandhills Research Station on 6 March 2007 and 3 March 2008. Soil was a Wakulla sand (siliceous, thermic psammentic hapludults) in JAC with 0.86% humic matter and pH 5.5. Soil in RAL was an Appling fine sandy loam (fine, kaolinitic, thermic typic kanhapludult) with 1.19% humic matter and pH 5.8.

At initiation, areas were mown at a 5.1 cm height to remove debris and make for ease of sowing large crabgrass seed. Large crabgrass[3] was slit and broadcast seeded at 170 – 190 kg/ha. A Toro Seeder 93 (Bloomington, MN 55420) attached to a John Deere 4700 Tractor (Moline, Illinois 61265-8098) was used in at least four directions to apply approximately 90 kg/ha of large crabgrass seed. A broadcast spreader was then used in two directions to apply the remaining (approximately 90 kg/ha) large crabgrass seed.

Mowing height treatments (2.5, 5.1, 7.6, and 10.2 cm) were initiated once soil temperatures reached a daily average of 12.8° C: 14 March 2007 and18 March 2008. Treatments were replicated four times each year at both locations. Plots were 2.1 by 1.2 m and treatments applied in a randomized complete block design. Mowing treatments were performed every 3 to 4 d with a rotary mower (Honda HRC 216, Alpharetta, GA 30005-8847) with clippings returned. Plot areas in RAL and JAC were fertilized[4] with N at 24 kg/ha and 38.4 kg/ha respectively throughout the growing season. To provide better contrast between large crabgrass and turfgrass, mesotrione[5] was applied to the entire plot area at 0.24 kg ai/ ha on 24 September 2007 and 05 September 2008. Mesotrione was applied with a CO_2 pressurized hand-held spray boom equipped with four VS8003XR[6] flat fan nozzles on 38 cm spacing's calibrated to deliver 304 L/ha.

VR, LIA, and DIA were used to determine crabgrass cover and recorded at 10 October 2007 and 18 September 2008. VR utilized a 0 (no crabgrass) to 100% (complete crabgrass cover) scale that was estimated by an evaluator looking at the research plots. LIA (5.1 cm spacing) utilized a 0 (no crabgrass) to 100% (complete crabgrass cover) scale after intersect counts were converted using Equation 1.

$$\text{(Counted Intersects / (Total Intersects=943)) x 100} \qquad [1]$$

DIA utilized a 0 (no crabgrass) to 100% (complete crabgrass cover) scale after digital images were analyzed using SigmaScan Pro (v 5.0, SPSS, Inc., Chicago, IL 60611).

Pre-emergence Herbicide Study. Experiments were conducted to determine if multiple ratings methods differed in determining the effect of pre-emergence herbicides on crabgrass populations in tall fescue. Field experiments were initiated in RAL and in JAC on 6 March 2007 and 3 March 2008. Large crabgrass was sown as described above for the mowing height study. Four replicates were included at both locations and both years. Plots were 1.5 by 3 m and treatments applied in a randomized complete block design.

Initial treatments were applied on 13 March 2007 and 2008. Treatments applied included prodiamine[7], at 0.84 or 0.57 fb 0.27 kg ai/ha, dithiopyr[8], at 0.57 or 0.27 fb 0.27 kg ai/ha, oxadiazon[9], at 3.36 or 1.68 fb 1.68 kg ai/ha, pendimethalin[10], at 3.36 or 1.68 fb 1.68 kg ai/ha, oryzalin[11], at 3.36 or 1.68 fb 1.68 kg ai/ha, and benefin + trifluralin[12], at 3.36 or 1.68 fb 1.68 kg ai/ha. Eight weeks after initial treatment (WAIT) applications were applied on 13 May 2007 and 6 May 2008. Treatments were applied with a CO_2 pressurized hand-held spray boom equipped with four VS8003XR[6] flat fan nozzles on 25 cm spacing's calibrated to deliver 304 L/ha. Plots were irrigated with 0.64 cm of water immediately after the initial treatments and 8 WAIT applications by overhead irrigation. The tall fescue was mowed every 3 to 4 d at 6.4 cm mowing height with a rotary mower. All tall fescue research plot areas received the same fertilizer regiment as the mowing height study described above. Mesotrione[5] was applied to entire plot area at 0.24 kg ai/ha on 24 September 2007 and 05 September 2008.

VR, LIA, and DIA were used to determine crabgrass cover and recorded at 10 October 2007 and 18 September 2008. VR, LIA, and DIA utilized same scale as previous mowing height study.

Digital image analysis. Digital images were obtained using a digital camera (Nikon D80, Nikon Inc., Chiyoda-ku, Tokyo, 100-8331, Japan) mounted on an aluminum tubing tri-pod stand (Manfrotto 190XPROB, Ramsey, NJ 07446-0506). Recent studies by Richardson et al (2001) described digital image collection. The tri-pod stand was 122 cm high and consisted of a 90°, 24 cm horizontal arm, allowing for a photo image from directly above the plot. A wired remote was used to operate the camera shutter. Images were saved in the JPEG (joint photographic experts group, .jpg) format. Digital images were 560 x 400 pixels with a color depth of 64,000 colors. Camera settings included focal length of 32 mm, aperture of F7.1, and a shutter speed of 1/200 s, with the white balance set to the natural light source.

Digital images were downloaded to a personal computer and batch analyzed by SigmaScan Pro, (Karcher and Richardson 2005). Initial work with similar images concluded that the hue range and saturation range to determine percent tall fescue were to be set at 43 to 100 and 0 to 100 respectively. Equation 2 was then used to determine the percent crabgrass cover from the digital images.

$$(100 - \%\ \text{Tall Fescue from SigmaScan Output}) = \%\ \text{Crabgrass Cover} \qquad [2]$$

Data analysis. Percent crabgrass cover estimates from DIA and LIA were compared to VR by regression analysis, subjected to ANOVA and means were separated according to Fisher's Protected LSD (P=0.05) using SAS Statistical Software (SAS Inc., Cary, NC) and SigmaPlot (v 11.1, Systat Software In., San Jose, CA). A treatment by year interaction for mowing height study prevented pooling data across years; thus data are presented separately. A treatment by year by location interaction for the pre-emergence herbicide study prevented pooling data across years and locations; thus data are presented separately.

RESULTS AND DISCUSSION

Mowing Height Study. Three rating methods were compared to estimate percent crabgrass cover in tall fescue at various mowing heights. In 2007, DIA compared to VR showed no significant difference between the rating methods (F-test = 2.34, P-value = 0.131) (Table 1). Likewise was the case for LIA when compared with VR, in 2007 (F-test = 0.74, P-value = 0.392). For the 2007 data, the coefficient of variation (CV) was 32.9, 27.5, and 51.8 for VR, DIA, and LIA respectively. Four statistical groupings were observed for each of the rating methods based upon mowing height. Note at the 10.2 cm mowing height DIA showed 12.6 % crabgrass cover while LIA and VR showed there to be none, 0 or 0.1 respectively. With no crabgrass present in the plots it can be said that DIA tended to over estimate percent crabgrass at the higher mowing heights when compared to VR and LIA underestimated percent crabgrass at lower lowing heights compared to VR (Table 1).

In the 2008 data similar results were found (Table 2). When comparing VR to DIA there was no significant difference between rating methods (F-test = 0.12, P-value = 0.725) and when comparing VR to LIA there was no significant difference (F-test = 0.52, P-value = 0.471). The CV followed the same trend in 2008 as in 2007 with 35.3, 41.1, and 64.7 for VR, DIA, and LIA respectively. VR and LIA for mowing heights of 2.5, 5.2, 7.6, and 10.2 cm resulted in all being significantly different from one another. DIA did not statistically separate the 7.6 and 10.2 cm mowing height while LIA and VR did. As in 2007 DIA in 2008 tended to over estimate the percent crabgrass cover in tall fescue at the higher mowing heights and LIA under estimate percent crabgrass cover compared to VR.

Because LIA (a quantitative data collection rating method) and VR (subjective data collection rating method) were shown to be no different from one another at all mowing heights and VR are commonly used in weed control studies, regression analysis was applied to the measured values of percent crabgrass cover for VR to DIA or LIA. In 2007 data, regression analysis showed DIA and LIA were closely related to VR with as noted by an r^2 of 0.99 (Figure 1). Both DIA and LIA had slopes of 0.89 and 0.84 respectively. Line intersect analysis seemed to underestimate percent crabgrass cover at the lower mowing heights (where values of crabgrass cover were higher) when compared to VR and were very similar at the higher mowing heights. Digital image analysis tended to over estimate percent crabgrass cover as seen in Figure 1 and in Table 1 in 2007. This is supported by a y-intercept value of 12.97 and near parallel lines. This explains a high correlation of these rating methods but more calibration was needed to fine-tune the rating methods. Due to better calibration of DIA the regression line of DIA versus VR for 2008 is closer to the 1:1 relationship (Figure 2) than in 2007 (Figure 1). DIA still overestimated percent crabgrass cover at the higher mowing heights because of shadows but not as drastic as in 2007. DIA and LIA versus VR as noted by the r^2 value of 0.99 are closely related. Both rating methods (DIA and LIA) had slopes of 0.84 and 0.83 respectively. In both years, Figure 1 and Figure 2 indicate no difference in rating methods when estimating percent crabgrass cover in tall fescue at multiple mowing heights.

Because of the multiple mowing heights, calibration of DIA was needed to compensate for shadows in the turfgrass system. DIA is an effective tool along with LIA and VR to estimate percent crabgrass cover in a tall fescue research plot. Advantages of VR and DIA are less time consuming compared to LIA, allowing evaluators more time in the field to rate multiple research plots. VR and DIA require the same amount of time once all initial calibration for DIA has been completed. Initial calibration of DIA is very time consuming. LIA is time consuming if counts are conducted in the field as was the case in this study. Disadvantages of DIA consist of equipment cost, moving equipment to and from research site, calibration of the camera for various locations for different weed species and turf species, calibration of Sigma Scan software to allow for thresholds to choose a pixel that is considered a weed or considered a turfgrass species. For DIA to be an effective methodology there must be a detectable color difference between the weed large crabgrass, and the turfgrass species tall fescue. To achieve this difference mesotrione was applied to the turfgrass system. In this case a color difference was achieved but there is not always an established recipe nor method to select for a detectable color difference by application of a chemical. These data indicate that VR can be accepted as reliable data in weed control research.

Pre-emergence Herbicide Study. Concurrent with the mowing height study, data were collected by three different methods in a pre-emergence herbicide study for crabgrass control in tall fescue. The same analysis was preformed in this study as was employed in the mowing height study. Performance of the various pre-emergence herbicides varied from location and year not allowing data to be pooled because of the wide range of percent crabgrass cover values. DIA and LIA were not different from VR with a F-Test = 0.14 (P-value = 0.713) and F-test = 1.2 (P-value = 0.275) respectively in 2007 at RAL (Table 3). The CV among the rating methods was 40.9, 27.4, and 27.3 for DIA, LIA, and VR, respectively. Table 4 shows the data collected in 2007 at JAC. DIA and LIA were not different from VR as well with F-test = 1.58 (P-value = 0.211) and F-Test = 0.39 (P-value = 0.532), respectively. CV for DIA and VR were very similar with 53.6 and 54.1 respectively and LIA had a CV of 29.9. In 2008, RAL, Table 5 shows that there was also no difference between DIA and VR with F-Test (2.93) and P-value of 0.09. LIA was also different from VR with a F-Test of 1.11 and a P-Value of 0.294. CV among the rating types were 53.6, 28.6, and 56.9 for VR, DIA, and LIA, respectively.

Lastly, in 2008 JAC provided the same results as all other locations, times, and studies (Table 6). Table 6 shows that DIA was no different from VR with a P-Value of 0.375 from a F-Test of 0.79 and LIA was not statistically different from VR with a P-Value of 0.681 from a F-Test of 0.17. The variances among VR, DIA, and LIA were 62.7, 30.4, and 71.2, respectively.

In RAL for 2007, DIA and LIA both showed a fairly high r^2 value of 0.83 and 0.88, respectively when compared to VR (Figure 3). Also, DIA had a slope of 0.48 but LIA had a slope of 0.77. For RAL in 2007 LIA more closely fit to the 1:1 relationship with VR than DIA. DIA also tended to over estimate the percent crabgrass cover at the lower values of percent crabgrass cover and under estimate percent crabgrass cover at higher values compared to VR. LIA generally, tended to underestimate percent crabgrass cover throughout all the pre-emergence herbicide treatments when compared to VR. Figure 4 shows the results for the regression in 2007 at JAC and similar results were found. DIA was more closely related to VR with an r^2 value of 0.86 but LIA again was more closely related to VR with an r^2 value of 0.94. DIA and LIA in general did not overestimate percent crabgrass cover as at RAL, but rather under estimate percent crabgrass when compared to VR. LIA had a very close relationship to the 1:1 line with a slope of 0.91 while DIA had a slope of 0.64 but still was not significantly different from VR. Both DIA and LIA underestimated the control plot compared to VR at higher values of percent crabgrass. In 2008, RAL (Figure 5) showed that DIA and LIA were closely related to VR with an r^2 value of 0.81 and 0.91, respectively. DIA tended to overestimate percent crabgrass but had a slope of 0.69 while LIA tended to underestimate percent crabgrass with a slope of 0.84. At JAC in 2008 (Figure 6) percent crabgrass had lower values compared to RAL in 2008 (Figure 5). In Figure 6, DIA was related to VR as noted by an r^2 value of 0.82 but LIA was more closely related to VR as noted by an r^2 value of 0.89. DIA tended to overestimate percent crabgrass at lower values. LIA was very close to the 1:1 relationship for all values except one high value of percent crabgrass. DIA and LIA had slopes of 0.62 and 0.78 respectively.

In conclusion, for both studies there are no differences among the DIA or LIA rating methods as compared to VR. In general, DIA tended to over estimate percent crabgrass and LIA tended to underestimated percent crabgrass when comparing to VR. This is believed to be caused by shadows that occur when the digital images are captured. The shadows are considered outside the threshold of green tissue selected in Sigma Scan and in turn are counted as the pixels in the crabgrass range. In the mowing height study the regression analysis shows that there needs to be more calibration in the rating methods to have a 1:1 relationship. Adjusting camera settings for light conditions can refine calibration and increase precision. Problems associated with DIA consist of being able to apply this rating method to a wide range of weed species. Because of the time required for data collection, LIA is time consuming and restricts the size of a research trial and the number of data collection dates. DIA is an ideal rating method for establishment studies where there is a greater difference between green leaf tissue and bare ground which Sigma Scan can easily differentiate. Also, DIA is more practical for a lower growing turf where shadows would not affect the outcome of the data. DIA and LIA are not practical for data collection in weed control studies for the various reasons stated herein, therefore VR can be more widely accepted and applicable for weed control studies. However, the inherent problems associated with VR remain.

This data contradicts findings from Richardson et al. in 2001 were it was found that DIA and subjective analysis (VR in current study) were different from one another when estimating turfgrass cover. The data from the current study shows no different between VR and DIA. Another study to estimate spring dead spot in bermudagrass showed that DIA was a more effective tool and different from VR and LIA (Butler et al. 2004), which was also contradictory to findings in this study. These two studies also were looking at only one species of vegetation, a turfgrass species. This research was looking at two different vegetative species, a turfgrass species and a weed species. The multiple species could have played a role in affecting DIA and LIA estimations by having close color relationship even if treated with a chemical bleaching agent.

SOURCES OF MATERIALS

[3] Lorenz's Ok Seeds, 511 W Oklahoma, Okeene, OK 73763

[4] Harrell's Fertilizer – Greensboro, NC

[5] Mesotrione, Callisto, Syngenta Crop Protection, Greensboro, NC 27409

[6] Teejet Spraying Systems Company, North Avenue Wheaton, IL 60189-7900

[7] Prodiamine, Barricade 65WG, Syngenta Crop Protection, Greensboro, NC 27409

[8] Dithiopyr, Dimension Ultra 40WP, Dow AgroSciences, LLC., Indianapolis, IN 46268

[9] Oxadiazon, Ronstar 2G- Bayer CropScience, Alfred-Nobel-Str.50 D-40789 Monheim am Rhein, Germany

[10] Pendimethalin, Pendulum AquaCap 3.8CS, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709

[11] Oryzalin, Surflan 4FL, Dow AgroSciences, LLC., Indianapolis, IN 46268

[12] Benefin + trifluralin – Team Pro 0.86G on 25-3-8, Anderson's Lawn Fertilizer, PO BOX 119, Mauee, OH 43537

ACKNOWLEDGEMENTS

The authors express appreciation to Travis Gannon and Leon Warren for their technical assistance and Dr. Arellano Consuelo for statistical assistance.

LITERATURE CITED

Booth, D.T., S.E. Cox, C. Fifield, M. Phillips, and N. Williamson. 2005. Image Analysis Compared with Other Methods for Measuring Ground Cover. Arid Land Research and Management. 19:91-100.

Butler, E.L., L. Tredway, C. Peacock, and D. Shew. "Development of Novel Strategies for Control of Spring Dead Spot in Bermudagrass". Thesis. North Carolina State University, 2004.

Cook, C.W. and J. Studdendieck. 1986. Range research: Basic problems and techniques. Society for Range Management, Denver, Colorado, USA.

Ewing, R.P., and R. Horton. 1999. Quantitative color image analysis of agronomic images. Agron. J. 76:619-622.

Horst, G.L., M.C. Engelke, and W. Meyers. 1984. Assessments of visual evaluation techniques. Agron. J. 76:619-622.

Interagency Technical Team (ITT). 1996. *Sampling Vegetation Attributes, Interagency Technical Report 17*. United States Department of Agriculture, Forest Service. Rocky Mountain Research Station, Fort Collins, Colorado, USA.

Johnson, D.E., M. Vulfson, M. Louhaichi, and N.R. Harris. 2003. *VegMeasure version 1.6 users manual*. Department of Rangeland Resources, Oregon State University, Corvallis, Oregon, USA.

Karcher, D.E. and M.D. Richardson. 2005. Batch Analysis of Digital Images to Evaluate Turfgrass Characteristics. Crop Sci. 45:1536-1539.

Karcher, D.E. and M.D. Richardson. 2003. Quantifying Turfgrass Color Using Digital Image Analysis. Crop Sci. 43:943-951.

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

Karcher, D.E., M.D. Richardson, J.W. Landreth, J.H. McCalla Jr. Recovery of Zoysiagrass Varieties from Divot Injury. 2005. Online. Applied Turfgrass Science. doi:10.1094/ATS-2005-0728-01-RS.

Kershaw, K.A. 1973. Quantitative and dynamic plant ecology. 2nd ed. Am. Elsevire Publishing Co., New York.

Landschoot, P.J., C.F. Mancino. 2000. A Comparison of Visual vs. Instrumental Measurement of Color Differences in Bentgrass Turf. HortScience. 35(5):914-916.

Laycock, R.W., and P.M. Canaway. 1980 An optical point quadrant frame for the estimation of cover in closely-mown turf. J. Sports Turf Res. Inst. 56:91-92.

Louhaichi, M., M.M. Borman, and D.E. Johnson. 2001. Spatially coated platform and aerial photography for documentation of grazing impacts in wheat. Geocarta. 16; 63-68.

Morris, K. N. 2002. A guide to NTEP turfgrass rating. A publication of the National Turfgrass Evaluation program, NETP. 11: 30-39.

Oosting, H.J. 1956. The study of plant communities. W.H. Freeman and Co. San

Francisco, California, USA.

Patton, A.J. and Z.J. Reicher. 2007. Zoysiagrass Species and Genotypes Differ in Their Winter Injury and Freeze Tolerance. Crop Sci. 47:1619-1627.

Purcell, L.C. 2000. Soybean canopy coverage and light interception measurements using digital imagery. Crop. Sci. 40:834-837.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying Turfgrass Cover Using Digital Image Analysis. Crop Sci. 41:1884-1888.

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

Skogley, C.R. and C.D. Sawyer. 1992. Field Research. pp 589-614 *In* D.V. Waddington et al. (ed.) Turfgrass. Agron. Monogr. 32. ASA, CSSA, and SSSA, Madison, WI.

Table 1. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2007. [a]

Mowing height	Large crabgrass cover		
	VR	DIA	LIA
cm		%	
2.5	63.8 a [b]	69.4 a	55.1 a
5.2	40.0 b	49.5 b	29.1 b
7.6	10.0 c	21.7 c	7.3 c
10.2	0.0 d	12.6 d	0.1 d
Coefficient of Variation	32.9	27.5	51.8
F-test comparing VR vs. DIA or LIA		2.34	0.74
P-value comparing VR vs. DIA or LIA		0.131	0.392

[a] Abbreviations: VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis.

[b] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD, P=0.05 level.

Table 2. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2008. [a]

	Large crabgrass cover		
Mowing height	VR	DIA	LIA
cm		%	
2.5	59.4 a [b]	58.6 a	49.6 a
5.2	34.8 b	36.7 b	27.4 b
7.6	10.3 c	16.4 c	8.6 c
10.2	2.2 d	10.8 c	1.9 d
Coefficient of Variation	35.3	41.1	64.7
F-test comparing VR vs. DIA or LIA		0.12	0.52
P-value comparing VR vs. DIA or LIA		0.725	0.471

[a] Abbreviations: VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis.

[b] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD, P=0.05 level.

Table 3. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2007 at Raleigh, NC. [a]

		Large crabgrass cover		
Treatments	Rate	VR	DIA	LIA
	kg ai/ha		%	
prodiamine	0.84	3.8 ef [b]	7.5 c	4.7 efg
prodiamine	0.57 fb 0.27	1.3 f	9.9 bc	0.8 h
dithiopyr	0.57	21.3 abc	14.9 abc	15.3 bc
dithiopyr	0.27 fb 0.27	10.0 bcde	12.9 abc	11.3 bcd
oxadiazon	3.36	5.3 def	8.3 c	3.1 fgh
oxadiazon	1.68 fb1.68	3.0 ef	7.5 c	1.7 gh
pendimethalin	3.36	13.8 bcd	11.0 bc	12.7 bcd
pendimethalin	1.68 fb 1.68	8.8 cde	13.3 abc	13.7 bcd
oryzalin	3.36	31.3 a	23.6 a	26.3 a
oryzalin	1.68 fb 1.68	20.0 abc	16.2 abc	14.2 bc
benefin + trifluralin	3.36	11.3 bcde	16.4 abc	8.0 cde
benefin +trifluralin	1.68 fb 1.68	13.8 bcde	15.3 abc	7.9 def
nontreated		23.8 ab	19.8 ab	19.4 ab
Coefficient of Variation		40.9	27.4	27.3
F-test comparing VR vs. DIA or LIA			0.14	1.2
P-value comparing VR vs. DIA or LIA			0.7136	0.2756

Table 3. Continued.

---

[a] Abbreviations: RAL, Raleigh, NC; VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis.

[b] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD, P=0.05 level.

Table 4. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2007 at Jackson Springs, NC. [a]

		Large crabgrass cover		
Treatments	Rate	VR	DIA	LIA
	kg ai/ha		%	
prodiamine	0.84	0.0 f [b]	1.2 c	0.0 f
prodiamine	0.57 fb 0.27	0.0 f	1.9 c	0.0 f
dithiopyr	0.57	8.8 cd	8.1 c	7.2 cd
dithiopyr	0.27 fb 0.27	0.5 ef	9.2 c	1.3 e
oxadiazon	3.36	7.5cde	2.5 c	4.4 cde
oxadiazon	1.68 fb1.68	11.8 bc	5.2 c	4.6 cde
pendimethalin	3.36	9.3 cd	3.1 c	8.0 c
pendimethalin	1.68 fb1.68	5.8 cdef	1.8 c	4.3 cde
oryzalin	3.36	25.0 b	17.4 b	28.8 b
oryzalin	1.68 fb 1.68	15.0 bcd	6.8 c	9.6 c
benefin + trifluralin	3.36	3.3 cdef	3.1 c	3.0 de
benefin + trifluralin	1.68 fb 1.68	2.8 def	2.2 c	2.5 e
nontreated		47.5 a	33.4 a	41.7 a
Coefficient of Variation		54.1	53.6	29.9
F-test comparing VR vs. DIA or LIA			1.58	0.39
P-value comparing VR vs. DIA or LIA			0.2113	0.5319

Table 4. Continued

[a] Abbreviations: JAC, Jackson Springs, NC; VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis.

[b] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD, P=0.05 level.

Table 5. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2008 at Raleigh, NC. [a]

Treatments	Rate	Large crabgrass cover		
		VR	DIA	LIA
	kg ai/ha	%		
prodiamine	0.84	10.0 ab [b]	14.1 ab	7.2 ab
prodiamine	0.57 fb 0.27	11.3 ab	13.7 ab	7.3 ab
dithiopyr	0.57	16.3 ab	21.7 ab	14.2 ab
dithiopyr	0.27 fb 0.27	6.3 b	13.8 ab	4.3 b
oxadiazon	3.36	7.5 b	10.0 b	5.7 b
oxadiazon	1.68 fb 1.68	10 b	12.7 b	9.2 b
pendimethalin	3.36	7.5 b	13.8 ab	4.9 b
pendimethalin	1.68 fb 1.68	6.3 b	12.0 b	8.5 b
oryzalin	3.36	12.5 ab	14.1 ab	10.8 ab
oryzalin	1.68 fb 1.68	20.0 ab	19.9 ab	16.1 ab
benefin + trifluralin	3.36	13.8 ab	20.7 ab	9.2 ab
benefin +trifluralin +	1.68 fb1.68	17.5 ab	19.4 ab	16.3 ab
nontreated		26.3 a	25.3 a	21.9 a
Coefficient of Variation		53.8	28.6	56.9
F-test comparing VR vs. DIA or LIA			2.93	1.11
P-value comparing VR vs. DIA or LIA			0.0901	0.2945

Table 5. Continued.

[a] Abbreviations: RAL, Raleigh, NC; VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis.

[b] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD, P=0.05 level.

Table 6. Comparison of digital image analysis, visual ratings, and line intersect analysis to estimate percent crabgrass cover in tall fescue in 2008 at Jackson Springs, NC; [a]

Treatments	Rate	Large crabgrass cover		
		VR	DIA	LIA
	kg ai/ha		%	
prodiamine	0.84	0.3 ef [b]	2.8 d	0.2 d
prodiamine	0.57 fb 0.27	0.0 f	2.6 d	0.0 d
dithiopyr	0.57	10.0 abc	9.9 ab	9.8 abc
dithiopyr	0.27 fb 0.27	3.0 cdef	4.1 cd	2.5 bcd
oxadiazon	3.36	2.0 cdef	3.8 cd	1.1 d
oxadiazon	1.68 fb 1.68	3.0 cde	3.9 cd	2.0 cd
pendimethalin	3.36	2.8 cdef	5.8 bcd	1.7 d
pendimethalin	1.68 fb 1.68	0.5 def	3.8 cd	0.3 d
oryzalin	3.36	10.0 ab	13.5 a	8.5 ab
oryzalin	1.68 fb 1.68	11.3 ab	8.9 abc	12.2 a
benefin + trifluralin	3.36	3.5 bcd	4.1 cd	2.5 bcd
benefin +trifluralin	1.68 fb 1.68	1.3 def	3.6 d	1.0 d
nontreated		17.5 a	11.8 a	16.1 a
Coefficient of Variation		62.7	30.4	71.2
F-test comparing VR vs. DIA or LIA			0.79	0.17
P-value comparing VR vs. DIA or LIA			0.3755	0.6815

Table 6. Continued.

---

[a] Abbreviations: JAC, Jackson Springs, NC; VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis.

[b] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD, P=0.05 level.

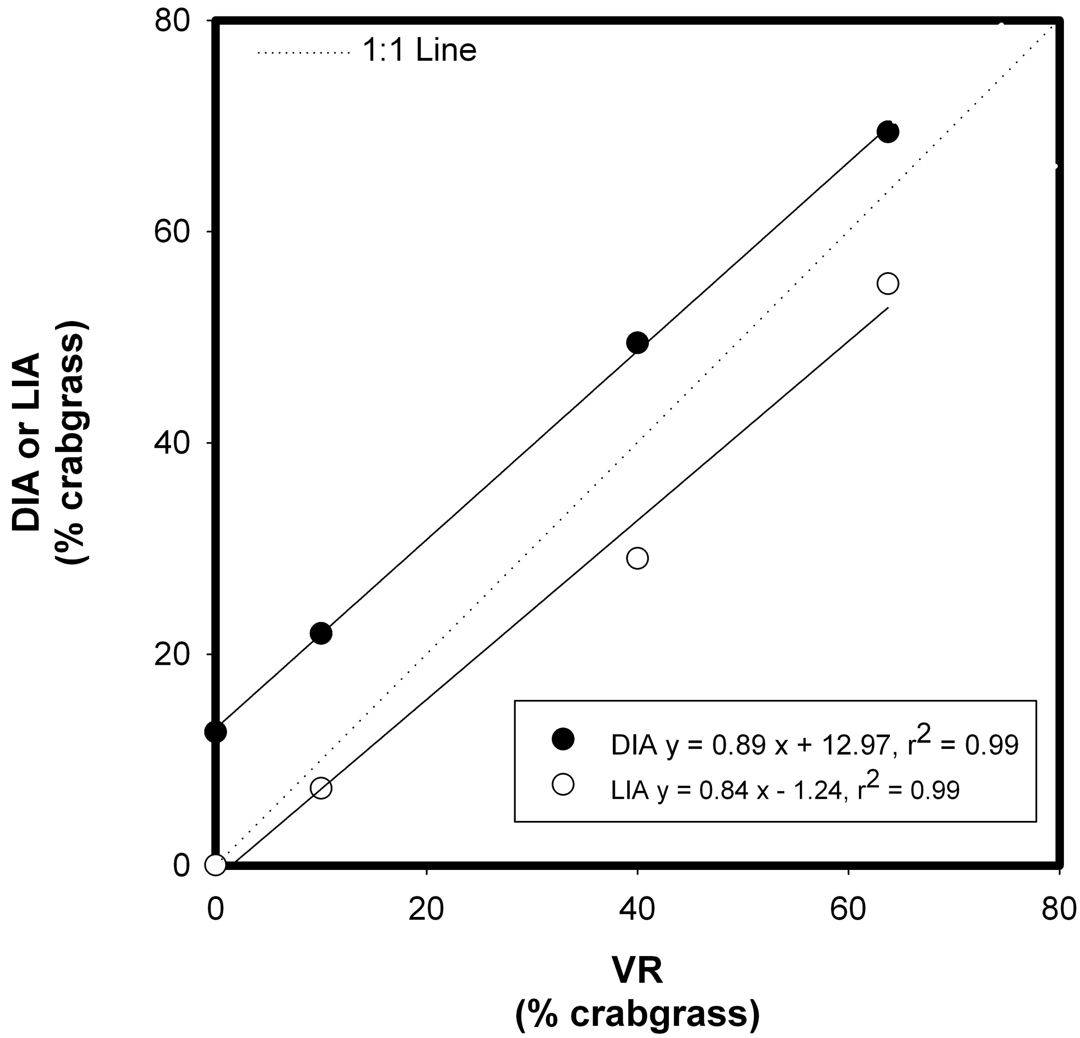

Figure 1. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2007, for the effect of mowing height on crabgrass incidence.[a]

[a] Abbreviations: VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis.

[b] 1:1 relationship is exemplified by the dotted line within the figure.

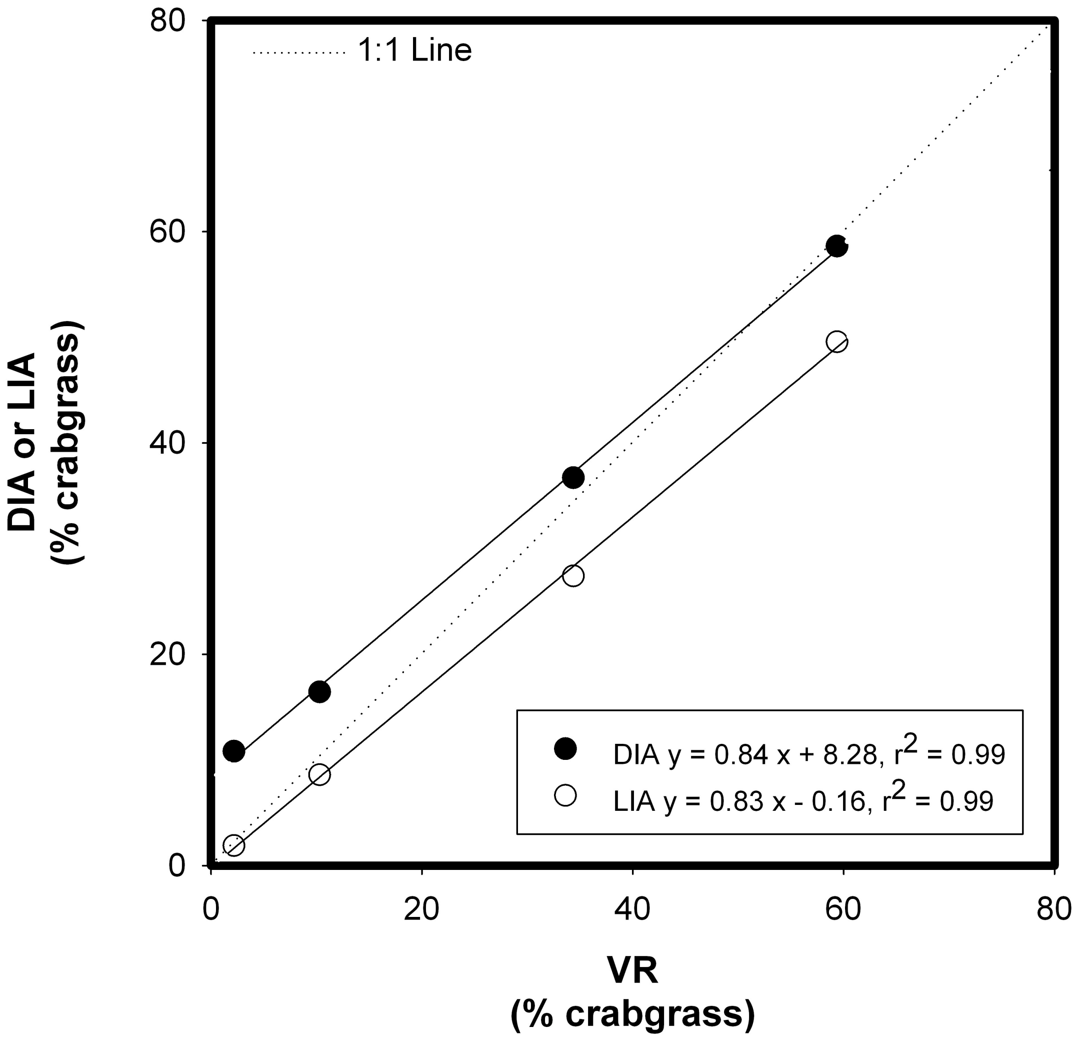

Figure 2. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2008, for the effect of mowing height on crabgrass incidence.[a]

[a] Abbreviations: VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis.

[b] 1:1 relationship is exemplified by the dotted line within the figure.

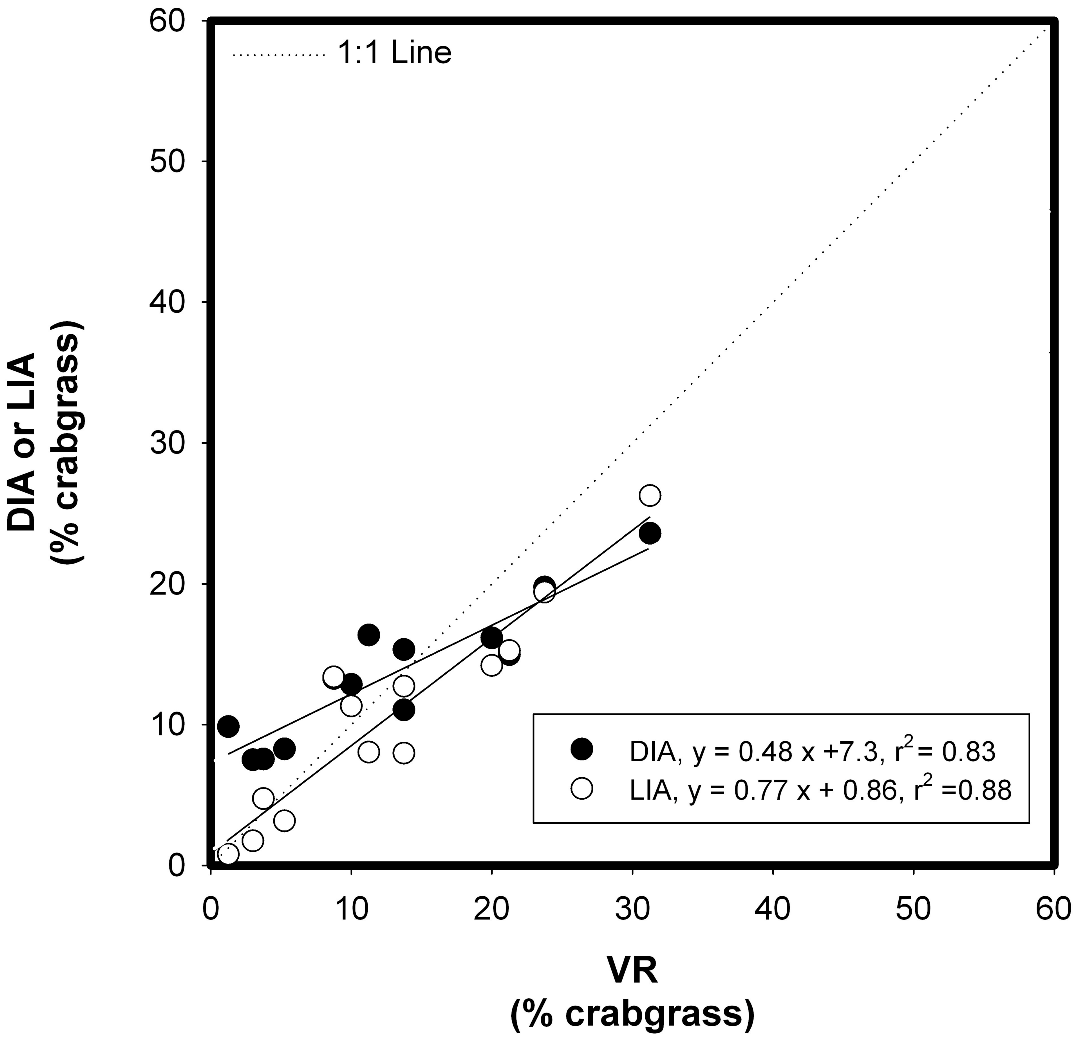

Figure 3. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2007 at Raleigh, NC, for the effect of various pre-emergence herbicides on crabgrass incidence.[a]

[a] Abbreviations: VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis; RAL, Raleigh (North Carolina).

[b] 1:1 relationship is exemplified by the dotted line within the figure.

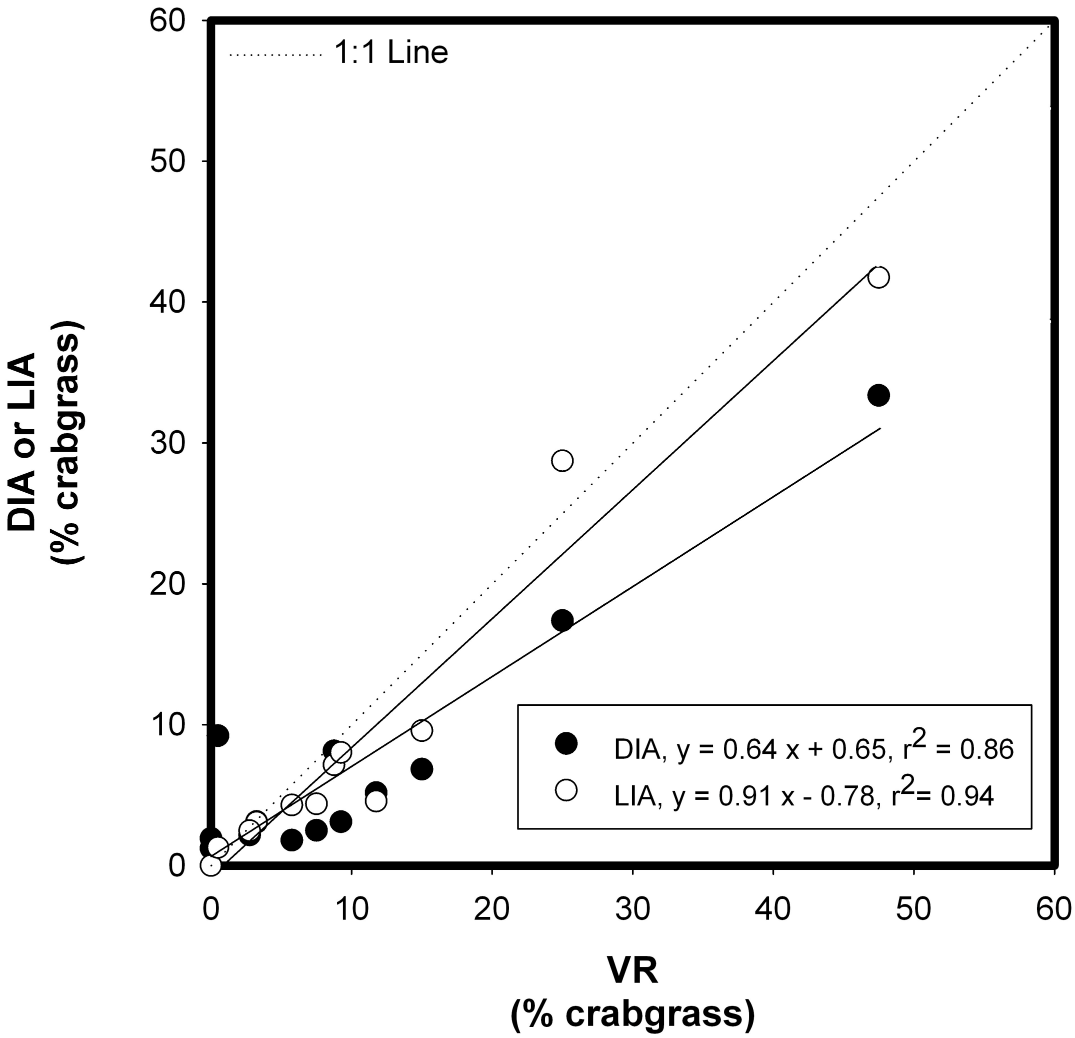

Figure 4. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2007 at Jackson Springs, NC, for the effect of various pre-emergence herbicides on crabgrass incidence.[a]

[a] Abbreviations: VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis; JAC, Jackson Springs (North Carolina).

[b] 1:1 relationship is exemplified by the dotted line within the figure.

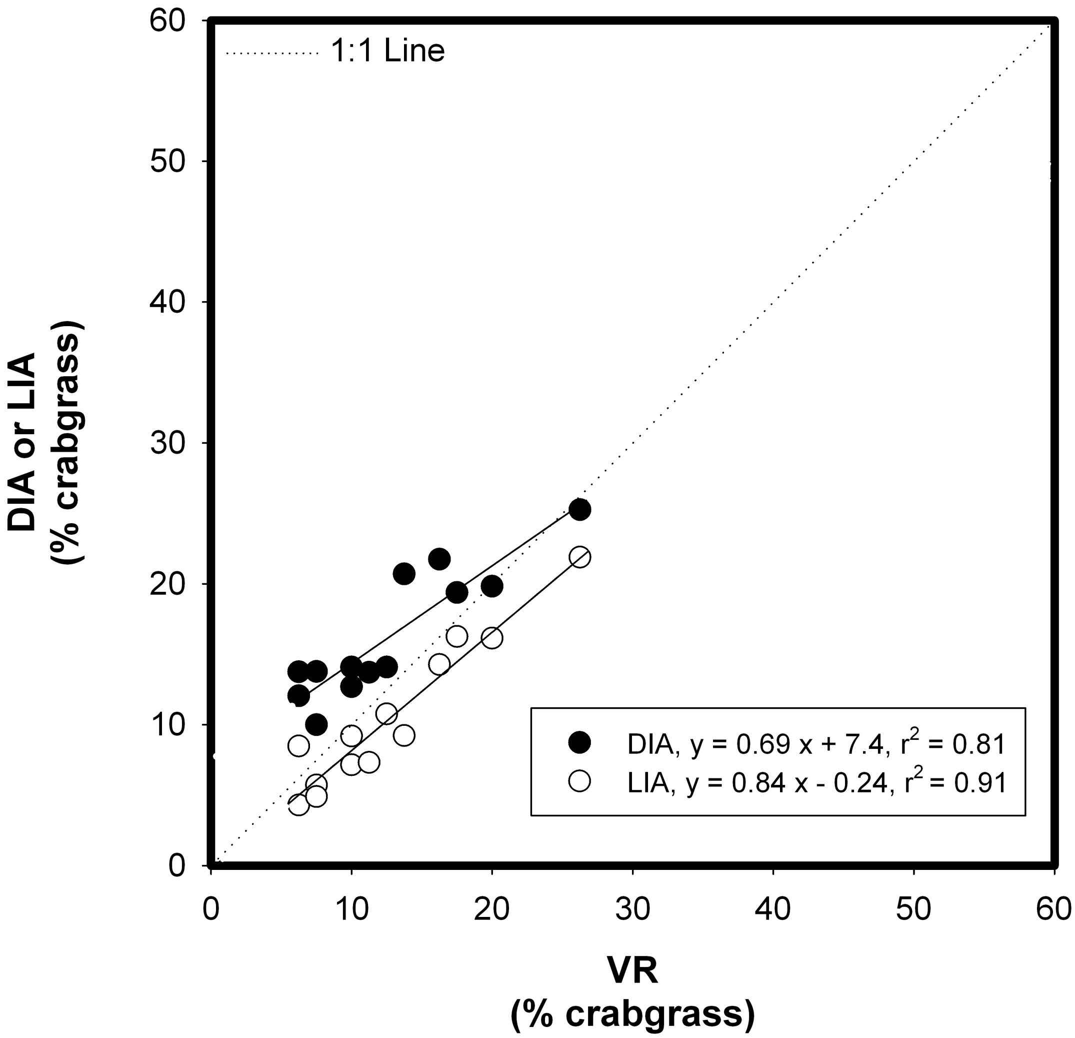

Figure 5. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2008 at Raleigh, NC, for the effect of various pre-emergence herbicides on crabgrass incidence.[a]

[a] Abbreviations: VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis; RAL, Raleigh (North Carolina).

[b] 1:1 relationship is exemplified by the dotted line within the figure.

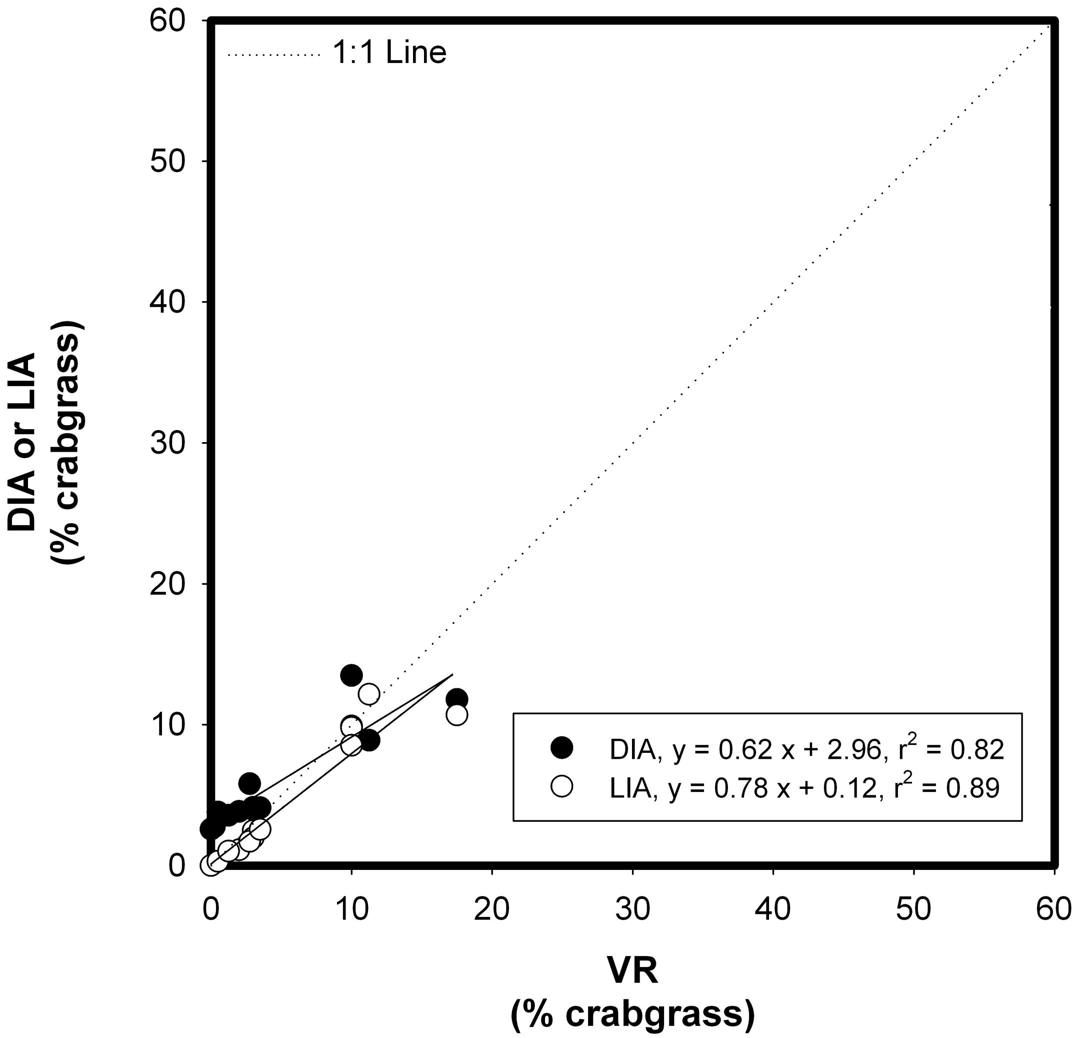

Figure 6. Regression analysis of visual ratings verses either line intersect analysis or digital image analysis in 2008 at Jackson Springs, NC, for the effect of various pre-emergence herbicides on crabgrass incidence.a

[a] Abbreviations: VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis; JAC, Jackson Springs (North Carolina).

[b] 1:1 relationship is exemplified by the dotted line within the figure.

CHAPTER 2

Effect of Mowing Height on Large Crabgrass (*Digitaria sanguinalis*) and Brown Patch (*Rhizoctonia solani*) Incidence in Turfgrass Systems.[1]

J. A. Hoyle, F. H. Yelverton, G. L. Miller, L. Tredway[2]

Tall fescue and common bermudagrass are widely used in turf areas including home lawns, commercial properties, schools, airports, etc. There are several pests that homeowners and turfgrass managers must contend with when managing these turf species. Large crabgrass is among the most troublesome weed in these areas and brown patch is one of the most common diseases affecting tall fescue. These common turf weeds and diseases become a major problem because they are able to establish quickly, reproduce quickly, and may be enhanced by the transitional zone climate. Field experiments were conducted during 2007 and 2008 at two locations to determine if turf mowing height could suppress large crabgrass in common bermudagrass and the effect on

---

[1] Received for publication ________________ and in approved form ____________.

[2] Graduate Research Assistant[a], Professor[a], Professor[a] and Associate Professor[b], respectively. North Carolina Sate University, [a]Department of Crop Science, Box 7620, Raleigh, NC 27695-7620. [b]Department of Pathology, Box 7616, Raleigh, NC 27695-7620.

large crabgrass and brown patch in tall fescue. Evaluated bermudagrass mowing heights included 1.3, 2.5, 3.8, and 5.1 cm and 2.5, 5.1, 7.6, and 10.2 cm in tall fescue. These mowing heights were initiated once soil temperatures reached an optimum for crabgrass emergence. In bermudagrass, no significant trends were discerned among mowing heights or locations. However, there were significant differences in crabgrass cover in tall fescue by early-September. The presence of brown patch did not affect crabgrass incidence. Increasing mowing height decreases crabgrass cover and increases brown patch infection. Fungicide applications reduce the amount of brown patch cover over all mowing heights. Results show that the growth habitat of tall fescue can be used to help control large crabgrass by implementing the correct mowing height but may also increase brown patch incidence.

Nomenclature: large crabgrass, *Digitaria sanguinalis* (L.) Scop; tall fescue, *Lolium arundinacuem* Schreb.; common bermudagrass *Cynodon dactylon* var 'Savannah'; brown patch, *Rhizoctonia solani* Kühn

Key Words: incidence, large crabgrass cover, brown patch cover, mowing height.

Abbreviations: VR, visual rating; LIA, line intersect analysis; RAL, Raleigh; JAC Jackson Springs, North Carolina, NC.

INTRODUCTION

There are many reasons that a turfgrass species can have an invasion of weeds of multiple species. Ultimately, it is the reduction in turfgrass cover that will eventually lead to an invasion of weeds. Turfgrass thinning can be a result of improper mowing and/or fertilization, disease infestation, insect invasion, drought stress, shading, nematodes, and/or other unwanted pests. Crabgrass (*Digitaria* spp.) is among the most common and competitive weeds in turf (Dernoeden et al. 1993) that will invade a turfgrass stand if turf cover is reduced. This can be caused by brown patch (*Rhizoctonia solani*) one of the most destructive diseases of tall fescue (*Lolium arundenaceum*) (Burpee 1995). With increasing amounts of herbicides, fungicides, and insecticides being removed from the turfgrass market and societal pressure for organic alternatives, many new ideas are being researched in the weed science industry to minimize the use of pesticides.

Brown patch and crabgrass are both serious pests that can invade turfgrass systems. Research in the past has shown that cultural factors such as mowing height can influence brown patch or crabgrass invasion in multiple species of turfgrasses (Voigt et al. 2001; Dernoeden 1993; Fidanza and Dernoeden 1996a, 1996b).

Brown patch is a disease that continues to limit the quality in many private and commercial properties (Burpee 1995). In 1914, *R. solani* Kühn was discovered by C. D. Piper (Piper and Coe 1919). It continues to be a problem today even with the common fungicides available. Research was conducted with brown patch to evaluate if canopy density plays a role in the severity of the disease where it was found that increased canopy density increased development of brown patch (Yuen et al. 1994). Research by Giesler et al. (1996a) used seeding rates of multiple tall fescue (*Lolium arundenaceum*) cultivars to determine if the density of the canopy played a role in brown patch disease severity. It was found that the least dense canopies sustained the least amount of disease. Additional research conducted by Giesler et al. (1996b) looked more in depth at the canopies and into the microclimate. Canopy densities were again created by different cultivars with different canopy densities or by seeding the same cultivar of tall fescue at different rates. It was concluded that the physical proximity of leaf blades in high-density turfs can be more favorable for brown patch disease.

Canopy density can be influenced by mowing height. It is hypothesized that the higher the cutting height of a turfgrass, the closer the proximity of leaf blades along with an increase in density can hold moisture inside the canopy allowing an optimal environment for the pathogen to grow and infect. This leaf orientation would give the brown patch pathogen an optimum environment for infection and growth in turfgrass species.

Research has been conducted to evaluate multiple mowing heights to determine the severity of brown patch infestation. Burpee (1995) conducted research into three mowing heights of 3.8, 6.4, and 8.9 cm in various tall fescue cultivars and one cultivar blend. Across all tested cultivars it was concluded that the severity of *Rhizoctonia* blight was significantly greater at the 8.9 cm mowing height in the first year. The next year concluded severity was greater in the 3.8 cm mowing height plots. Fidanza and Dernoedon (1996b) conducted research with comparing 1.7 and 4.5 cm mowing heights for the severity of brown patch in perennial ryegrass (*Lolium perenne* L. var. ‘Caravelle’) along with other cultural factor inputs. It was concluded that in the first year the lower mowing height of 1.7 cm was blighted more than the 4.5 cm mowing height. The following two years showed a more severe blight in the 4.5 cm mowing height compare to the 1.7 cm mowing height. Contradictory studies have shown results of brown patch having greater severity in low cut-turf (Rowell 1951) and others having no difference between mowing height and disease incidence (Shurtleff 1953).

Research conducted into the effect of mowing height on cool season turfgrass has shown that lower mowing heights increase weed density in various turfgrass species (Busey 2003). Jagschitz and Ebdon (1985) reported that with the increase in mowing height there are decreased crabgrass populations in chewings fescue {*Festuca rubra* var. *commtata* Gaudin [= *F. rubra* subsp. *fallax (*Thuill.) Nyman]}. Niehus (1974) and Dunn et al. (1981) reported the same with Kentucky bluegrass. With regard to fine fescue, a decrease in mowing height increases percent crabgrass cover (Dernoden et al. 1998). Experiments by Hall (1980), Dernedoen et al. (1993), and Voigt et al. (2001) resulted in a decrease in percent crabgrass cover with increasing mowing height.

Even though there are conflicting reports of mowing height affecting the severity of brown patch, the postulation that increasing mowing height increases the compatibility of the environment for the pathogen of *Rhizoctonia* to develop and infect the turfgrass species holds because research shows that increased canopy density increases brown patch infestation. It is not understood if once brown patch has established in the turfgrass, will the desired turf species cover be reduced allowing voids for weed infestation, especially crabgrass?

It is known that a reduction in crabgrass results from increasing mowing height and further there are varying reports of brown patch across a range of mowing heights. The question is will the brown patch severity influence crabgrass infestation?

The purpose of the research was to determine the effect of mowing height on crabgrass and brown patch incidence along with the effect of mowing height in bermudagrass for crabgrass incidence. This research will provide evidence that can contribute to better Integrated Pest Management strategies with reduced amounts of pesticide inputs.

MATERIALS AND METHODS

Mowing Height Study in Tall Fescue. Experiments were conducted to determine the effect of mowing height on crabgrass and brown patch incidence in tall fescue. Field experiments were initiated in Raleigh (RAL), NC and in Jackson Springs (JAC), NC on 6 March 2007 and 3 March 2008. Soil was a Wakulla sand (siliceous, thermic psammentic hapludults) in JAC with 0.86% humic matter and pH 5.5. Soil in RAL was an Appling fine sandy loam (fine, kaolinitic, thermic typic kanhapludult) with 1.19% humic matter and pH 5.8.

At initiation, areas were mown at a 5.1 cm height to remove debris facilitate crabgrass seeding. Large crabgrass[3] was slit and broadcast seeded at 170 – 190 kg/ha. A

Toro Seeder 93 (Bloomington, MN 55420) attached to a John Deere 4700 Tractor (Moline, IL 61265) was used in at least four directions to apply approximately 90 kg/ha of crabgrass seed. A broadcast spreader was then used in two directions to apply the remaining crabgrass seed (90 kg / ha).

Five isolates of *Rhizoctonia solani* Kühn, originally isolated from tall fescue in Knightdale, NC (ECC-A, ECC-B, ECC-C, and ECC-E)[4] were grown on sterilized rye grain for field inoculations. First, 1000 ml flasks were filled with 250 ml of rye grain, 9.86 ml of calcium carbonate power and 220 ml of warm water. Flasks were caped with foam plugs and aluminum foil and then autoclaved for 45 minutes on fast exhaust. Eight, approximately 0.6 cm squares from one of the five actively growing *Rhizoctonia solani* cultures were then inserted into the rye grain flasks. The flasks were shaken every 3 to 4 d to encourage uniform colonization of the grain. On 7 June 2007 and 3 June 2008, 10 cm^3 of the *Rhizoctonia solani* infested grain was applied in two locations in each plot and brushed down through the turfgrass canopy by hand. Immediately after inoculation, irrigation was applied to the plot area to keep the rye grain spawn moist. Irrigation was then set to apply approximately 0.25 cm of irrigation water to cover the research plots at 0800 hour and 2000 hour to create an optimum environment for brown patch occurrence. Split plots were treated with azoxystrobin[5] at 0.628 kg ai/ha in 2007 on 9 June, 9 July, and 13 August and in 2008 on 5 June, 8 July, and 7 August. Azoxystrobin was applied with a CO_2 pressurized hand-held spray boom equipped with four VS8008XR[6] flat fan nozzles on 38-cm spacing calibrated to deliver 818 L/ha.

Whole plot mowing treatments were applied when soil temperatures reached a daily average of 12.8° C, 14 March 2007 and18 March 2008. Treatments applied to the whole plots were 2.5, 5.1, 7.6, and 10.2 cm mowing height. Mowing height treatments were applied with a rotary mower (Honda HRC 216, Alpharetta, GA 30005-8847) every 3 to 4 d with clippings returned. Plot areas in RAL were fertilized[7] with nitrogen at 24 kg/ha for the entire growing season. Plot areas in JAC were fertilized[7] with nitrogen 38.4 kg/ha for the entire growing season.

Visual Rating (VR) was used to determine crabgrass cover and recorded on 13 September 2007 and 11 September 2008. VR utilized a 0 (no crabgrass) to 100% (complete crabgrass cover) scale that was visual estimated by an evaluator. Line Intersect Analysis (LIA) (5.1 cm spacing) was used to determine brown patch cover recorded on 17 September 2007 and 10 September 2008. LIA utilized a 0 (no brown patch cover) to 100% (complete brown patch cover) scale after intersect counts were converted using Equation 1.

$$(\text{Counted Intersects} / (\text{Total Intersects}=943)) \times 100 \qquad [1]$$

Four replicates were included at both locations and years. Plots were 2.1 by 1.2 m and arranged in a randomized split-block design. Data were arcsine square root transformed to increase homogeneity of variance (Zar 1999), subjected to ANOVA and means were separated according to Fisher's Protected LSD (P=0.05) using SAS Statistical Software (SAS Inc., Cary, NC). Nontransformed means are presented for clarity.

Mowing Height Study in Common Bermudagrass. Experiments were conducted to determine the effect of mowing height on crabgrass incidence in common bermudagrass (*Cynodon dactylon* var 'Savannah'). Experiments were initiated in RAL and in JAC on 6 March 2007 and 3 March 2008. Soil was the same as those reported for tall fescue mowing height study.

At initiation, plot areas were verticut with Graden Verticutter (Victoria, Australia 3061) on 2.5 cm spacing in two directions. Large crabgrass[3] was sown into common bermudagrass as reported in tall fescue mowing height study. Areas were then dragged with a coco-mat to ensure soil seed contact.

Mowing height treatments (1.3, 2.5, 3.8, and 5.1 cm) were initiated when soil temperatures reached a daily average of 12.8° C; 14 March 2007 and 18 March 2008. 2.5, 3.8, and 5.1 cm treatments were maintained with a rotary mower (Honda HRC 216, Alpharetta, GA 30005-8847) whereas the 1.3 cm mowing height treatment was maintained with a Toro reel mower (Toro Groundsmaster 1000, Bloomington, MN 55420). Mowing was performed every 3 to 4 d with clippings returned. Plot areas in RAL were fertilized[7] with nitrogen at 14.4 kg/ha throughout growing season. Fertilizer[7] in JAC was applied for a total nitrogen amount of 19.6 kg/ha during growing season.

Visual ratings were used to determine large crabgrass cover and recorded on 16 August 2007 and 18 August 2008. VR utilized a 0 (no crabgrass) to 100% (complete crabgrass cover) scale and evaluated visually by an evaluator. Four replicates were included at both locations and years. Plots were 1.5 by 3 m and arranged in a randomized complete block design. Data were arcsine square root transformed to increase homogeneity of variance (Zar, 1999), subjected to ANOVA and means were separated according to Fisher's Protected LSD (P=0.05) using SAS Statistical Software (SAS Inc., Cary, NC). Nontransformed means are presented for clarity.

RESULTS AND DISCUSSION

Mowing Height Study in Common Bermudagrass. A treatment by year interaction prevented pooling data across years; thus data are presented separately. In 2007, 5 months after initiation mowing heights of 1.3, 2.5, 3.8, and 5.1 cm resulted in 43.1, 56.3, 61.9, and 62.5 % large crabgrass cover, respectively (Table 1). Mowing heights of 1.3 and 2.5 cm were not significantly different from one another. Mowing heights of 2.5, 3.8, and 5.1 cm were also not significantly different from one another. No significant differences in crabgrass infestation were observed among mowing height treatments in 2008 (Table 1). Mowing heights of 1.3, 2.5, 3.8, and 5.1 cm resulted in 63.1, 70.6, 66.3, and 65.0 % large crabgrass cover, respectively.

These results are similar to previous research by Callahan and Overton (1978) showing that mowing height in common bermudagrass did not influence crabgrass populations. Common bermudagrass is a horizontal spreading warm season turf that emerges from dormancy about mid-March. This is approximately the same time the summer annual large crabgrass emerges (when soil temperatures reach 12.8°C). Therefore there is not a competitive edge of the common bermudagrass over the crabgrass. The large crabgrass has growth characteristics requiring high light for emergence. The common bermudagrass is not able to grow to heights that are needed to compete with or shade the large crabgrass that reaches the high light requirement.

Mowing Height Study in Tall Fescue. A treatment by year by location interaction prevented pooling data across years and locations for the crabgrass data; thus data are presented separately. A treatment by year interaction and a treatment by fungicide application prevented pooling data across years for brown patch data; thus data are presented separately. Results from data showed there was no interaction between the presence of brown patch, from a fungicide treatment to non-fungicide treatment, in predicting the amount of large crabgrass cover (F-Value = 0.07, P-Value = 0.7922). Therefore, the amount of brown patch did not contribute to explaining crabgrass cover, and data was pooled over fungicide treated and non-fungicide treated. Data are presented separately for the effect of mowing height on crabgrass incidence in tall fescue and the effect of mowing height on brown patch incidence in tall fescue. All crabgrass data and brown patch data were collected 6 months after initiation.

The main effect of mowing height on large crabgrass cover for 2007 and 2008 had an F-value (646.99; P-Value < 0.0001) over ten times greater than the interaction of mowing height by year by location (F-value = 5.32; P-Value = 0.0020), therefore this main effect is shown in Table 2. Mowing heights of 2.5, 5.1, 7.6, and 10.2 cm resulted in 96, 63, 22, and 3% large crabgrass cover, respectively. Table 3 shows the significant interaction in predicting large crabgrass cover from height by location by year. In JAC in 2007, mowing heights of 2.5, 5.1, 7.6, and 10.2 resulted in percent large crabgrass cover of 97.5, 83.8, 33.8, and 0.3, respectively. In JAC in 2008, there was 94.4, 48.2, 18.1, and 4.4% crabgrass cover, respectively for mowing heights of 2.5, 5.1, 7.6, and 10.2 cm. The 2007 data in RAL showed 98.3, 63.8, 10.1, and 0.4% crabgrass cover, respectively for 2.5, 5.1, 7.6, and 10.2 cm mowing heights. The 2008 data at the same location resulted in 97.3, 55.0, 24.4, and 6.4% large crabgrass cover, respectively for mowing heights of 2.5, 5.2, 7.6, and 10.2 cm. Through both years and at both locations all mowing height treatments were significantly different from one another.

Results show that tall fescue is able to have a competitive edge over the large crabgrass at higher mowing heights compared to the lower mowing heights as was the case for previously conducted research. The vertical bunch type growth habit of tall fescue at higher mowing heights is able to produce a high canopy density to prevent the sun from penetrating to the soil and allowing the large crabgrass seed to emerge. Homeowners can help suppress large crabgrass emergence by keeping a healthy lawn at taller mowing heights. Keeping a healthy tall fescue stand can reduce the amount of pressure that is applied to a pre-emergence herbicide program commonly used to prevent large crabgrass emergence. A pre-emergence herbicide is needed to control a higher population of emerging large crabgrass seeds at lower mowing heights. According to this study, a pre-emergence herbicide applied on a tall fescue turf mown at 2.5 cm must control 96% large crabgrass cover compared to a pre-emergence herbicide applied to a tall fescue turf mown at 10.2 cm to control only 3% crabgrass cover. There is less pressure applied to a pre-emergence herbicide program that is applied in tall fescue mown at 10.2 cm.

The effect of mowing height on brown patch incidence in tall fescue was pooled between locations and fungicide treatment but not years because of a mowing height by year interaction (Table 4). Percent brown patch cover (Table 4) increased with increasing mowing heights of 2.5, 5.1, 7.6, and 10.2 cm, resulting in 0.3, 1.8, 4.1, and 6.3% respectively in 2007. In 2008 the same trend held with 0.0, 0.2, 0.9, and 1.7% brown patch cover respectively for mowing heights 2.5, 5.1, 7.6, and 10.2 cm. Both years resulted in every mowing height treatment being different from one another. A mowing height by fungicide treatment interaction (F-Value = 23.52; P-Value = <0.0001) was also observed. Table 5 shows the difference between mowing heights with and with out a preventative fungicide treatment. If a fungicide was applied to the tall fescue, percent brown patch cover resulted in 0.0, 0.2, 0.8, and 1.3% brown patch cover, respectively for mowing heights 2.5, 5.1, 7.6, and 10.2 cm. This resulted in mowing heights of 2.5 and 5.1 cm not being significantly different and mowing heights 7.6 and 10.2 cm not being significantly different. If no fungicide was applied mowing heights of 2.5, 5.1, 7.6, and 10.2 cm resulted in 0.3, 1.8, 4.3, and 6.7% brown patch cover, respectively with all mowing height treatments being different from one another.

Increasing mowing height increases the percent brown patch cover in tall fescue. With the increased mowing height there is more capability for the turfgrass canopy to become denser and retain water longer to provide an optimum environment for the *Rhzoctonia* pathogen to grow, develop and infect the tall fescue. At the highest mowing height (10.2 cm) percent brown patch cover was over the accepted threshold of 5%. Also, there is a fungicide application effect on the amount of brown patch present in all tall fescue mowing heights. If a fungicide is applied there is less brown patch cover than if no fungicide is applied at all mowing heights less than the common threshold for home lawns.

In conclusion, mowing height does not have an effect on crabgrass incidence in common bermudagrass. Brown patch does not have an effect on the amount of crabgrass present through 2.5, 5.1, 7.6 and 10.2 cm mowing heights. This is speculated that brown patch is not severe enough to create voids in tall fescue that would then lead to large crabgrass emergence. Mowing height has an effect on large crabgrass incidence and brown patch incidence. With increasing mowing heights crabgrass populations decreases in tall fescue. This supports findings from Jagschitz and Ebdon (1985) in chewings fescue, Niehus (1974) and Dunn et al. (1981) in Kentucky bluegrass, and Dernoden et al. (1998) in fine fescues. With increasing mowing heights, brown patch development increases in tall fescue. This is speculated by with the increase in mowing height the increase in canopy density therefore increase brown patch severity. This supports results that were found from Giesler et al. (1996a) that the increased turfgrass density the increase in disease severity. This research also supports results from Burpee (1995) that the severity of *Rhizoctonia* blight was significantly greater at the higher mowing heights (8.9 cm) in tall fescue than at lower mowing heights (3.8 and 6.4 cm).

SOURCES OF MATERIALS

[3] Lorenz's Ok Seeds, 511 W Oklahoma, Okeene, OK 73763

[4] Brown Patch Isolates (*Rhizoctonia solani* Kühl) - ECC-A, ECC-B, ECC-C, ECC-E, Knightdale, NC

[5] Azoystrobin – Heritage TL – Syngenta Crop Protection, Greensboro, NC 27409

[6] Teejet Spraying Systems Company, North Avenue Wheaton, IL 60189-7900

[7] Harrell's Fertilizer – Greensboro, NC

ACKNOWLEDGEMENTS

The authors express appreciation to Travis Gannon and Leon Warren for their technical assistance and Dr. Arellano Consuelo for statistical assistance.

LITERATURE CITED

Burpee, L. 1995. Interactions among mowing height, nitrogen fertility, and cultivar affect the severity of *Rhizoctonia* blight of tall fescue. Plant Dis. 79:721-726.

Busey, P., 2003. Cultural management of weeds in turfgrass: a review. Crop Sci. 43:1899-1911.

Callahan, L.M. and J.R Overton. 1978. Effects of lawn management practices on a bermudagrass turf. p.37-40. Tennessee Farm and Home Science No. 108. Tennesee Agric. Exp. Stn., Knoxsville, TN.

Dernoeden, P.H., M.J. Carrol, and J.M. Krouse. 1993. Weed mamagement and tall fescue quality as influenced by mowing, nitrogen, and herbicides. Crop Sci. 33:1055-1061.

Dernoedon, P.H., M.A. Fidanza, and J.M. Krouse. 1998. Low maintenance performace of five *Festuca* species in monostands and mixtures. Crop Sci. 38:434-439.

Dunn, J.H., C.J. Nelson, and R.D. Winfrey. 1981. Effects of mowing and fertilization on quality of ten Kentucky bluegrass cultivars. p. 293-301. *In* R.W. Sheard (ed.) Proc 4th Int. Turfgrass Res. Conf., Guelph, ON, Canada. 19-23 July 1981. Ontario Agric. College, Univ. Guelph, and Int. Turfgrass Soc., Guelph, ON, Canada.

Fidanza, M.A., P.H. Dernoedon. 1996a. Brown patch severity on perennial ryegrass as influenced by irrigation, fungicide, and fertilizers. Crop Sci. 36:1631-1638.

Fidanza, M.A., P.H. Dernoedon. 1996b. Influence of mowing height, nitrogen source, and iprodine on brown patch severity in perennial ryegrass. Crop Sci. 36:1620-1630.

Giesler, L.J., G.Y. Yuen, and G.L. Horst. 1996a. Tall fescue canopy density effects on brown patch disease. Plant Dis. 80:384-388.

Giesler, L.J., G.Y. Yuen, and G.L. Horst. 1996b. The microclimate in tall fescue as affected by canopy density and its influence on brown patch disease. Plant Dis. 80:389-394.

Hall, J.R., III. 1980. Effect of cultural factors on tall fescue-Kentucky bluegrass sod quality and botanical composition. p. 367-377 *In* J.B. Beard (ed.) Proc. 3rd Int Turfgrass Res. Conf., Munich, West Germany. 11-13 July 1977. ASA, CSSA, SSSA, and Int. Turfgrass Soc., Madison, WI.

Jagschitz, J.A., and J.S. Ebdon. 1985. Influence of mowing, fertilizer and herbicide on crabgrass infestation in red fescue turf. p. 699-704. *In* F. Lemaire (ed.) Proc. 5th Int. Turfgrass Res. Conf., Avignon, France. 1-5 July 1985. Institut National de la Recherche Agronomique, Paris.

Niehaus, M.H. 1974. Effects of nitrogen fertilizer and mowing height on weed content of a Kentucky bluegrass turf. Research Summary No. 79. Ohio Agric. Res. And Dev. Center, Wooster, OH.

Piper, C.V. and Coe H.S. 1919. *Rhizoctonia* in lawns and pastures. Phytopathology 9:89-92.

Rowell, J.B. 1951. Observations on the pathogenicity of *Rhizoctonia solani* on bent grasses. Plant Dis. Rept. 35:240-242.

Shurtleff, M.C. 1953. Brown patch of turf caused by *Rhizoctonia solani* Kühn. PhD. Diss. Department of Pathology, University of Minnesota, St. Paul (Diss. Abst. 53-11120).

Voigt, T.B., T.W. Fermanian, and J.E. Haley, 2001. Influence of mowing and nitrogen fertility on tall fescue turf. Int. Turfgrass Soc. Res. J. 9:953-956.

Yuen, G.Y., L.J. Giesler, and G.L. Horst. 1994. Influence of canopy structure on tall fescue cultivar susceptibility to brown patch disease. Crop Prot. 13:439-442.

Zar, J.H. 1999. Biostatistical analysis, 4th Ed. Prentice Hall, New Jersey. pp. 273-281

Table 1. Effect of mowing height on large crabgrass incidence in common bermudagrass pooled over Jackson Springs, NC and Raleigh, NC, 5 months after initiation.

Mowing height	Large crabgrass cover	
	2007	2008
cm	%	
1.3	43.1 b [a]	63.1 a
2.5	56.3 ab	70.6 a
3.8	61.9 a	66.3 a
5.1	62.5 a	65.0 a

[a] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD, 0.05 level.

Table 2. Effect of mowing height on large crabgrass incidence in tall fescue pooled over Jackson Springs, NC and Raleigh, NC; 2007 and 2008, 6 months after initiation.

Mowing height	Large crabgrass cover
cm	—————%—————
2.5	96 a[a]
5.1	63 b
7.6	22 c
10.2	3 d

[a] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD, 0.05 level.

Table 3. Effect of mowing height on large crabgrass incidence in tall fescue at Jackson Springs, NC and Raleigh, NC, 6 months after initiation. [a]

	Large crabgrass cover			
	JAC		RAL	
Mowing height	2007	2008	2007	2008
cm	%			
2.5	97.5 a[b]	94.4 a	98.3 a	97.3 a
5.1	83.8 b	48.2 b	63.8 b	55.0 b
7.6	33.8 c	18.1 c	10.1 c	24.4 c
10.2	0.3 d	4.4 d	0.4 d	6.4 d

[a] Abbreviations: JAC, Jackson Springs; RAL Raleigh

[b] Means within a column followed by the same letter are not significantly different according to Fisher's projected LSD, 0.05 level.

Table 4. Effect of mowing height on brown patch incidence in tall fescue pooled over fungicide treatments, 6 months after initiation.

	Brown patch cover	
Mowing height	2007	2008
cm	%	
2.5	0.3 d [a]	0.0 d
5.1	1.8 c	0.2 c
7.6	4.1 b	0.9 b
10.2	6.3 a	1.7 a

[a] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD, 0.05 level.

Table 5. Effect of mowing height and fungicide application on brown patch incidence in tall fescue pooled over locations and years, 6 months after initiation.

	Brown patch cover	
Mowing height	No Fungicide	Fungicide [a]
cm	%	
2.5	0.3 d [b]	0.0 b
5.1	1.8 c	0.2 b
7.6	4.3 b	0.8 a
10.2	6.7 a	1.3 a

[a] Azoxystrobin applied at 0.628 kg ai/ha, early June, July, August

[b] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD, 0.05 level.

CHAPTER 3

Effect of Mowing Height on Common Bermudagrass (*Cynodon dactylon*) Encroachment in Tall Fescue (*Lolium arundinaceum*).[1]

J. A. Hoyle, F. H. Yelverton, G. L. Miller, L. Tredway[2]

In 2007 and 2008 field research trials were conducted to determine the effect of mowing height on bermudagrass encroachment in tall fescue. A standard USGA cup cutter (10.8 cm diameter) was used to harvest common bermudagrass (*Cynodon dactylon* var. 'Riviera') plugs. Four plugs were installed into each plot (3.05 x 3.05 meters), 0.76 meters from the corner. Evaluated mowing heights included 2.5, 5.1, 7.6 and 10.2 cm in tall fescue, which were initiated once the bermudagrass plugs were installed. Line intersect analysis was used to determine the percent bermudagrass cover starting 12 weeks after initiation (WAI) continuing twice monthly through 28 WAI (early/mid-

---

[1] Received for publication ________________ and in approved form ____________.

[2] Graduate Research Assistant[a], Professor[a], Professor[a] and Associate Professor[b], respectively. North Carolina Sate University, [a]Department of Crop Science, Box 7620, Raleigh, NC 27695-7620. [b]Department of Pathology, Box 7616, Raleigh, NC 27695-7620.

October), when the bermudagrass entered dormancy. In 2007, at 28 WAI there were significant differences in common bermudagrass cover resulting in 19.3, 7.4, 3.2, and 1.9%, respectively for mowing heights 2.5, 5.1, 7.6 and 10.2 cm. While in 2008, 28 WAI contained 20.2, 6.3, 2.7, and 1.7% bermudagrass cover, respectively, with mowing heights 2.5, 5.1, 7.6 and 10.2 cm. At 80 WAI of the 2007 initiated research trial significant differences in common bermudagrass cover occurred in mowing heights of 2.5, 5.1, 7.6 and 10.2 cm, resulting in 79.4, 39.9, 12.2, and 2.9%, respectively. These data indicate the growth habit of tall fescue may be used to help suppress bermudagrass encroachment by implementing a correct mowing regime.

Nomenclature: common bermudagrass *Cynodon dactylon* var. ‘Riviera’; tall fescue, *Lolium arundinaceum* Schreb.

Key Words: bermudagrass cover, contamination

Abbreviations: WAI, weeks after initiation; LIA, line intersect analysis

INTRODUCTION

Tall fescue (*Lolium arundinaceum* Schreb) and common bermudagrass (*Cynodon dacytlon* var. ‘Riviera’) are common turf types in the transitional zone of the United States. Tall fescue delivers a nice year round green color with a vertical bunch type growth habit and thrives in the cooler seasons of the year; spring and fall. Common bermudagrass is a warm season turfgrass species with a horizontal rhizomatous and stonliferous growth habit, which thrives in the summer months and becomes dormant in the winter. With these two types of turfgrass species grown in the transitional zone of the United States, there is concern for contamination and a non-uniform turfgrass stand. Common bermudagrass can commonly contaminate tall fescue stand by vegetative means (Brede 1992). Common bermudagrass is particularly invasive in cool-season turf like tall fescue because of its vigorous growth rate and rhizomatous-stoloniferous habit (Brede 1992). During the winter months when the tall fescue is green, the common bermudagrass is dormant and brown. It is non-uniform in appearance and also difficult to maintain the two species together (Decker et al. 1974). The bi-species turfgrass stand causes problems when trying to manage for weeds because most common herbicides have selective tolerance to the either tall fescue or common bermudagrass but not both. It also can cause safety problems when turf is in a high traffic area. For example, in playgrounds where children can trip on the height differences present in the bi-species turfgrass stand. Lastly, it can cause ball playability issues, as in golf course roughs when the mixture of turf species does not allow for golfers to anticipate the club reaction when swung at the ball in a bi-species turfgrass stand. Most importantly the color discrepancy causes unsightly views in the winter months in the transitional zone.

There are selective herbicidal control options to remove common bermudagrass in tall fescue. These options are pricey and require multiple applications of multiple products during the year. Also, application by a licensed pesticide applicator is required. These applications include monthly applications of fenoxaprop plus triclopyr from June through September. Fluzaifop can be applied in the spring and fall for bermudagrass suppression (Yelverton et al. 2008). These applications are expensive because of tank mixing and multiple applications.

Past studies have been conducted in an attempt to manage these two grass species together to produce higher yields for a forage crop (Decker et al. 1974; Fribourg and Overton 1979; Wilkerson et al. 1968). Wilkerson et al. (1968) conducted research to determine if fertilization and mowing height could contribute to competition with tall fescue and dormant 'Coastal' bermudagrass. It was found that the higher mowing height increased tall fescue content in the dormant 'Coastal' bermudagrass. This indicates raising the mowing height when there is contamination of a common bermudagrass species in tall fescue, even in months where the bermudagrass is dormant, can increase the desired tall fescue species.

Other research has shown cultural factors for minimizing invasion of common bermudagrass into tall fescue (Brede 1992). The cultural factors specifically evaluated included mowing height, seeding rate of tall fescue 'Mustang' and 'Kentucky 31', and source of bermudagrass 'Guymon' introduction (seed, rhizomes, clippings). Results showed that there was no bermudagrass invading tall fescue at the higher mowing height (57mm) compared to the lower mowing height (19mm). Brede (1992) concluded that cultural practices influenced the amount of bermudagrass invasion in tall fescue.

Therefore, options exist which homeowners can implement through regular maintenance of their lawn to allow for suppression of common bermudagrass in a contaminated tall fescue stand. The objective of this study was to determine the spread of common bermudagrass in tall fescue by implementing multiple mowing heights common in home lawn maintenance.

MATERIALS AND METHODS

Experiments were conducted to determine the effect of mowing height on common bermudagrass 'Riviera' encroachment in tall fescue. Field experiments were initiated in Raleigh, North Carolina at Lake Wheeler Field Labs on 30 March 2007 and 28 March 2008. Soil in Raleigh was an Appling fine sandy loam (fine, kaolinitic, thermic typic kanhapludult) with 1.19% humic matter and pH 5.8.

A standard USGA cup cutter[3] (10.8 cm dia) was used to harvest common bermudagrass plugs (2.5 cm turfgrass height) from Jackson Springs, North Carolina at the Sandhills Research Station where the soil was a Wakulla sand (siliceous, thermic psammentic hapludults) with 0.86% humic matter and pH 5.5. Four plugs were installed into each plot 0.76 m from the corners of the plots in holes (10.8 cm dia) augured out with a hand auger (BT 121 STIHL Earth Auger, Virginia Beach, VA, 23352) (Figure 1).

Mowing height treatments of 2.5, 5.1, 7.6, and 10.2 cm were applied once common bermudagrass plugs were installed. Treatments were maintained with a rotary mower (Honda HRC 216, Alpharetta, GA 30005) at the initial mowing height with a frequency of every 3 to 4 d with clippings returned. Plot areas in Raleigh were fertilized[4] with N at 19.2 kg/ha throughout the growing season.

Line Intersect Analysis (LIA) (2.5 cm spacing) was used to determine common bermudagrass cover and recorded twice monthly starting 12 WAI and continuing 28 WAI until common bermudagrass entered dormancy in mid October. The 2007 initiated trials were maintained at the same mowing height in 2008 and data was recorded twice monthly from 64 WAI to 80 WAI in 2008. LIA utilized a 0 (no common bermudagrass cover) to 100% (complete common bermudagrass cover) scale after intersect counts were converted using Equation 1.

$$(\text{Counted Intersects} / (\text{Total Intersects}=1225)) \times 100 \qquad [1]$$

Four replicates were included for both years of the study. Plots were 3.1 by 3.1 m and arranged in a randomized complete block design. Data were arcsine square root transformed to increase homogeneity of variance (Zar 1999), subjected to repeated measures and ANOVA and means were separated according to Fisher's Protected LSD ($P=0.05$), using SAS Statistical Software (SAS Inc., Cary, NC). Nontransformed means are presented for clarity.

RESULTS AND DISCUSSION

A treatment by year interaction prevented pooling data across years; thus data are presented separately. In 2007, at 12 WAI each mowing height had similar results showing 1.1, 0.9, 0.8, and 0.6 % bermudagrass cover respectively for mowing heights of

2.5, 5.1, 7.6, and 10.2 cm (Table 1). Bermudagrass cover in 2.5, 5.1, and 7.6 cm mowing height treatments were not different from one another but all were different in the 10.2 cm height. From 14 WAI through 20 WAI bermudagrass cover in all mowing treatments was different from one another. At 14 WAI mowing treatments of 2.5, 5.1, 7.6, and 10.2 cm height resulted in 2.2, 1.7, 1.3, and 0.9% bermudagrass cover respectively. There was 3.9, 2.5, 1.9, and 1.1% bermudagrass cover at 16 WAI in 2.5, 5.1, 7.6 and 10.2 cm mowing height treatments, respectively. At 16 WAI, percent bermudagrass cover was different for every mowing height treatment. At 18 WAI the 2.5, 5.1, 7.6, and 10.2 cm mowing heights treatments resulted in 4.4, 3.0, 1.9, and 1.2% bermudagrass cover, respectively. The mowing treatments 2.5, 5.1, 7.6, and 10.2 cm height at 20 WAI were also different resulting in 7.6, 3.8, 2.3, and 0.9% bermudagrass cover, respectively. At 22 WAI the 7.6 and 10.2 cm mowing height treatments were not different at 2.3 and 1.5% bermudagrass cover, respectively. These mowing height treatments were different from the 5.1 cm mowing height with 5% bermudagrass cover that was also different from the 2.5 cm mowing height with 13.5% bermudagrass cover. The trend of percent bermudagrass cover at the 2.5 cm mowing height treatment being different from the percent bermudagrass cover for all other mowing height treatments started at 22 WAI and continued through 28 WAI. The same was the case for percent bermudagrass cover at the 5.1 cm mowing height treatment. The percent bermudagrass cover for 7.6 and 10.2 cm mowing height treatments continued the trend of not being different from one another but different from the 2.5 and 5.1 cm mowing height treatments. At 24 WAI mowing heights of 2.5, 5.1, 7.6, and 10.2 cm resulted in 14.6, 5.6, 2.8, and 1.7% bermudagrass cover, respectively. There was 18.9, 7.1, 3.1, and 1.9% bermudagrass cover, respectively for mowing heights of 2.5, 5.1, 7.6, and 10.2 cm at 26 WAI. Lastly, as the common bermudagrass was proceeding to dormancy at 28 WAI there was 19.3, 7.4, 3.2, and 2.0% bermudagrass cover, respectively for 2.5, 5.1, 7.6, and 10.2 cm mowing heights.

Note that the 2.5 cm mowing height treatment had a greater difference in growth starting at 1.1% bermudagrass cover at 12 WAI to 19.3% bermudagrass cover at 28 WAI. The 5.1 cm mowing height had only 7.4% bermudagrass cover at 28 WAI. Also note that the 7.6 and 10.2 cm mowing heights had a higher competition between tall fescue and common bermudagrass in that the 7.6 cm height had only 3.2% bermudagrass cover and 10.2 cm mowing height had 2% bermudagrass cover. From 12 WAI to 28 WAI the 10.2 cm mowing height treatment only increased a total of 1.4% bermudagrass cover. Mowing height treatments of 2.5, 5.1, and 7.6 cm increased 18.2, 6.5, and 2.4% bermudagrass cover, respectively from 12 WAI to 28 WAI.

The 2008 data showed similar results (Table 2). At 12 WAI each mowing height of 2.5, 5.1, 7.6, and 10.2 cm were different in percent bermudagrass cover resulting in 2.8, 1.8, 1.5, and 1.1, respectively. The trend of percent bermudagrass cover for each mowing height treatment being different from one another continued through 20 WAI. At 14 WAI, mowing heights of 2.5, 5.1, 7.6, and 10.2 cm resulted in all different values of 4.9, 2.6, 2.0, and 1.4% bermudagrass cover, respectively. The same was true for 16 WAI with 5.8, 3.4, 2.6, and 1.8% bermudagrass cover, respectively for mowing heights of 2.5, 5.1, 7.6, and 10.2 cm. Mowing heights of 2.5, 5.1, 7.6, and 10.2 cm resulted in 6.6, 3.3, 2.1, and 1.6% bermudagrass cover, respectively at 18 WAI, all different. At 20 WAI there was 8.4, 3.1, 1.8, and 1.1% bermudagrass cover, respectively for mowing heights of 2.5, 5.1, 7.6, and 10.2 cm which was the last data recording for percent bermudagras cover being different. At 22 WAI there was no difference between percent bermudagrass cover for mowing height treatments 7.6 and 10.2 cm with 2.3 and 1.6% bermudagrass cover, respectively. The 2.5 and 5.1 cm mowing height treatments showed differences at 18.3 and 5.6% bermudagrass cover, respectively but were also different from 7.6 and 10.2 cm mowing height treatments. This trend continued through 28 WAI. At 24 WAI mowing heights of 2.5, 5.1, 7.6, and 10.2 cm resulted in 19.7, 5.5, 2.5, and 1.6% bermudagrass cover, respectively. At 26 WAI percent bermudagrass cover was 20.8, 6.1, 2.7, and 1.6 respectively for mowing heights of 2.5, 5.1, 7.6, and 10.2 cm. At the last data collection for 20 WAI in 2008, the mowing heights consisted of 20.2, 6.3, 2.7, and 1.7% bermudagrass cover respectively for mowing heights of 2.5, 5.1, 7.6, and 10.2 cm. There was no difference in percent bermudagrass cover between the 7.6 and 10.2 cm mowing height treatments. Both the 2.5 and 5.1 cm mowing heights were different in percent bermudagrass cover from all other mowing heights.

As in 2007, the 2008 data showed again percent bermudagrass cover increased as mowing height increased from 12 WAI to 28 WAI. Mowing heights 2.5, 5.1, 7.6, and 10.2 cm increased 17.4, 4.5, 1.2, and 0.6% bermudagrass cover, respectively over the entire growing season for common bermudagrass.

Further research was conducted on the 2007-initiated trial in 2008. At 64 WAI mowing heights of 2.5, 5.1, 7.6, and 10.2 cm resulted in 23.9, 7.0, 2.7, and 0.6% bermudagrass cover, respectively with all treatment heights being different (Table 3). Mowing heights 7.6 and 10.2 cm resulted in no differences from one another at 4.5 and 1.2% bermudagrass cover at 66 WAI. Percent bermudagrass cover for mowing heights of 2.5 and 5.1 cm were different from one another and from 7.6 and 10.2 cm at 66 WAI. The 34.8 and 11.4% bermudagrass cover resulted from 2.5 and 5.1 cm mowing height treatments at 66 WAI. At 68 WAI mowing heights resulted in 37.1, 12.6, 5.1, and 1.3% bermudagrass cover, respectively for mowing heights of 2.5, 5.1, 7.6, and 10.2 cm, all different. This trend continued at 70 WAI for mowing heights of 2.5, 5.1, 7.6, and 10.2 cm with 47.9, 14.8, 5.6, and 1.4% bermudagrass cover, respectively. Percent bermudagrass cover for mowing heights 7.6 and 10.2 cm at 72 WAI were not different resulting in 5.9 and 1.7% bermudagrass cover, respectively. Response for mowing height treatments 2.5 and 5.1 cm at 72 WAI were different from all other mowing height treatments resulting in 58.5 and 17.7% bermudagrass cover. At 74 WAI all mowing height treatments were different in percent bermudagrass with four separate groupings having 64.9, 29.4, 10.6, and 2.3% cover, respectively for mowing heights 2.5, 5.1, 7.6, and 10.2 cm. Percent bermudagrass for mowing heights 7.6 and 10.2 cm were not different from one another at 76 WAI resulting in 10.4 and 2.4% bermudagrass cover, respectively. Mowing heights 2.5 and 5.1 at 76 WAI resulted in 71.6 and 31.8% bermudagrass cover respectively, and were different from mowing heights 7.6 and 10.2

cm and from each other. The trend continued through 78 WAI with 77.6, 37.4, 11.9, and 3.5% bermudagrass cover, respectively for mowing heights of 2.5, 5.2, 7.6, and 10.2 cm. Lastly, at 80 WAI percent bermudagrass cover for all mowing height treatments were different resulting in 79.4, 39.9, 12.2, and 2.9% bermudagrass cover, respectively for mowing heights 2.5, 5.1, 7.6, and 10.2 cm.

The same trend continued from 12 WAI to 28 WAI as well as from 64 WAI to 80 WAI. From 64 WAI to 80 WAI mowing heights 2.5, 5.1, 7.6, and 10.2 cm increased 55.5, 32.9, 9.5, and 2.3% bermudagrass cover, respectively. From 12 WAI to 80 WAI mowing heights of 2.5, 5.1, 7.6, and 10.2 cm increased 78.3, 39.0, 11.4, and 2.3% bermudagrass cover, respectively.

The data shows that the sole cultural practice of mowing height can suppress common bermudagrass encroachment in tall fescue. The greatest increase in bermudagrass cover resulted after one full year of growth showing that if bermudagrass is not controlled at lower mowing heights and that each year the problem can increase drastically. It has been postulated that tall fescue suppresses bermudagrass through competition for light (Wilkinson et al. 1968). This research helps to prove this postulate presuming the lower cut height would allow for more light penetration to reach the bermudagrass. Also, that the lower mowing heights stress the tall fescue. During the prime growth season common bermudagrass can tolerate lower mowing heights than tall fescue therefore giving the bermudagrass an advantage. This research shows that the taller mowing heights give the advantage to tall fescue even if bermudagrass is present in the turfgrass stand and helps suppress the spread or encroachment of the bermudagrass even though bermudagrass is an aggressive turf species. In conclusion, cultural practices can influence bermudagrass encroachment in tall fescue even if bermudagrass has already been contaminated into the tall fescue stand. This research can now be used in conjunction with chemical control options to minimize the amount of herbicidal applications therefore allowing applications to be more cost effective to turfgrass managers.

SOURCES OF MATERIALS

[3] Par-Aide-USGA Standard Cup Cutter, John Deere Landscapes/LESCO, 650 Stephenson Hwy, Troy, MI, 48083-1110

[4] Harrell's Fertilizer – Greensboro, NC

ACKNOWLEDGEMENTS

The authors express appreciation to Travis Gannon and Leon Warren for their technical assistance and Dr. Arellano Consuelo for statistical assistance.

LITERATURE CITED

Brede, A.D. 1992. Cultural factors for minimizing bermudagrass invasion into tall fescue turf. Agron. J. 84:919-922.

Decker, A.M., H.J. Retzer, and F.R. Dudley, 1974. Cool-season perennials vs. cool-season annuals sod seeded into a bermudagrass sward. Agron. J. 66:381-383.

Fribourg, H.A. and J.R. Overton. 1979. Persistence and productivity of tall fescue in bermudagrass sods subjected to different clipping managements. Agron. J. 71:620-624.

Wilkinson, S.R., L.F. Welch, G.A. Hillsman, and W.A. Jackson. 1968. Compatibility of tall fescue as affected by nitrogen fertilizer and height of clip. Agron. J. 60:359-362.

Yelverton, F. H., B. R. Lassiter, G. G. Wilkerson, L. Warren, T. W. Gannon, J. J. Reynolds, and B. S. Boul. "Berudagrass (*Cynodon dactylon* L. Pers.)." Turffiles. 15 July 2008. North Carolina State University. 24 Mar. 2009 <http://www.turffiles.ncsu.edu/Weeds/Bermudagrass.aspx>.

Table 1. Effect of mowing height on bermudagrass encroachment in tall fescue over multiple weeks after incitation; 2007.[a]

	Bermudagrass cover								
Mowing Height	12 WAI	14 WAI	16 WAI	18 WAI	20 WAI	22 WAI	24 WAI	26 WAI	28 WAI
cm	%								
2.5	1.1 a [b]	2.2 a	3.9 a	4.4 a	7.6 a	13.5 a	14.6 a	18.9 a	19.3 a
5.1	0.9 a	1.7 b	2.5 b	3.0 b	3.8 b	5.0 b	5.6 b	7.1 b	7.4 b
7.6	0.8 a	1.3 c	1.9 c	1.9 c	2.3 c	2.3 c	2.8 c	3.1 c	3.2 c
10.2	0.6 b	0.9 d	1.1 d	1.2 d	0.9 d	1.5 c	1.7 c	1.9 c	2.0 c

[a] Abbreviations: WAI, weeks after initiation.

[b] Means within a column followed by the same letter are not significantly different according to Fisher's projected LSD, 0.05 level.

Table 2. Effect of mowing height on bermudagrass encroachment in tall fescue over multiple weeks after incitation; 2008.[a]

	Bermudagrass cover								
Mowing Height	12 WAI	14 WAI	16 WAI	18 WAI	20 WAI	22 WAI	24 WAI	26 WAI	28 WAI
cm	%								
2.5	2.8 a [b]	4.9 a	5.8 a	6.6 a	8.4 a	18.3 a	19.7 a	20.8 a	20.2 a
5.1	1.8 b	2.6 b	3.4 b	3.3 b	3.1 b	5.6 b	5.5 b	6.1 b	6.3 b
7.6	1.5 c	2.0 c	2.6 c	2.1 c	1.8 c	2.3 c	2.5 c	2.7 c	2.7 c
10.2	1.1 d	1.4 d	1.8 d	1.6 d	1.1 d	1.6 c	1.6 c	1.6 c	1.7 c

[a] Abbreviations: WAI, weeks after initiation.

[b] Means within a column followed by the same letter are not significantly different according to Fisher's projected LSD, 0.05 level.

Table 3. Effect of mowing height on bermudagrass encroachment in tall fescue over multiple weeks after incitation; 2007-2008.[a]

	Bermudagrass cover								
Mowing Height	64 WAI	66 WAI	68 WAI	70 WAI	72 WAI	74 WAI	76 WAI	78 WAI	80 WAI
cm	%								
2.5	23.9 a [b]	34.8 a	37.1 a	47.9 a	58.5 a	64.9 a	71.6 a	77.6 a	79.4 a
5.1	7.0 b	11.4 b	12.6 b	14.8 b	17.7 b	29.4 b	31.8 b	37.4 b	39.9 b
7.6	2.7 c	4.5 c	5.1 c	5.6 c	5.9 c	10.6 c	10.4 c	11.9 c	12.2 c
10.2	0.6 d	1.2 c	1.3 d	1.4 d	1.7 c	2.3 d	2.4 c	3.5 c	2.9 d

[a] Abbreviations: WAI, weeks after initiation.

[b] Means within a column followed by the same letter are not significantly different according to Fisher's projected LSD, 0.05 level.

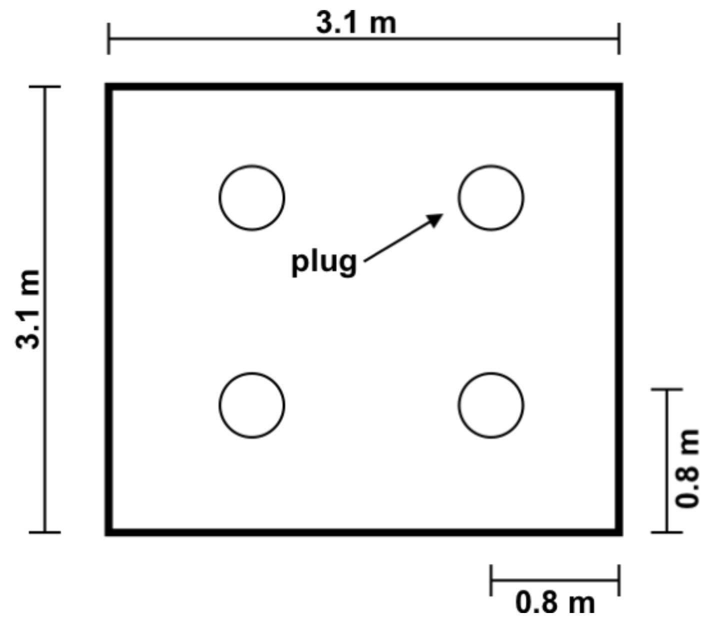

Figure 1. Plot layout for common bermudagrass installation in tall fescue