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Effects of Trinexapac-ethyl and Winter Overseeding on the Morphological Characteristics and Traffic Tolerance of Bermudagrass Cultivars

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To the Graduate Council:

I am submitting herewith a thesis written by William D. Haselbauer entitled "Effects of Trinexapac-ethyl and Winter Overseeding on the Morphological Characteristics and Traffic Tolerance of Bermudagrass Cultivars." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant Sciences.

John C. Sorochan, Major Professor

We have read this thesis and recommend its acceptance:

Jim T. Brosnan, Brandon J. Horvath, Tom J. Samples

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Carolyn R. Hodges
Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

EFFECTS OF TRINEXAPAC-ETHYL AND WINTER OVERSEEDING ON THE MORPHOLOGICAL CHARACTERISTICS AND TRAFFIC TOLERANCE OF BERMUDAGRASS CULTIVARS

A Thesis Presented for the
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Degree
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William Donald Haselbauer
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DEDICATION

I dedicate this Thesis to my parents, Donald and Katie, who have provided me with more love and support any son could hope for. Also, to my brother Ben and my sisters Meghan and Gretchen who are my best friends and have helped shape me into the person I have become. Lastly, to the love of my life Megan, thank you for taking a chance and moving to Tennessee with me. I look forward to the many years we have ahead of us.

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ABSTRACT

Common bermudagrass [*Cynodon dactylon* (L.) Pers.] and hybrid bermudagrass [*C. dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] are some of the most common turfgrasses used on athletic fields. Subsequently, the traffic tolerance of commercially available cultivars and the effects of trinexapac-ethyl (TE) on bermudagrass athletic fields with or without perennial ryegrass are often limited. A two year study at the University of Tennessee was conducted under simulated athletic field traffic to evaluate the performance of bermudagrass cultivars as affected by TE and overseeding. Bermudagrass cultivars evaluated were Tifway, Riviera, Patriot, and Celebration. TE treatments consisted of an untreated control, TE at 76.3 g a.i. ha^{-1} every 14 days until 14 days prior to trafficking (TE A), and TE at 76.3 g a.i. ha^{-1} every 14 days until 14 days after trafficking (TE B). Overseeding treatments consisted of no overseeding and overseeding at 670 kg ha^{-1} of perennial ryegrass (*Lolium perenne* L.). Plots were rated for percent green cover using digital image analysis after every 5 traffic events. Soil physical characteristic measurements were performed after every traffic season. Morphological data was determined by measuring number of leaves, internode lengths, leaf angle, and leaf width of the bermudagrass. Cultivar was significant for percent green cover for both years of this study with Tifway and Celebration having the highest ratings and Patriot having the lowest rating. TE was also significant for percent green cover for the first 10 traffic events with TE treatment B having lower percent cover values. Morphological characteristic was significant for leaf angle for both years of the study. A more vertical leaf angle to the shoot occurred in the more traffic resistant cultivars

Tifway and Celebration. Finally, both TE treatments yielded higher percent green cover values in 2008 when morphological characteristic data was collected and a more vertical leaf angle to the shoot occurred compared to the untreated control. Tifway, Celebration, and Riviera when applied with trinexapac-ethyl before the traffic season and overseeded with perennial ryegrass would be beneficial for athletic field managers.

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CHAPTER I

LITERATURE REVIEW

Bermudagrass

Athletic fields in the transition zone have the option of growing either cool or warm season turfgrasses, but one of the most common turfgrasses used is the warm season species, bermudagrass (Trenholm et al., 1999). This is because bermudagrass has good recuperative potential and the ability to tolerate high temperature extremes in summer (Puhalla et al., 1999). Although native to Africa, in the United States bermudagrass is frequently used on athletic fields and golf courses. Common bermudagrass [*Cynodon dactylon* (L.) Pers] is still used but hybrid bermudagrasses [*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy] are preferred for athletic fields due to its finer texture and denser turfgrass cover (Trenholm et al., 2000; Younger, 1958). Highly maintained bermudagrass athletic fields require daily maintenance such as mowing, fertilization, irrigation, thatch management, topdressing, and aeration.

Bermudagrass use in the United States is primarily concentrated in the southeast but does extend to parts of the southwest, California, and the east coast (Juska and Hanson, 1964). Bermudagrass grows well when temperatures exceed 24° C (Juska and Hanson, 1964) and dormancy will occur when soil temperatures reach below 10° C (Younger, 1959). Bermudagrass grows well in fine textured soils, with an optimum pH range of 5.0 to 6.5 (Johnson and Burns, 1985; Belesky and Wilkinson, 1983).

Bermudagrass is a perennial grass that grows by both rhizomes and stolons (Juska and Hanson, 1964). Use in the southern United States is widespread due to its heat and drought tolerance, however, its low temperature tolerance is the reason for poor northern progression (Burton et al., 1954). Most athletic fields use either common or hybrid bermudagrass (Trenholm et al., 1999). Common bermudagrass [*Cynodon dactylon* (L.) Pers] can be established vegetatively or by seed (Patton et al., 2008). It is coarse textured, lighter colored, and exhibits an intermediate growth rate and density compared to hybrid bermudagrass. Shade tolerance is poor, however, it is still used on athletic fields due to its high wear tolerance (Beard, 1973). Hybrid bermudagrass which is a cross between common bermudagrass (*C. dactylon*) and African bermudagrass (*C. transvaalensis* Burtt-Davy) is a sterile triploid requiring establishment by vegetative means (Brilman, 2001). Hybrid bermudagrass exhibits a finer leaf texture, darker green color, lower growth habit, shorter internodes, and shallower rhizomes compared to common bermudagrass (Beard, 1973).

Management practices for bermudagrass include mowing, fertilization, irrigation, and thatch maintenance. Mowing should be done frequently (at least three times per week), never removing more than 1/3 of the top growth, as reserve carbohydrates will be wasted in shoot regrowth (Crider, 1955). Bermudagrass used for athletic fields should be maintained at heights from 2.0 cm to 2.5 cm using a reel mower for a cleaner even cut (Bruneau et al., 2004). Bermudagrass requires minimum applications of 30 kg N ha^{-1} per growing month (Dudeck et al., 1985). Irrigation for bermudagrass athletic fields is highly variable and depends on soil type and environmental factors such as temperature and rainfall. Supplemental irrigation is necessary to prevent wilt. However, high frequency of irrigation can cause reduced shoot and root growth and reduced chlorophyll content

(Madison and Hagan, 1962). A thatch depth of approximately 1.27 cm is desirable for athletic fields because it provides increased wear tolerance and impact absorption (Rogers and Waddington, 1989; Shearman, 1988). However, excess thatch can harbor destructive turf insects and negatively affect the playability of the field (Brosnan and Deputy, 2007). One management option for thatch control is topdressing. Topdressing has been found to reduce thatch accumulation (White and Dickens, 1984). Topdressing also will help create a smooth, even playing surface, an important aspect for athletic field playability (Rogers, 2001). Another management technique, aeration, has been found to reduce thatch accumulation (McWhirter and Ward, 1976). Long term aeration practices also have the benefit of relieving soil compaction and allowing air, water, and nutrients to penetrate into the soil (Murphy et al., 1993).

Plant Growth Regulators

Plant growth regulators (PGRs) have been around for many years, but were not widely accepted for use on highly maintained turfgrass until the 1990's when trinexapac-ethyl (TE) was introduced (Fry and Huang, 2004). Typically plant growth regulators are divided into two types. Type I PGR's are foliar absorbed and inhibit cell division and differentiation in meristematic regions, inhibiting shoot elongation and suppressing seed head development (Watschke and DiPaola, 1995). Type II inhibits the biosyntheses of gibberellins (GA) late in the biosynthesis pathway, reducing cell elongation (Watschke and DiPaola, 1995). One of the most common PGRs in the type II classification is TE. PGR's have also been identified to fit into another category defined as those that have other effects on turfgrass growth. An example is ethephon (Proxy), which promotes ethylene production inhibiting cell elongation and promoting leaf senescence (Huang, 2007). An alternative classification for PGR's has been established. This classification divides PGR's into the five groups A, B, C, D, and E (Turgeon, 2002). Class A and B were the result of splitting type II PGR's into two groups. Class A inhibits GA late in the biosynthesis pathway reducing cell elongation. Currently TE is the only available class A PGR for turf. Class B, such as flurprimidol inhibits GA early in the pathway. Class C, such as mefluidide is the former type I PGR and class D, such as glyphosate are herbicides which suppress plant growth. The final class, E, such as ethephon are phytohormones that influence turf growth.

Trinexapac-Ethyl

TE [4-(Cyclopropyl-alpha-hydroxymethylene)-3, 5-dioxocyclohexanecarboxylic acid ethyl ester] is a class A or type II PGR that prevents cell elongation (Adams et al., 1992). It inhibits the biosynthesis of gibberellins (GA_1) late in the biosynthesis pathway preventing GA_{20} from converting to GA_1 (Adams et al., 1992). Originally referred to as CGA-163935, TE was found to reduce vegetative growth, thereby reducing mowing frequency and the amount of clippings collected after each mowing event (Abbott et al., 1991). TE was commercialized in 1993 and has since changed the views and use of PGRs on turfgrass (Stier, 2006).

TE affects bermudagrass density, color, and quality. TE has been found to reduce vertical vegetative growth of several bermudagrasses (Fagerness et al., 2004; Totten et al., 2006; Johnson, 1994). When applied at a rate of 0.104 kg a.i. ha^{-1} every three weeks, clippings of 'Tifway' bermudagrass were reduced by 33% and 54% at 4 and 8 weeks after initial treatment, respectively (Totten et al., 2006). Fagerness et al. (2004) also found that when TE was applied at 0.11 kg a.i. ha^{-1} twice, on a four week interval, clippings were reduced up to 50% after mowing Tifway at 2.5 cm. TE was also found to reduce vegetative growth in common bermudagrass when applied at 0.2 kg ha^{-1} followed by 0.1 kg ha^{-1} at 4 and 8 weeks after initial treatment (Johnson, 1994). The result of reduced vertical vegetative growth from TE effecting cell elongation inhibition supports these results (Ervin and Zhang, 2007). Johnson (1994) also found a reduction in seed head occurrence for 'Tifway' bermudagrass for 12 weeks after the initial application. Fagerness and Yelverton (2000) found that more consistent inhibition of bermudagrass growth was achieved with lower rates (0.071 kg a.i. ha^{-1}) of TE applied more frequently, as compared to a higher rate (0.107 kg a.i. ha^{-1}) with less frequent applications.

Applications of TE also may aid in the reduction of wear stress on bermudagrass athletic fields. It has been hypothesized that TE will partition the non-structural carbohydrate content of turfgrass (Ervin and Koski, 2001). Waltz and Whitwell (2005) found that on TE treated plots total non-structural carbohydrates increased ≥38% in the roots and 32% in the shoot tissue as compared to the untreated control. Non-structural carbohydrates have been correlated with the ability of a plant to tolerate and recover from stress damage (Huang and Jiang, 2002). Multiple studies have shown that applications of TE aid in recovery from stresses such as drought, heat, and shade (McCann and Huang, 2007; Qian and Engelke, 1999). TE has also been found to increase tiller and stolon density, which could lead to improved traffic tolerance (Ervin and Koski, 2001;

Fagerness et al., 2002). Carrow and Petrovic (1980) stated that any increase in the verdure of turfgrass increases the possibility of tolerance to traffic stress. Applications of TE during the growing season that are stopped before the traffic season and utilize the observed "rebound" effect caused by TE (Lickfeldt et al., 2001) may aid in traffic tolerance of a bermudagrass field. The "rebound" effect of TE is observed when TE wears off and a surge of growth occurs from the buildup of reserves in the plant due to GA suppression (Lickfeldt et al., 2001). However, Deaton (2009) found that with applications of TE throughout the growing and traffic season there was no difference in traffic tolerance between treated and untreated plots.

Another aspect important to athletic field managers is turfgrass color and quality. Ervin and Zhang (2007) found that TE applied at 0.045 kg a.i. ha^{-1} every 14 days increased green color of 'Tifway' bermudagrass at 4 and 8 weeks after initial applications. Fagerness et al. (2001) also found that applications of 0.11 kg a.i. ha^{-1} of TE increased the amount of green color on bermudagrass plots. TE has also been found to extend the fall color of bermudagrass with late season applications (Richardson, 2002). TE also increased quality in 'Tifway' bermudagrass during the growing season and with sequential applications it was suggested that it delayed the onset of dormancy (Fagerness and Yelverton, 2000).

Overseeding

To improve aesthetic and functional quality during winter dormancy, bermudagrasses are often overseeded with cool season species like perennial ryegrass (*Lolium perenne* L.). Winter overseeding is performed to provide color, an actively growing surface for winter, and protection for the bermudagrass from wear (Cockerham et al., 1993; Mazur and Wagner, 1987). However, one main problem with winter overseeding is the spring transition from cool-season turf back to the warm-season bermudagrass (Mazur and Wagner, 1987). Emergence of bermudagrass from dormancy in the spring has been found to be delayed by competition from overseeded cool-season grasses like perennial ryegrass (Bingham et al., 1969; Horgan and Yelverton, 2001). However, removing cool season turf too soon or too fast will result in a thin stand of bermudagrass (Horgan and Yelverton, 2001). The biggest influence on the speed of spring transition to a bermudagrass stand is temperature. Until recently, cultural practices effects such as using herbicides have not been very consistent in facilitating this transition (Horgan and Yelverton, 2001). In recent years, herbicides such as foramsulfuron (Revolver) and trifloxysulfuron (Monument) have been very successful in eradicating perennial ryegrass from bermudagrass fields (Willis et al., 2007; Umeda and Towers, 2004). Foramsulfuron is a useful product for eradicating perennial ryegrass when soil temperatures are above 18° C (Willis et al., 2007). Trifloxysulfuron are less dependent on temperature and can be used to eradicate perennial ryegrass when temperatures are colder (Willis et al., 2007).

Many cool season turfgrasses have been used for winter overseeding in bermudagrass, but the two most popular for athletic fields are annual ryegrass (*Lolium multiflorum* L.) and perennial ryegrass. Annual ryegrass was one of the first turfgrasses used for winter overseeding and offers many benefits such as rapid establishment and germination, low cost, easy transition back to bermudagrass, and seed availability (Richardson, 2004; Volterrani et al., 2004; Schmidt and Shoulders, 1977). However, the disadvantages of annual ryegrass such as poor density, texture, color, and traffic tolerance do not make annual ryegrass the best choice for winter overseeding on athletic fields (Richardson, 2004; Dudeck and Peacock, 1981). Perennial ryegrass is the more ideal turfgrass for winter overseeding on bermudagrass athletic fields. It has been found to have a higher traffic tolerance (Dudeck and Peacock, 1981), and a darker green color than annual ryegrass (Meyer and Funk, 1989). Other attributes such as establishment vigor, disease resistance, and increased heat and drought tolerance also make perennial ryegrass a good choice (Horgan and Yelverton, 2001; Meyer and Funk, 1989). However, the same breeding efforts that make perennial ryegrass advantageous have also caused it to be a problem when transitioning out of overseeding.

There is no standard timeline for performing winter overseeding on an athletic field; however, timing is very important. Overseeding when the bermudagrass is still aggressively growing can impede perennial ryegrass establishment (Ward et al., 1974). Efficacy is maximized when cool-season grasses are overseeded into soils ranging from 22° and 29° C at a depth of 100 mm (Batten et al., 1981). Perennial ryegrass can be overseeded at rates up to 1750 kg ha^{-1} (Minner et al., 2008). Starter fertilizer can also be applied to aid in the ryegrass establishment (Cockerham et al., 1993). Seed bed preparation and reduced thatch allowing for seed to soil contact is also very important when winter overseeding (Ward et al., 1974). Topdressing after overseeding can increase seed to soil contact for a better stand of turfgrass (Ward et al., 1974).

Athletic Field Research

In recent years, turfgrass research has begun to pay more attention to the needs of athletic fields, with traffic being a major concern. Recently, traffic simulators have been developed that accurately represent the traffic seen on a field (Henderson et al., 2005). With these accurate research tools, traffic tolerant cultivars can be more easily identified. Research evaluating turf quality, density, color, disease resistance, cold tolerance, and traffic tolerance help determine bermudagrass cultivars better suited for use on athletic fields.

Athletic Field Traffic

Traffic stress is a major concern on all athletic fields. Traffic is the combined stress of soil compaction and plant wear (Carrow and Weicko, 1989). Soil compaction alters the physical properties of the soil and will adversely affect plant growth (Carrow and Weicko, 1989). Plant wear is defined as direct injury to the plant such as abrasions, tearing, and pressure (Carrow and Weicko, 1989). On football fields, most traffic occurs on a small area of the field called the zone of traffic concentration (ZOTC) (Cockerham, 1989). The ZOTC is located between the hash marks on the 40 yard line where 597 cleat dents m^{-2} $game^{-1}$ occur (Cockerham, 1989). The ZOTC should be a primary concern of athletic field research.

When looking at traffic stress, accurately simulating athletic field traffic is a major component in obtaining accurate research results. Devices have been developed to simulate athletic field traffic stress. Sled weights attached to a rotating arm moved by an electric motor have been used to simulate wear and soil compaction (Shearman et al., 1974). Also, a modified aerator with a compaction foot instead of tines has been used (Goss and Roberts, 1964). Two of the most common athletic field traffic simulators used today are the Brinkman Traffic Simulator (BTS) and the Cady Traffic Simulator (CTS). The BTS consists of two cleated rollers that turn at unequal speeds to create a shearing action on the turf as well as soil compaction (Cockerham and Brinkman, 1989). The CTS, has been found to better simulate traffic stress on athletic fields (Vanini et al., 2007; Henderson et al., 2005). The CTS is a modified walk behind core cultivation unit that has a foot attached to each of the four core heads. The feet are rubber tires with studs that strike at alternating times, creating the dynamic forces seen on an athletic field (Henderson et al., 2005). Two passes are made with the CTS to represent one game. The BTS and the CTS produce a similar number of cleat marks per unit area; 603 cleat marks m^{-2} and 667 cleat marks m^{-2}, respectively (Henderson at al., 2005). Both the BTS and the CTS produce high compressive forces on the turfgrass (Henderson at al., 2005). The BTS produces 2831 N with the front drum and 2297 N with the back drum. The CTS produced 5899 N in the forward direction and 1041 in the reverse direction. However, the CTS produces a much higher force per unit area than the BTS due to differences in cleat size (1354.9 mm^2 for the CTS and 3483.9 mm^2 for the BTS). This, in turn, may be more representative of a highly trafficked area (Vanini et al., 2007 and Henderson et al., 2005).

Cultivar Research

When deciding on what type of turfgrass to use on an athletic field, turfgrass traffic tolerance is an important characteristic to consider. Turfgrasses with high lignin and cellulose content in the shoot, and hardened cells perform the best because they are stronger and more rigid (Cockerham et al., 1993). These characteristics are typically found in bermudagrass and perennial ryegrass (Cockerham et al., 1993). As a result, bermudagrass is a popular choice for athletic fields. Also, the fast recuperative potential of bermudagrass based on multiple meristematic growing points makes it a popular choice for athletic fields (Cockerham et al., 1993). Hybrid bermudagrass has been found to have more meristematic growing points than common bermudagrass making it the ideal bermudagrass for athletic fields (Cockerham et al., 1993). However, due to the high cost of these hybrid cultivars many fields still use common seeded cultivars.

Although bermudagrass is the best choice for athletic field use in the transition zone, all cultivars are not equal in their traffic tolerance. Numerous studies have shown that Tifway exhibits superior traffic tolerance compared to other bermudagrasses (Brosnan and Deputy, 2009; Trappe et al., 2009; Goddard et al., 2008; Thoms et al., 2008; Trenholm et al., 1999). Other hybrid bermudagrass cultivars that hold up well when subjected to traffic are TifSport and Riviera (Trappe et al., 2009; Goddard et al. 2008; Thoms et al., 2008; Trenholm et al., 1999). Comparing bermudagrass cultivars when using the CTS, it was found that Riviera and Tifway performed better than Quickstand, Mississippi Choice, Patriot, and Tift No. 3 (Trappe et al., 2009; Goddard et al., 2008; Thoms et al., 2008). Among 42 bermudagrass cultivars, Trappe et al. (2009) also found that Celebration bermudagrass performed in the best wear tolerance category. When using the BTS, Tifway and Riviera have also performed in the best category for traffic tolerance (Deaton and Williams, 2009; Cropper et al., 2008). Based on the consistency of Tifway and Riviera bermudagrass cultivars, under different traffic simulators, they are found to offer improved traffic tolerance as compared to other turfgrasses.

Trenholm et al. (2000) and Brosnan and Deputy (2009) compared the traffic tolerance of bermudagrass to seashore paspalum. Trenholm et al. (2000) performed two traffic events using a rubber roller traffic device (90 total passes) and Brosnan and Deputy (2009) used the CTS (18 passes per week). Trenholm et al. (2000) found cultivars Tifway and TifSport exhibited traffic tolerance greater than or equal to seashore paspalum and Brosnan and Deputy (2009) found that Tifway performed just as well if not better than the seashore paspalum cultivars.

Observation Procedures

When measuring turfgrasses for their wear tolerance the method of evaluation is very important. Until recently, the most common method used to evaluate turfgrass color and cover was visual. Visually evaluating a plot means giving each plot a cover rating from 0 – 100% and a color rating from 1-9. This method relies on arbitrary decisions and requires experience from a non-biased evaluator (Shearman and Beard, 1975). In fact, when ten trained turfgrass researchers visually assessed quality and density of turfgrasses, more variation was due to the evaluator than the actual turfgrass (Horst et al., 1984). Due to the inaccuracy of visual evaluation digital image analysis (DIA) has become an accepted way of measuring percent green cover and color of turfgrass (Karcher and Richardson, 2003; Richardson et al., 2001). DIA takes images using a digital camera mounted on an enclosed system with artificial lighting to eliminate light variability (Karcher and Richardson, 2003). The images are then analyzed with SigmaScan Pro (v. 5.0, SPSS, Inc., Chicago, IL 60611) software to determine color and percent green cover (Karcher and Richardson, 2003; Richardson et al., 2001). To determine color, the average red, green, and blue (RGB) levels are determined for each image and converted to hue, saturation, and brightness values, which is then converted to a dark green color index (DGCI) on a 1-9 scale for turfgrass rating (Karcher and Richardson, 2003). Percent green cover is determined by detecting and summing the total number of pixels with hue, brightness, and saturation levels that represent green turf and dividing that by the total number of pixels in the image (Richardson et al., 2001).

Soil Physical Properties

The effect of traffic on altering soil physical properties is a major concern on athletic fields; especially, fields built with native soils (Carrow and Weicko, 1989). Soil compaction will reduce the possibility for optimum turfgrass growth to occur by creating more susceptibility to environmental and pest stresses (Carrow and Weicko, 1989). Related to bulk density and porosity, soil compaction is a major concern on athletic fields with most research showing that root growth declines under increasing compaction

(Bouffor and Carrow, 1980, Carrow, 1980; O'Neil and Carrow, 1982). In previous athletic field research, Goddard et al. (2003) and Thoms (2008) found that significant differences occurred between bermudagrass cultivars for soil physical properties. Goddard et al. (2003) found that when trafficked 'Riviera' plots had a significantly higher bulk density and lower air filled and total porosity compared to 'Tifway'. Thoms, (2008) also found that 'Riviera' had a higher bulk density than 'Tifway' bermudagrass when trafficked. Rogers and Waddington (1993) stated that harder more compact surfaces are related to a higher bulk density. Testing how different treatments affect soil physical properties when applied with traffic is important for determining correct athletic field management techniques.

A very common test for soil physical properties is saturated hydraulic conductivity (K_{sat}). One such method for this test is described by the American Society for Testing and Materials (ASTM) (2006). ASTM's method involves taking the undisturbed soil cores from the ground and using a permeameter to determine the flow of water throughout the soil sample. The equation used for determining K_{sat} is

$$Ksat = \left(\frac{Q}{At}\right)\left(\frac{L}{\Delta H}\right)$$

where Q is the volume of water that passes through the sample at a known time t, ΔH is the hydraulic head difference, and L is the height of the sample. Saturated hydraulic conductivity is based on pore space relations in the soil; therefore, porosity determinations of bulk density, non-capillary porosity, capillary porosity, and total porosity must also be made (Ferguson et al., 1960). Bulk density is calculated by dividing the oven dry weight of the sample by the volume of the sample. Non-capillary porosity is $(s - w)/V$, capillary porosity is $(w - d)/V$ and total porosity is non-capillary and capillary porosity added together when s is the weight of the saturated sample, w is the weight of the sample at field capacity, d is the weight of the oven dried sample, and V is the volume of the sample.

Objectives

The objectives of this project were:

1. To measure the effects of bermudagrass cultivar (‘Tifway’, ‘Riviera’, ‘Patriot’, and ‘Celebration’), trinexapac-ethyl, perennial ryegrass overseeding, and their interactions on traffic tolerance.
2. To measure the effects of bermudagrass cultivar (‘Tifway’, ‘Riviera’, ‘Patriot’, and ‘Celebration’), trinexapac-ethyl, perennial ryegrass overseeding, and their interactions on soil physical properties.
3. To measure the effects of bermudagrass cultivar (‘Tifway’, ‘Riviera’, ‘Patriot’, and ‘Celebration’), trinexapac-ethyl and their interactions on the morphological characteristics of bermudagrass.

CHAPTER II

EFFECT OF CULTIVAR, TRINEXAPAC-ETHYL, AND WINTER OVERSEEDING ON BERMUDAGRASS TRAFFIC TOLERANCE

Abstract

Common bermudagrass [*Cynodon dactylon* (L.) Pers.] and hybrid bermudagrass [*C. dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] are some of the most common turfgrasses used on athletic fields in the United States. Trinexapac-ethyl (TE), a Type A plant growth regulator, used to increase density and improve stress resistance, is frequently used by athletic field managers. In the transition zone, perennial ryegrass overseeding is a common management practice to maintain an actively growing playing surface and help protect the bermudagrass throughout the winter. Research data describing the effects of TE and overseeding on bermudagrass traffic tolerance are often limited. A two year study at the University of Tennessee was conducted under simulated athletic field traffic to evaluate the traffic tolerance of bermudagrass cultivars as affected by TE and overseeding. Cultivars evaluated included Tifway, Riviera, Patriot, and Celebration. TE treatments consisted of untreated control, TE at 76.3 g a.i. ha^{-1} every 14 days until 14 days prior to trafficking (TE A), and TE at 76.3 g a.i. ha^{-1} every 14 days until 14 days after trafficking (TE B). The perennial ryegrass (*Lolium perenne* L.) overseeding treatments were seeded at 0 and 670 kg ha^{-1}. Plots were rated for percent green cover after every 5 traffic events using digital image analysis (DIA). Saturated hydraulic conductivity (K_{sat}), soil bulk density (BD), total porosity (TP), air filled porosity (AP), capillary porosity (CP), organic matter (OM) and surface organic matter

(SOM) were collected at the end of each year. Tifway and Celebration had the highest percent green cover ratings throughout the two years of this study, while Patriot had the lowest percent green cover ratings of all cultivars tested. TE had a significant effect on percent green cover both years for the first 10 traffic events, with TE applied into the traffic season having lower percent green cover values as compared to no TE and TE applied before the traffic season. A turfgrass manager should not apply TE into the traffic season.

Introduction

Common bermudagrass [*Cynodon dactylon* (L.) Pers.] and hybrid bermudagrass [*C. dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] are some of the most common turfgrasses used on athletic fields in the United States due to its recuperative potential and its ability to withstand high temperatures (Cockerham et al., 1993; Juska and Hanson, 1964). Although common bermudagrass is used, hybrid bermudagrass is preferred for athletic fields because of its finer leaf texture and higher recuperative potential (Trenholm et al., 2000; Younger, 1958).

Traffic stress on turfgrass is a combination of two types of damage; turfgrass wear and soil compaction (Carrow and Weicko, 1989). Wear is direct injury to the plant such as tearing, abrasion, and damage to the crown tissue. Soil compaction is an alteration of the soil physical properties affecting attributes such as saturated hydraulic conductivity, bulk density and porosity. This alteration adversely affects plant growth (Carrow and Weicko, 1989). Compaction is a major concern on turfgrass athletic fields. Related to bulk density, and porosity compaction is a major concern on athletic fields with most research showing that root growth declines under increasing compaction (Bouffor and Carrow, 1980, Carrow, 1980; O'Neil and Carrow, 1982). On football fields, the zone of traffic concentration (ZOTC) located between the hash marks on the 40 yard line is where most traffic stress occurs (Cockerham, 1989).

Bermudagrass traffic tolerance has been reported to vary by cultivar. The hybrid bermudagrass cultivar Tifway has been shown to exhibit superior traffic tolerance by numerous studies (Brosnan and Deputy, 2009; Trappe et al., 2009; Goddard et al, 2008; Thoms et al., 2008; Trenholm et al., 1999). Trenholm et al. (1999) and Brosnan and Deputy (2009) compared the traffic tolerance of seashore paspalum (*Paspalum vaginatum*) to bermudagrass cultivars and found that Tifway offered traffic tolerance greater than or equal to several seashore paspalum cultivars. The common bermudagrass 'Riviera' has been reported to offer traffic tolerance similar to 'Tifway' bermudagrass (Trappe et al., 2009; Goddard et al., 2008; Thoms et al., 2008). Both 'Riviera' and 'Tifway' have been shown to offer superior traffic tolerance compared to 'Quickstand', 'Mississippi Choice', and 'Patriot' (Trappe et al., 2009; Goddard et al., 2008; Thoms et al., 2008).

Trinexapac-ethyl (TE) [4-(Cyclopropyl-alpha-hydroxymethylene)-3, 5-dioxocyclohexanecarboxylic acid ethyl ester] is a commonly used plant growth regulator (PGR) that inhibits the biosynthesis of gibberellins late in the biosynthesis pathway. TE is a Type A PGR that prevents GA_{20} from converting to GA_1 (Adams et al., 1992). TE has been shown to reduce mowing frequency and clipping yield by reducing vertical turfgrass growth (inhibiting cell elongation) (Abbott et al., 1991). When applied, TE increases the total non-structural carbohydrates in turfgrass (Ervin and Koski, 2001). Waltz and Whitwell (2005) found that on TE treated plots total non-structural carbohydrates increased ≥38% in the roots and 32% in the shoot tissue as compared to the untreated control. Non-structural carbohydrates have been correlated with the ability of a plant to tolerate and recover from stress damage (Huang and Jiang, 2002). Applications of TE have been found to help turfgrass recover from drought, heat, and shade stress (McCann and Huang, 2007; Qian and Engelke, 1999). Carbohydrate partitioning may also aid in traffic tolerance of turfgrass due to its ability to increase tiller and stolon density (Fagerness et al. 2002; Ervin and Koski, 2001). Carrow and Petrovic (1980) stated that any increase in the verdure of turfgrass increases the possibility of tolerance to traffic stress. Applications of TE during the growing season that are stopped before the traffic season and utilize the observed "rebound" effect caused by TE (Lickfeldt et al., 2001) may aid in traffic tolerance of a bermudagrass field. The "rebound" effect of TE is observed when TE wears off and a surge of growth occurs from the buildup of reserves in the plant due to GA suppression (Lickfeldt et al., 2001).

Winter overseeding of bermudagrass is a common practice in the transition zone. It provides green color, an actively growing playing surface, and protection for the dormant bermudagrass from wear (Cockerham et al., 1993; Mazur and Wagner, 1987). One of the most common cool season turfgrass used for winter overseeding bermudagrass athletic fields is perennial ryegrass (*Lolium perenne* L.). Perennial ryegrass is selected for its high traffic tolerance, dark green color, and establishment vigor (Horgan and

Yelverton, 2001; Meyer and Funk, 1989; Dudeck and Peacock, 1981). Perennial ryegrass overseeding usually occurs when soil temperatures range from 22° and 29° C at a depth of 100 mm (Batten et al., 1981). However, for bermudagrass athletic fields, overseeding is often based upon field use and down time between events.

Currently, there is limited research comparing new bermudagrass cultivars with Tifway and Riviera based on cultivar and management practices. The objective of this research was to examine the effects of cultivar, TE, and overseeding on traffic tolerance of four bermudagrass cultivars commonly selected for use on athletic fields.

Materials and Methods

Bermudagrass sod was installed on 30 June 2008. Four commercially available cultivars of bermudagrass sod were established as 1.5 m by 3 m plots at the East Tennessee Research and Education Center (Knoxville, TN) on a tilled and leveled Sequatchie silt loam soil (fine-loamy, siliceous, semi active, thermic Humic Hapludult). Cultivars included two common bermudagrasses (Riviera and Celebration) and two hybrid bermudagrasses (Tifway and Patriot). Plots were mown with a Jacobsen (Textron Inc., Charlotte, NC) walk behind reel mower three times per week at a height of 2.2 cm. Plots were fertilized each month with ammonium nitrate (34-0-0) at rate of 5 g N m^{-2} from May through September and with a complete fertilizer (23-6-12) at a rate of 5 g N m^{-2} October and November. Plots were irrigated as needed to prevent wilt.

The experimental design was a two year, three factor (bermudagrass cultivar, trinexapac-ethyl, and overseeding), randomized complete block design with three replications. Cultivars established were Tifway, Riviera, Patriot, and Celebration. Three treatments were evaluated: 1) untreated, 2) TE at 76.3 g a.i. ha^{-1} every 14 days until 14 days prior to trafficking (TE A), and 3) TE at 76.3 g a.i. ha^{-1} every 14 days until 14 days after trafficking (TE B). TE A plots received 3 applications while TE B received 5 applications of TE each year. TE applications were initiated on 18 July 2008 and 17 July 2009. Overseeding treatments included no overseeding and overseeding with perennial ryegrass (32.28% All Star 2, 32.84% Derby Xtreme, and 32.82% Top Hat 2 in 2008, and 48.42% SR4600, 29.34% SR4420, and 19.75% Penguin 2) at 670 kg ha^{-1} on 22 September 2008 (after 7 simulated games) and 21 September 2009 (after 6 simulated games).

Many models of traffic simulators have been used in the past with two of the most popular being the Cady Traffic Simulator (CTS) and the Brinkman Traffic Simulator (BTS). The BTS consists of two cleated rollers that run at unequal speeds creating a shearing action on the turf as well as compaction (Cockerham and Brinkman, 1989). The CTS is a modified walk behind core cultivation unit. It has a foot attached to each of the four core heads. The feet are rubber tires with studs that strike at alternating times, creating the dynamic forces seen on an athletic field (Henderson et al., 2005). The BTS and the CTS produce a similar number of cleat marks per unit area; 603 cleat marks m^{-2} and 667 cleat marks m^{-2}, respectively (Henderson at al., 2005). Both the BTS and the CTS produce high compressive forces on the turfgrass (Henderson at al., 2005). The BTS produces 2831 N with the front drum and 2297 N with the back drum. The CTS produced 5899 N in the forward direction and 1041 in the reverse direction. However, the CTS produces a much higher force per unit area than the BTS due to differences in cleat size (1354.9 mm^2 for the CTS and 3483.9 mm^2 for the BTS). This, in turn, may be more representative of a highly trafficked area (Vanini et al., 2007 and Henderson et al., 2005). Two passes with the CTS produces the same number of cleat marks that occurs between the hash marks on the 40 yard line during one National Collegiate Athletic Association (NCAA) or National Football League (NFL) football game (Henderson et al., 2005). Traffic was applied to the whole plot with the Cady Traffic Simulator (CTS) (Henderson et al., 2005). Three simulated traffic events were applied per week beginning on 8 September 2008 and 7 September 2009 until a total of 25 simulated events were applied each year to mimic fall high school football schedules. Traffic was withheld for one week following overseeding to facilitate germination and seedling emergence.

Turfgrass percent green cover was measured after 5, 10, 15, 20, and 25 simulated traffic events using digital image analysis (DIA). A random location was chosen for each plot and subjected to DIA for the duration of the trial. Digital images of each plot were taken with a Canon G5 (Canon Inc., Japan) mounted on a 0.28 m^2 enclosed light box with four TCP 40w Spring Lamps® (Lighthouse Supply Co., Bristol, VA), powered by a Xantrex 600 HD Power Pack® (Xantrex Technology, Burnaby, BC).

The images were then analyzed using SigmaScan Pro© (v. 5.0, SPSS, Inc., Chicago, IL 60611) which determines percent green cover by counting the number of green pixels and dividing that by the total number of pixels (307,200) in the image (Richardson et al., 2001). Green pixels were determined in SigmaScan Pro© by a defined hue (45-120°), saturation (0 to 100%), and brightness (0-100%) range and converted to a

1-9 color scale using the methods of Karcher and Richardson (2003). This method of data collection was found to provide quantitative measurements of turfgrass performance while removing observational bias (Karcher and Richardson, 2003).

Soil cores were pulled from each plot on 22 January 2009 and 18 November 2009. Three (5 cm diameter, 5 cm depth) cores were taken from each plot using a manual core driver, and core extractor made. Cores were analyzed for saturated hydraulic conductivity (K_{sat}), bulk density (BD), total porosity (TP), air filled porosity (AP), capillary porosity (CP), organic matter (OM) and surface organic matter (SOM) (ASTM, 2006). SOM was determined by removing the above ground biomass from each soil core and oven drying (DK-63, Baxter Co., Japan) them at 105° C for 24 hours. Samples were weighed then placed in an muffle furnace (F-6020, Sybron Corporation, Dubuque, IA) at 200° C for one hour to acclimate the crucibles and then ashed at 400° C for four hours. Samples were allowed to cool then final weight was subtracted from oven dried weight to determine SOM content. All other soil physical properties were measured using the methods of ASTM (2006) and Ferguson et al. (1960).

Statistical analysis was performed using mixed model ANOVA (MMAOV) in the SAS system version 9.1.3 (Statistical Analysis Software, Cary, N.C.) for percent green cover and soil physical properties. Significance year by TE, year by cultivar, year by overseeding, date by TE, date by cultivar, and date by overseeding were found on percent green cover data; therefore, data from each year and date were analyzed separately. Soil samples were averaged before MMAOV was performed. Data from each year were analyzed separately for the soil data due to a significant year by cultivar, year by TE and year by overseeding interaction. Least significant difference (LSD) values are reported when the F-ratio was significant at α=0.05 level.

Results and Discussion

Percent Green Cover

Percent green cover values varied due to cultivar and overseeding on all rating dates each year (Table 1, 2). Cover values varied due to TE on all rating dates in 2008 but only two out of the five rating dates in 2009 (Table 1, 2).

In 2008, Tifway ranked in the highest percent green cover category for all rating dates. Celebration had similar percent green cover ratings to Tifway through the first 20 games as well (Table 3). On all rating dates in 2009, Tifway, Celebration, and Riviera ranked in the highest percent green cover category (Table 3). These results are consistent with past research that found Tifway and Celebration to exhibit improved traffic tolerance (Brosnan and Deputy, 2009; Trappe et al., 2009; Goddard et al., 2008; Thoms et al., 2008; Trenholm et al. 1999). Riviera performed the same on all rating dates on 2009 as Tifway; however, it had lower percent green cover than Tifway for only three of the five rating dates in 2008 (Table 3). Past studies support these results that 'Riviera' is an acceptable choice for athletic fields (Trappe et al., 2009; Goddard et al., 2008; Thoms et al., 2008). Consistent with Thoms et al. (2008), Patriot performed in the lowest percent green cover categories in 2008 and 2009 (Table 3). Four out of the five dates in 2008 (10, 15, 20, and 25 games) and two out of the five dates in 2009, (10 and 15 games) Patriot had the lowest percent green cover (Table 3).

After 25 games in 2009, all bermudagrass cultivars performed poorly with less than 26% green cover ratings (Table 3). Patriot performed as well as Tifway at 20 games and Riviera at 20 and 25 games (Table 3). Compared to the fall of 2008, the fall of 2009 was an unusually wet fall, with substantial rainfall and multiple traffic events occurring during wet or saturated soil conditions (Figures 1, 2). This caused a sharp decline in percent green cover at 15 and 20 games for all cultivars (Table 3). Athletic events taking place after or near rain events can cause substantial damage to turfgrass stands (Thoms, 2009; Boufford and Carrow, 1980). Also, with the substantial damage to the turfgrass stand, differences in traffic tolerance were likely harder to distinguish; thus, cultivars such as Patriot performed as well as Tifway and Riviera.

TE treatments showed consistent results over the two years of this study for the first 15 games of traffic simulation (Table 4). In 2008, after five games, TE treatment A had higher percent green cover than TE treatment B, but did not measure higher in percent green cover than the untreated control (Table 4). After 10 games, TE treatment B had the lowest percent green cover as compared to the untreated control and TE treatment A (Table 4). In 2009 after 5 and 10 games, TE treatment B had lower percent green cover than the untreated control and TE treatment A (Table 4). This is most likely due to the fact that the last two applications of TE treatment B occurred while simulated traffic was being applied. This is similar to Ervin and Koski's (2001) finding of Kentucky bluegrass having lower quality while under TE and simulated traffic as compared to the trafficked only plots. Applying the TE during traffic likely resulted in poor recovery of the bermudagrass due to TE's effect on impeding the cell elongation and growth (Ervin and Koski, 2001; Johnson, 1994). However, after 15 games in both 2008 and 2009 TE treatment B yielded percent green cover values greater than or equal to the untreated control and TE treatment A. This is most likely due to the fact that the last application of TE treatment B occurred approximately four weeks prior to the rating date. TE induced growth regulation had ceased and the "rebound effect" that utilizes the plants stored carbohydrates caused a flourish of growth (Lickfeldt et al., 2001).

Effects of TE were inconsistent after 15 games of traffic simulation were applied each year (Table 4). In 2008 after 15 games, TE treatments A and B maintained higher percent green cover on all dates as compared to the untreated control until the conclusion of the traffic season (Table 4). At 25 games, the untreated control, TE treatment A, and TE treatment B had percent green cover values of 41.4%, 52.4% and 49.8%, respectively. These results are consistent with TE's ability to increase sod tensile strength in bermudagrass making it an effective management practice for traffic tolerance (McCalla et al., 2008). In 2009, no differences due to TE treatments were reported after 15 simulated traffic events (Table 4). Compared to 2008, the fall of 2009 was an uncharacteristically wet fall with substantial rainfall and multiple traffic events occurring on wet or saturated soils (Figure 1, 2). Simulating traffic on wet soils may have accelerated reductions in green cover rendering treatments effects difficult to determine (Table 3). Application of foot traffic after rain events can cause substantial damage to turfgrass (Thoms, 2009; Boufford and Carrow, 1980).

As expected, overseeding in 2008 and 2009 increased cover of all plots. After 15 games in 2008 and 10 games in 2009, overseeding plots had a significantly higher percent green cover than non-overseeded plots (Table 5). These results are consistent with the fact that overseeding improves bermudagrass athletic fields by providing color and an actively growing turf throughout periods of dormancy (Cockerham et al., 1993; Mazur and Wagner, 1987).

Soil Physical Properties

Soil physical properties of saturated hydraulic conductivity (K_{sat}), bulk density (BD), total porosity (TP), air filled porosity (AP), capillary porosity (CP), organic matter (OM) and surface organic matter (SOM) were evaluated each year at the end of the traffic season. In 2008, treatments did not show significantly different results (Table 6). In 2009, bulk density, capillary porosity, and organic matter were significant for cultivar (Table 7). Also, a three way interaction of cultivar, TE, and overseeding was found for total porosity in 2009 (Table 7).

In 2009, bulk density values varied due to cultivar. Tifway had the lowest bulk density (0.9 g cm^{-3}) as compared to Riviera (1.0 g cm^{-3}) (Table 8). Organic matter ratings were also significantly different with Tifway measuring greater in organic matter than Riviera, Patriot, and Celebration (Table 8). Differences in capillary porosity were also detected. Tifway, Patriot, and Celebration yielded higher capillary porosity values than Riviera (Table 8). Tifway also had significantly higher total porosity than Riviera, but the same as Patriot and Celebration (Table 8). These results would be consistent with the fact that Tifway has been found to produce more rhizomes than seeded cultivars such as Riviera (Philley and Krans, 1998). It is believed that vigorous rhizomatous growth will probably increase porosity in the soil (Peacock and Daniel, 1995). Consistent with the fact that Riviera produces fewer rhizomes that could reduce compaction as compared to Tifway, Riviera measured higher in bulk density and lower in organic matter content. Riviera also measured lowest in both capillary and total porosity due to increased compaction.

A cultivar by TE by overseeding interaction was detected in total porosity data in 2009. All Riviera interactions were in the lowest category for total porosity in 2009 (Figure 3). As stated before with Riviera being a seeded cultivar that produces fewer rhizomes than Tifway, a lower total porosity is expected. Any treatment of overseeding or TE will not improve the total porosity of 'Riviera' bermudagrass. All overseeding treatments were in the highest category of total porosity for all cultivars but Riviera (Figure 3). Overseeding Riviera with perennial ryegrass improved total porosity to the highest group for all treatments except when applied with TE treatment B (Figure 3). This effect was not seen in any other cultivars. No other differences can be seen from this three way interaction.

Conclusion

Cultivars exhibited differences in traffic tolerance. Tifway and Celebration bermudagrasses exhibited a superior traffic tolerance throughout the study. Riviera performed similarly to both Tifway and Celebration. Patriot exhibited the least traffic tolerance of all cultivars tested making it an unacceptable choice for use on athletic fields in Tennessee. When using a seeded cultivar, Riviera is a good option. However, the best choice for an athletic field to maintain the highest percent green cover would be improved cultivars such as Tifway and Celebration. This is due to the fact that soil compaction will be reduced and porosity increased.

Applications of TE on athletic fields should be a pre-treatment to traffic and should not be applied into the traffic season. If TE is applied during traffic, bermudagrass traffic tolerance will be reduced. If traffic events do not occur soon after rain events TE applications will increase the traffic tolerance of bermudagrass.

Overseeding will improve traffic tolerance of all bermudagrass cultivars. The addition of perennial ryegrass provides color and an actively growing surface throughout periods of slow growth and dormancy.

CHAPTER III

MORPHOLOGICAL CHARACTERISTICS OF WEAR TOLERANT BERMUDAGRASS AS AFFECTED BY CULTIVAR AND TRINEXAPAC-ETHYL

Abstract

Common bermudagrass [*Cynodon dactylon* (L.) Pers.] and hybrid bermudagrass [*C. dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] are some of the most common turfgrasses used on athletic fields in the United States. Trinexapac-ethyl (TE) is used to increase density and improve stress resistance, is management practice implemented by many athletic field managers. Currently, there is limited research that can distinguish how cultivar and TE affect the traffic tolerance based on morphological characteristics of the bermudagrass. A two year study was conducted at the University of Tennessee to evaluate the morphological characteristics of four bermudagrass cultivars treated with TE. The four bermudagrass cultivars consisted of Tifway, Riviera, Patriot, and Celebration. TE treatments consisted of an untreated control, TE at 76.3 g a.i. ha^{-1} every 14 days with a total of 3 applications (TE A), and TE at 76.3 g a.i. ha^{-1} every 14 days with a total of 5 applications (TE B). The numbers of leaves per shoot, internode lengths, leaf angle, and leaf width of each cultivar by TE combination were assessed to quantify morphology. Cultivars that exhibit superior traffic tolerance (Tifway, Celebration) had increased vertical leaf orientation compared to the cultivars that exhibit poor traffic tolerance (Patriot). In 2008, when TE treated plots exhibited more traffic tolerance than the untreated plots a more vertical leaf orientation was also found.

Introduction

Common bermudagrass [*Cynodon dactylon* (L.) Pers.] and hybrid bermudagrass [*C. dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] are some of the most common turfgrasses used on athletic fields in the United States due to its recuperative potential and its ability to withstand high temperatures (Cockerham et al., 1993; Juska and Hanson, 1964). Common bermudagrasses are still used on athletic fields; however, hybrid bermudagrasses are the most sought after for athletic fields due to their finer leaf texture and higher recuperative potential (Trenholm et al., 2000; Younger, 1958).

Bermudagrass traffic tolerance has been reported to vary by cultivar. The hybrid bermudagrass cultivar Tifway has been shown to exhibit superior traffic tolerance by numerous studies (Brosnan and Deputy, 2009; Trappe et al., 2009; Goddard et al, 2008; Thoms et al., 2008; Trenholm et al., 1999). Trenholm et al. (1999) and Brosnan and Deputy (2009) compared the traffic tolerance of seashore paspalum (*Paspalum vaginatum*) to bermudagrass cultivars and found that Tifway offered traffic tolerance greater than or equal to several seashore paspalum cultivars. The common bermudagrass 'Riviera' has been reported to offer traffic tolerance similar to 'Tifway' bermudagrass (Trappe et al., 2009; Goddard et al., 2008; Thoms et al., 2008). Both 'Riviera' and 'Tifway' have been shown to offer superior traffic tolerance compared to 'Quickstand', 'Mississippi Choice', and 'Patriot' (Trappe et al., 2009; Goddard et al., 2008; Thoms et al., 2008).

Trinexapac-ethyl (TE) [4-(Cyclopropyl-alpha-hydroxymethylene)-3, 5-dioxocyclohexanecarboxylic acid ethyl ester] is a commonly used plant growth regulator (PGR) that inhibits the biosynthesis of gibberellins late in the biosynthesis pathway. TE is a Type A PGR that prevents GA_{20} from converting to GA_1 (Adams et al., 1992). TE has been shown to reduce mowing frequency and clipping yield by reducing vertical turfgrass growth (inhibiting cell elongation) (Abbott et al., 1991). When applied, TE increases the total non-structural carbohydrates in turfgrass (Ervin and Koski, 2001). Waltz and Whitwell (2005) found that on TE treated plots total non-structural carbohydrates increased ≥38% in the roots and 32% in the shoot tissue as compared to the untreated control. Non-structural carbohydrates have been correlated with the ability of a plant to tolerate and recover from stress damage (Huang and Jiang, 2002). Applications of TE have been found to help turfgrass recover from drought, heat, and shade stress (McCann and Huang, 2007; Qian and Engelke, 1999). Carbohydrate partitioning may also aid in traffic tolerance of turfgrass due to its ability to increase tiller and stolon density (Fagerness et al. 2002; Ervin and Koski, 2001). Carrow and Petrovic (1980) stated that any increase in the verdure of turfgrass increases the possibility of tolerance to traffic stress. Applications of TE during the growing season that are stopped before the traffic season and utilize the observed "rebound" effect caused by TE (Lickfeldt et al., 2001) may aid in traffic tolerance of a bermudagrass field. The "rebound" effect of TE is observed when TE wears off and a surge of growth occurs from the buildup of reserves in the plant due to GA suppression (Lickfeldt et al., 2001).

Data describing morphological characteristics of traffic tolerant turfgrasses are limited. Wear tolerance (a component of traffic) has been associated with morphological characteristics including verdure, total cell wall content, leaf width, leaf tensile strength, shoot density, and leaf angle (Brosnan et al., 2005; Trenholm et al., 2000; Shearman and Beard, 1975). Trenholm et al. (2000) found that increases in shoot density within seashore paspalum and bermudagrass genotypes increased with wear tolerance. Increased total cell wall content (TCW) has been associated with increased wear tolerance in red fescue (*Festuca rubra* L.), chewings fescue (*F. trivialis* L.), tall fescue (*F. arundinacea* Shreb.), perennial ryegrass (*Lolium perenne* L.), Italian ryegrass (*L. multiflorum* Lam.), Kentucky bluegrass (*Poa pratensis* L.), and rough bluegrass (*P. trivialis* L.) (Shearman and Beard, 1975). Brosnan et al. (2005) reported that wear tolerant genotypes of Kentucky bluegrass were associated with an increase in TCW. However, Trenholm et al. (2000) reported that at the intraspecies level of seashore paspalum, lower TCW was associated with higher wear tolerance. He also found that in bermudagrass higher stem moisture and reduced stem cellulose content were associated with better wear tolerance. Lastly, Trenholm et al. (2000) also found that greater leaf moisture, shoot density, leaf lignin, stem and leaf lignocelluloses, and concentrations of K, Mn, and Mg were associated with better wear tolerance. Brosnan et al. (2005) also found leaf angle to be associated with wear tolerance in Kentucky bluegrass. Wear tolerant cultivars exhibited an increased vertical leaf angle compared to those not tolerant of wear. Leaf number and internode length may have an effect on wear tolerance of turfgrass (Shildrick, 1974). In perennial ryegrass Hoffman et al. (2010) found that as shoot growth rate, relative leaf water content, and shoot water content increase. Shoot growth rate, relative leaf water content, and shoot water content have also been associated with wear tolerance. As they increase wear tolerance of perennial ryegrass decreases (Hoffman et al., 2010).

Currently there is limited data describing the morphological characteristics associated with traffic tolerance in bermudagrass. The objective of this research was to examine the effects of cultivar and TE applications on the morphological characteristics of bermudagrass and compare that to the traffic tolerance of bermudagrass.

Materials and Methods

For the research in this chapter of the study the same site, construction, and management techniques as chapter 2. Therefore, please see chapter 2 for that information.

The experimental design was a two year, three factor (bermudagrass cultivar, trinexapac-ethyl, and overseeding), randomized complete block design with three replications. 15 samples were taken from each plot. Cultivars established were Tifway, Riviera, Patriot and Celebration with Tifway and Celebration being the most traffic tolerant, Riviera being the intermediate traffic tolerant, and Patriot being the poor traffic tolerant cultivar (Chapter, 2). TE applications were initiated on 18 July 2008 and 17 July 2009. The three applications were untreated TE, TE applied at 76.3 g a.i. ha^{-1} every 14 days for three total applications (TE A), and TE applied at 76.3 g a.i. ha^{-1} every 14 days for five total applications (TE B). In 2008, TE treatment A and TE treatment B were in the highest wear tolerant category as compared to the untreated control while in 2009 no wear tolerant differences existed between the TE treatments (Chapter 2).

Morphological data were collected 14 to 16 October 2008, and 7 to 9 October 2009. 15 stolons were randomly removed from the non-trafficked area of each plot. A total of five morphological characteristics were evaluated, number of leaves, internode lengths one and two, leaf angle, and leaf width. Number of leaves was measured off of the youngest shoot of the stolon. The first internode length was measured between the youngest and the second node on the stolon. The second internode was measured from the second youngest node to the third youngest node on the stolon. Leaf angle was measured using the second subtending leaf from the budleaf on the youngest shoot of each stolon. Leaf angle was measured according to the methods of Brosnan et al. (2005). Angle was rated on a scale of 1 to 4 with the sheath as the vertical axis with a score of 1 indicating a horizontal leaf orientation (0 to 22.5°), 2 indicating a semi-horizontal (22.5 to 45°), 3 indicating a semi-vertical (45 to 67.5°), and 4 indicating a vertical leaf orientation (67.5 to 90°). Leaf width was measured on the second youngest leaf on the youngest shoot. Data was collected from the second leaf due to the fact that in Kentucky bluegrass, it has been reported that the second subtending leaf from the budleaf exhibits the most variation between genotypes and the least variation within genotype (Brede and Duich, 1982; Sheffer et al., 1978). Han et al. (2008) used the second youngest leaf on bermudagrass shoots to measure morphological characteristics.

Statistical analysis was performed with mixed model ANOVA (MMAOV) in the SAS system version 9.1.3 (Statistical Analysis Software, Cary, N.C.) for morphological data. Significant cultivar by year and TE by year interactions were detected; thus data from each year were analyzed separately. Least significant difference (LSD) values are reported when the F-ratio was significant at $\alpha=0.05$ level. Results for morphological data are compared with cover data (Chapter 2) to determine which morphological characteristics support wear tolerance.

Results and Discussion

A cultivar by TE interaction was detected in leaf number data in both 2008 and 2009 (Table 9). Tifway with untreated TE measured in the lowest category for number of leaves both years (Figure 4, 5). In the first year, applications of TE did not increase leaf number; however, in the second year, both applications of TE increased the number of leaves on Tifway. Leaf number of Patriot was unaffected by TE both years (Figure 4, 5). TE treatment B did lower the number of leaves in 'Celebration' bermudagrass both years as well. This was likely not observed for TE treatment A due to the fact that TE induced growth regulation had ceased prior to the date which data were collected. Since Patriot exhibited the least traffic tolerance (Chapter 2) and didn't differ from other cultivars in leaf number, it is likely that leaf number is not associated with bermudagrass traffic tolerance

Leaf angle was the only morphological characteristic associated with traffic tolerance in 2008 and 2009 (Table 9). Each year Tifway and Celebration (the most traffic tolerant cultivars) expressed a more vertical leaf angle to Patriot bermudagrass (the least traffic tolerant cultivar) (Table 10). In 2008, Tifway and Celebration expressed angle values of 2.2 and 2.1, respectively; while Patriot measured an angle value of 1.9. In 2009, values for each measured 2, 1.9, and 1.6, respectively. These results are consistent with the findings of Brosnan et al. (2005) who reported increases in Kentucky bluegrass wear tolerance and increase leaf angle. ‘Riviera’ bermudagrass had a more vertical leaf angle (2.1) in 2008 as compared to Patriot (1.9). No differences in angle between these cultivars were found in 2009.

Although leaf width has been found to account for variation in the wear tolerance of several turfgrass species (Shearman and Beard, 1975), differences in leaf width due to cultivar were only reported in the first year of this study. Consistent with past research showing that a finer leaf texture is associated with increased wear resistance (Cole, 1988). Tifway was in the highest traffic tolerant category (Chapter 2) and in the lowest category for leaf width in this study in 2008 (Table 10). However, Celebration exhibited similar traffic tolerance to Tifway in 2008, but exhibited the widest leaf of all cultivars tested.

In 2008, TE was significant for internode lengths, leaf angle, and leaf width (Table 9). In 2008, TE plots also had a higher percent green cover than no TE plots (Chapter 2). Leaf width in 2008 showed that the untreated control had a thinner leaf (1.85mm) than both TE treatment A and TE treatment B, (1.96 mm and 1.98 mm, respectively) (Table 11). TE treatment A and TE treatment B expressed a more vertical leaf angle compared to the untreated control (2.1, 2.1 and 1.9, respectively). In 2008, for the untreated control and TE treatment A, internode lengths one and two had longer internodes as compared to TE treatment B (Table 11). This may be due to the fact that the "rebound effect" seen with TE had not occurred in treatment B. In 2009, no differences between TE applications occurred.

Conclusion

This study showed that certain morphological characteristics are associated with traffic tolerance in bermudagrass. Increases in vertical leaf angle occurred in the most traffic tolerant cultivars and may be an important attribute to determine traffic tolerance in bermudagrass.

The effect of TE on morphological characteristics of bermudagrass was not consistent over the two years of this study; however, significance only occurred when there was a significant difference in traffic tolerance of the TE treatments (in year 2008). When TE applications improved traffic tolerance in 2008, a more vertical leaf angle and a wider leaf were morphological characteristics of these plots. Internode length was not consistent with the traffic tolerance of TE plots.

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Appendices

Appendix A
Tables

Table 1. ANOVA table for cultivar (C)†, trinexapac-ethyl (TE)‡, overseeding (O)§, and interactions for percent green cover after traffic events in 2008 in Knoxville, TN.

		Number of simulated games				
Treatments	**df**	**5**	**10**	**15**	**20**	**25**
C	**3**	***	***	***	***	**
TE	**2**	*	***	***	**	*
O	**1**	**NS¶**	*	***	***	***
C x TE	**6**	**NS**	**NS**	**NS**	**NS**	**NS**
C x O	**3**	**NS**	**NS**	**NS**	**NS**	**NS**
TE x O	**2**	**NS**	**NS**	**NS**	**NS**	*
C x TE x O	**6**	**NS**	**NS**	**NS**	**NS**	**NS**
Error	**46**					

*** Significant at the 0.05 level.**

**** Significant at the 0.01 level.**

***** Significant at the 0.001 level.**

† Bermudagrass cultivars consisted of Tifway, Riviera, Patriot, and Celebration.

‡ TE applications consisted of untreated Control, TE A=TE applied every 14 days until 14 days before traffic at 76.3 g ha^{-1}, and TE B= TE applied every 14 days until 14 days after traffic at 76.3 g ha^{-1}.

§ Overseeding applications consisted of no overseeding and overseeding at 670 kg ha^{-1} occurring on 22 September 2008.

¶ Not significant at the $p<0.05$ level of significance.

Table 2. ANOVA table for cultivar (C)[†], trinexapac-ethyl (TE)[‡], overseeding (O)[§], and interactions for percent green cover after traffic events in 2009 in Knoxville, TN.

		Number of simulated games				
Treatments	**df**	**5**	**10**	**15**	**20**	**25**
C	**3**	**NS[¶]**	**	**	*	**
TE	**2**	***	***	**NS**	**NS**	**NS**
O	**1**	*	**	***	***	***
C x TE	**6**	**NS**	**NS**	**NS**	**NS**	**NS**
C x O	**3**	**NS**	**NS**	**NS**	**NS**	**NS**
TE x O	**2**	**NS**	**NS**	**NS**	**NS**	**NS**
C x TE x O	**6**	**NS**	**NS**	**NS**	**NS**	**NS**
Error	**46**	**NS**	**NS**	**NS**	**NS**	**NS**

*** Significant at the 0.05 level.**
**** Significant at the 0.01 level.**
***** Significant at the 0.001 level.**
[†] Bermudagrass cultivars consisted of Tifway, Riviera, Patriot, and Celebration.
[‡] TE applications consisted of untreated Control, TE A=TE applied every 14 days until 14 days before traffic at 76.3 g ha^{-1}, and TE B= TE applied every 14 days until 14 days after traffic at 76.3 g ha^{-1}.
[§] Overseeding applications consisted of no overseeding and overseeding at 670 kg ha^{-1} occurring on 22 September 2008.
[¶] Not significant at the $p<0.05$ level of significance.

Table 3. Effect of bermudagrass cultivar on percent green cover† after 5, 10, 15, 20, and 25 games of simulated athletic field traffic‡ in 2008 and 2009 in Knoxville, TN.

		Number of simulated games‡				
Cultivars		**5**	**10**	**15**	**20**	**25**
2008	**Tifway**	**93.0**	**85.7**	**74.0**	**61.8**	**46.9**
	Riviera	**90.6**	**83.8**	**66.8**	**49.4**	**30.7**
	Patriot	**89.0**	**73.1**	**38.1**	**23.2**	**13.5**
	Celebration	**93.9**	**86.2**	**73.9**	**57.1**	**38.1**
	LSD (0.05)§	**2.3**	**5.4**	**6.5**	**7.1**	**7.6**
2009	**Tifway**	**84.6**	**80.2**	**53.0**	**20.3**	**20.2**
	Riviera	**85.2**	**85.2**	**54.6**	**18.3**	**15.3**
	Patriot	**79.8**	**70.5**	**37.2**	**10.5**	**8.5**
	Celebration	**84.6**	**83.7**	**58.5**	**25.7**	**21.4**
	LSD (0.05)§	**7.1**	**9.1**	**12.2**	**9.8**	**7.5**

† Digital Image Analysis used to determine percent green cover (Richardson et al., 2001).

‡ Traffic was initiated with the Cady Traffic Simulator on 8 September 2008 and 7 September 2009 with three games applied per week (two passes=one game).

§ Fishers least significance difference value used to determine differences between means at p<0.05 level.

Table 4. Effect of trinexapac-ethyl (TE) on percent green cover † after 5, 10, 15, 20, and 25 games of simulated athletic field traffic‡ in 2008 and 2009 in Knoxville, TN.

		Number of simulated games‡				
TE§		**5**	**10**	**15**	**20**	**25**
2008	**Untreated Control**	**91.8**	**83.2**	**55.9**	**41.4**	**26.4**
	TE A - 3 Applications	**92.9**	**87.2**	**68.6**	**52.4**	**36.1**
	TE B - 5 Applications	**90.2**	**76.2**	**63.5**	**49.8**	**34.5**
	LSD (0.05)¶	**2.0**	**4.7**	**5.6**	**6.1**	**6.5**
2009	**Untreated Control**	**89.3**	**87.8**	**53.4**	**18.7**	**16.4**
	TE A - 3 Applications	**88.2**	**87.9**	**54.8**	**18.6**	**16.3**
	TE B - 5 Applications	**73.3**	**64.0**	**44.2**	**18.8**	**16.4**
	LSD (0.05)¶	**6.1**	**7.9**	**10.6**	**8.5**	**6.5**

† Digital Image Analysis used to determine percent green cover (Richardson et al., 2001).

‡ Traffic was initiated with the Cady Traffic Simulator on 8 September 2008 and 7 September 2009 with three games applied per week (two passes=one game).

§ TE applications consisted of untreated control, TE A=TE applied every 14 days until 14 days before traffic at 76.3 g ha^{-1}, and TE B= TE applied every 14 days until 14 days after traffic at 76.3 g ha^{-1}.

¶ Fishers least significance difference value used to determine differences between means at $p<0.05$ level.

Table 5. Effect of overseeding on percent green cover† after 5, 10, 15, 20, and 25 games of simulated athletic field traffic‡ in 2008 and 2009 in Knoxville, TN.

		Number of simulated games‡				
Overseeding§		**5**	**10**	**15**	**20**	**25**
2008	**Not Overseeded**	**91.5**	**80.2**	**53.3**	**35.8**	**18.3**
	Overseeded Plots	**91.8**	**84.2**	**72.1**	**59.9**	**46.3**
	LSD (0.05)¶	**1.7**	**3.8**	**4.6**	**5.0**	**5.3**
2009	**Not Overseeded**	**80.4**	**74.7**	**36.8**	**10.1**	**8.0**
	Overseeded Plots	**86.7**	**85.1**	**64.8**	**27.3**	**24.7**
	LSD (0.05)¶	**5.0**	**6.4**	**8.6**	**7.0**	**5.3**

† Digital Image Analysis used to determine percent green cover (Richardson et al., 2001).

‡ Traffic was initiated with the Cady Traffic Simulator on 8 September 2008 and 7 September 2009 with three games applied per week (two passes=one game).

§ Overseeding occurred at 670 kg ha^{-1} occurring on 22 September 2008 (after 7 simulated games) and 21 October 2009 (after 6 simulated games).

¶ Fishers least significance difference value used to determine differences between means at $p<0.05$ level.

Table 6. ANOVA table for cultivar (C)[†], trinexapac-ethyl (TE)[‡], overseeding (O)[§], and interactions for soil physical properties in 2008 in Knoxville, TN.

Treatments	df	K_{sat}	BD	Total Porosity	Air Filled Porosity	Capillary Porosity	Organic Matter	Surface Organic Matter
C	3	NS[¶]	NS	NS	NS	NS	NS	NS
TE	2	NS	NS	NS	NS	NS	NS	NS
O	1	NS	NS	NS	NS	NS	NS	NS
C x TE	6	NS	NS	NS	NS	NS	NS	NS
C x O	3	NS	NS	NS	NS	NS	NS	NS
TE x O	2	NS	NS	NS	NS	NS	NS	NS
C x TE x O	6	NS	NS	NS	NS	NS	NS	NS
Error	46							

[†] Bermudagrass cultivars consisted of Tifway, Riviera, Patriot, and Celebration.

[‡] TE applications consisted of untreated Control, TE A=TE applied every 14 days until 14 days before traffic at 76.3 g ha^{-1}, and TE B= TE applied every 14 days until 14 days after traffic at 76.3 g ha^{-1}.

[§] Overseeding applications consisted of no overseeding and overseeding at 670 kg ha^{-1} occurring on 22 September 2008.

[¶] Not significant at the $p<0.05$ level of significance.

Table 7. ANOVA table for cultivar (C)[†], trinexapac-ethyl (TE)[‡], overseeding (O)[§], and interactions for soil physical properties in 2009 in Knoxville, TN.

Treatments	df	K_{sat}	BD	Total Porosity	Air Filled Porosity	Capillary Porosity	Organic Matter	Surface Organic Matter
C	3	NS[¶]	*	*	NS	*	*	NS
TE	2	NS	NS	NS	NS	NS	NS	NS
O	1	NS	NS	NS	NS	NS	NS	NS
C x TE	6	NS	NS	NS	NS	NS	NS	NS
C x O	3	NS	NS	NS	NS	NS	NS	NS
TE x O	2	NS	NS	NS	NS	NS	NS	NS
C x TE x O	6	NS	NS	*	NS	NS	NS	NS
Error	46							

*** Significant at the 0.05 level.**

† Bermudagrass cultivars consisted of Tifway, Riviera, Patriot, and Celebration.

‡ TE applications consisted of untreated Control, TE A=TE applied every 14 days until 14 days before traffic at 76.3 g ha^{-1}, and TE B= TE applied every 14 days until 14 days after traffic at 76.3 g ha^{-1}.

§ Overseeding applications consisted of no overseeding and overseeding at 670 kg ha^{-1} occurring on 22 September 2008.

¶ Not significant at the p<0.05 level of significance.

Table 8. Effect of cultivar on significant soil physical properties in 2009 in Knoxville, TN.

Cultivar	Bulk Density	Total Porosity	Capillary Porosity	Organic Matter
	($g\ cm^{-3}$)	(%)	(%)	(g)
Tifway	0.91	42.6	33.2	4.5
Riviera	0.99	39.4	30.0	4.0
Patriot	0.96	41.3	31.3	4.1
Celebration	0.97	41.9	31.3	4.1
LSD (0.05)†	0.05	1.9	1.9	0.3

† Fishers least significance difference value used to determine differences between means at $p<0.05$ level.

Table 9. ANOVA table for cultivar (C)[†], trinexapac-ethyl (TE)[‡] and interactions for morphological characteristics[§] in 2008 and 2009 in Knoxville, TN.

			Morphological Characteristics				
Treatments		**df**	**# Leaves**	**Internode 1**	**Internode 2**	**Leaf Angle**	**Leaf Width**
2008	**C**	**3**	***	**NS**	**NS**	*	*
	TE	**2**	**NS[¶]**	**	**	**	**
	C x TE	**6**	**	**NS**	**NS**	**NS**	**NS**
	Error	**29**					
2009	**C**	**3**	**NS**	**NS**	**NS**	*	**NS**
	TE	**2**	**NS**	**NS**	**NS**	**NS**	**NS**
	C x TE	**6**	***	**NS**	**NS**	**NS**	**NS**
	Error	**29**					

*** Significant at the 0.05 level.**

**** Significant at the 0.01 level.**

***** Significant at the 0.001 level.**

[†] Bermudagrass cultivars consisted of Tifway, Riviera, Patriot, and Celebration.

[‡] TE applications consisted of untreated TE, TE applied at 76.3 g a.i. ha^{-1} every 14 days for three total applications, and TE applied at 76.3 g a.i. ha^{-1} every 14 days for five total applications.

[§] # leaves - number of leaves off of the shoot, internode 1 - length in mm between the first and second youngest node, internode 2 - length in mm between the second and third youngest node, leaf angle - angle of the second youngest leaf off of the shoot, leaf width - width in mm of the second youngest leaf off of the shoot.

[¶] Not significant at the $p<0.05$ level of significance.

Table 10. Effect of cultivar on morphological characteristics of bermudagrass in 2008 and 2009 in Knoxville, TN.

		Morphological Characteristics†	
Cultivar		**Leaf Angle‡**	**Leaf Width**
		(1-4)	**(mm)**
2008	**Tifway**	**2.2**	**1.88**
	Riviera	**2.1**	**1.96**
	Patriot	**1.9**	**1.9**
	Celebration	**2.1**	**2**
	LSD (0.05) §	**0.15**	**0.09**
2009	**Tifway**	**2**	**1.44**
	Riviera	**1.8**	**1.56**
	Patriot	**1.6**	**1.41**
	Celebration	**1.9**	**1.63**
	LSD (0.05) §	**0.21**	**0.23**

† Leaf angle - angle of the second youngest leaf off of the shoot, leaf width - width in mm of the second youngest leaf off of the shoot.

‡ Angle was rated on a scale of 1 to 4 with the sheath as the vertical axis with a score of 1 indicating a horizontal leaf orientation (0 to 22.5°), 2 indicating a semi-horizontal (22.5 to 45°), 3 indicating a semi-vertical (45 to 67.5°), and 4 indicating a vertical leaf orientation (67.5 to 90°).

§ Fishers least significance difference value used to determine differences between means at $p<0.05$ level.

Table 11. Effect of trinexapac-ethyl (TE) on morphological characteristics of bermudagrass in 2008 and 2009 in Knoxville, TN.

TE‡		Internode 1	Internode 2	Leaf Angle§	Leaf Width
		Morphological Characteristics†			
		(mm)	(mm)	(1-4)	(mm)
2008	Untreated Control	7.6	8.3	1.9	1.85
	TE A - 3 Applications	8.0	8.4	2.1	1.96
	TE B - 5 Applications	6.8	7.3	2.1	1.98
	LSD (0.05) ¶	0.6	0.7	0.1	0.08
2009	Untreated Control	5.2	5.3	1.9	1.5
	TE A - 3 Applications	5.7	6.0	1.8	1.5
	TE B - 5 Applications	4.8	5.0	1.8	1.5
	LSD (0.05) ¶	0.7	0.7	0.2	0.2

† Internode 1 - length in mm between the first and second youngest node, internode 2 - length in mm between the second and third youngest node, leaf angle - angle of the second youngest leaf off of the shoot, leaf width - width in mm of the second youngest leaf off of the shoot.

‡ TE applications consisted of untreated TE, TE applied at 76.3 g a.i. ha^{-1} every 14 days for three total applications, and TE applied at 76.3 g a.i. ha^{-1} every 14 days for five total applications.

§ Angle was rated on a scale of 1 to 4 with the sheath as the vertical axis with a score of 1 indicating a horizontal leaf orientation (0 to 22.5°), 2 indicating a semi-horizontal (22.5 to 45°), 3 indicating a semi-vertical (45 to 67.5°), and 4 indicating a vertical leaf orientation (67.5 to 90°).

¶ Fishers least significance difference value used to determine differences between means at $p<0.05$ level.

Appendix B
Figures

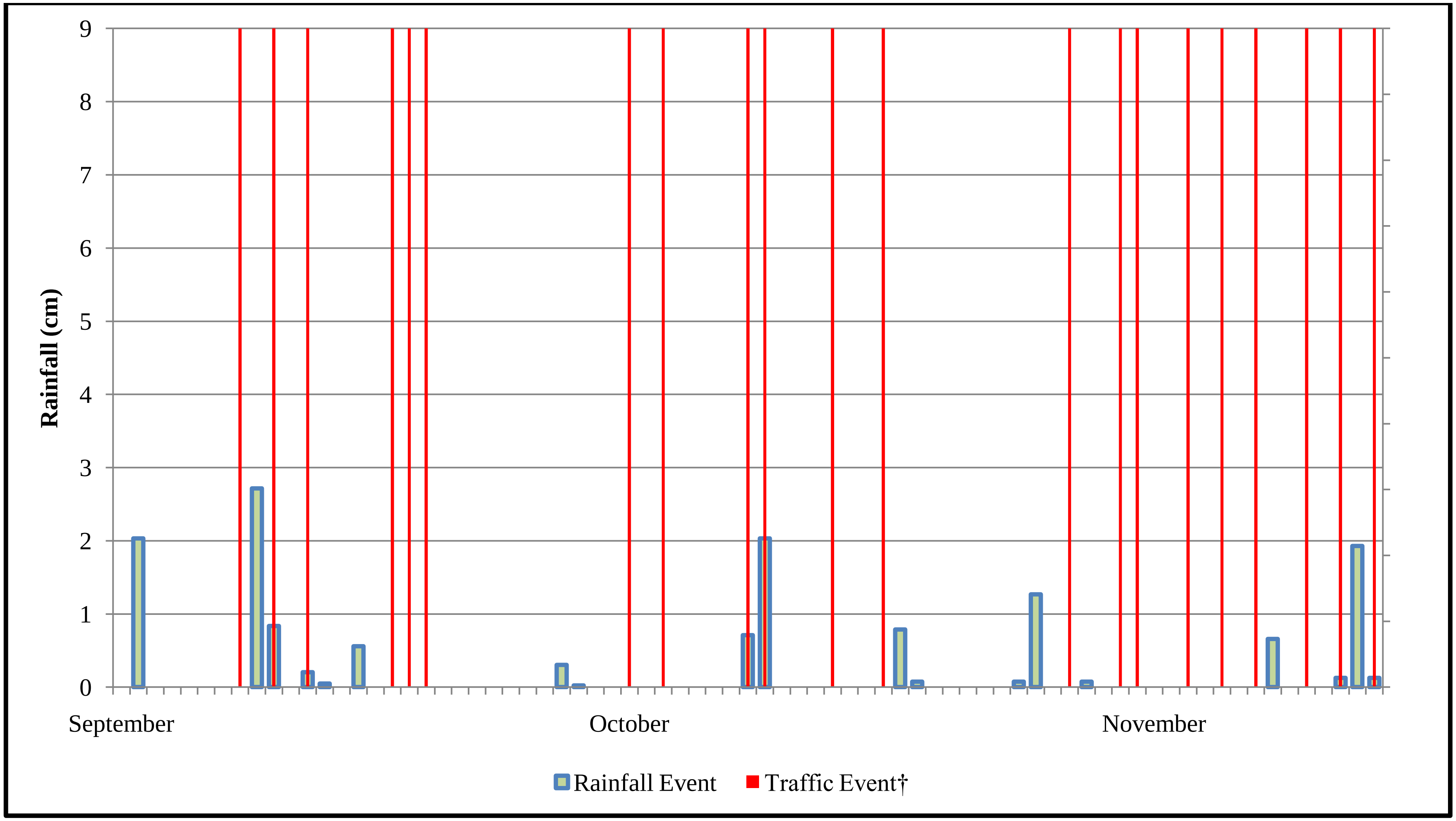

Figure 1. Daily rainfall data for the University of Tennessee East Tennessee Research and Education Center compared to traffic events in 2008 in Knoxville, TN.

†Each red line represents when a simulated traffic event occurred with two simulated traffic events occurring on some days (a total of 25 traffic events occurred over the traffic season).

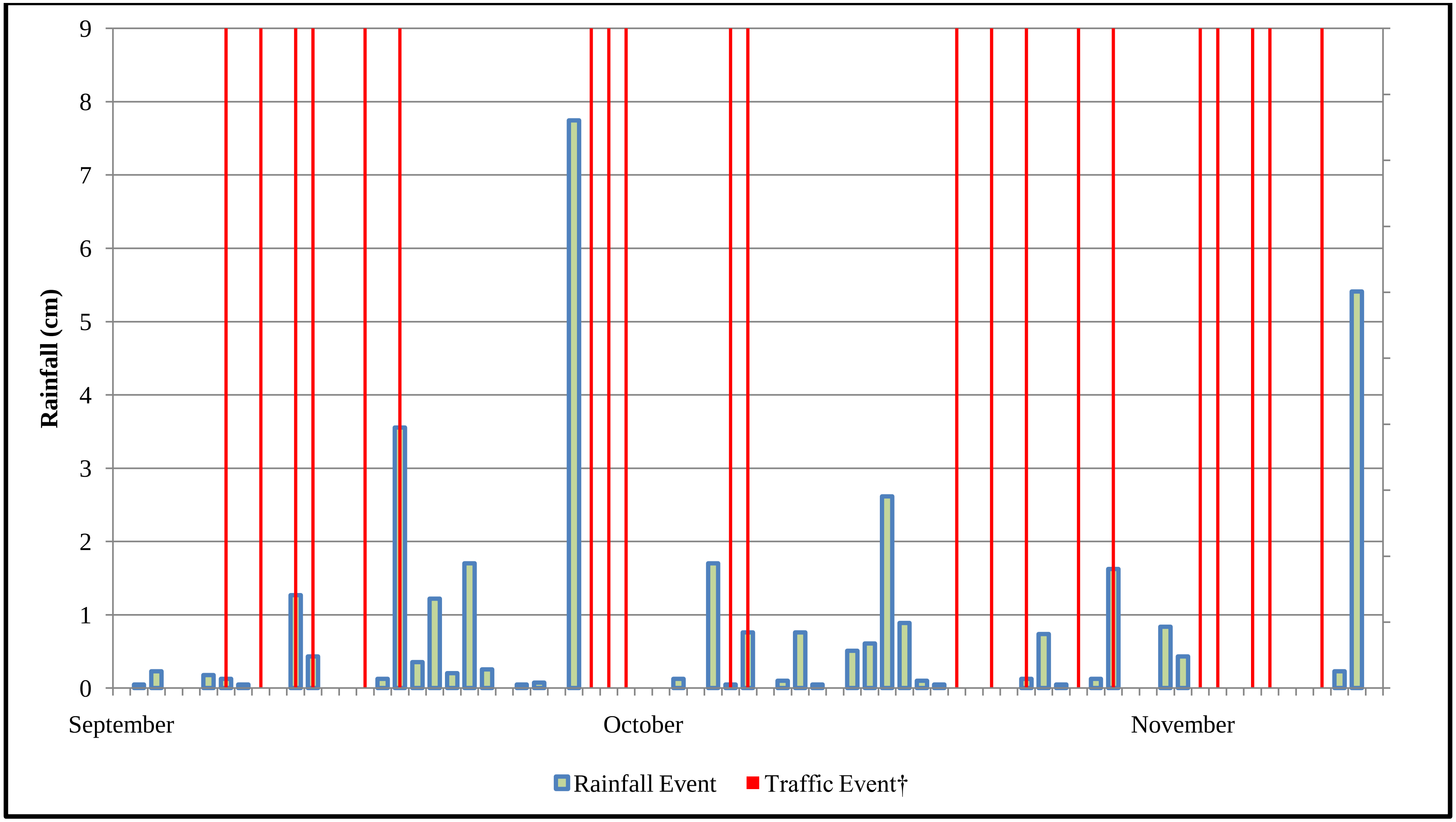

Figure 2. Daily rainfall data for the University of Tennessee East Tennessee Research and Education Center compared to traffic events in 2009 in Knoxville, TN.

†Each red line represents when a simulated traffic event occurred with two simulated traffic events occurring on some days (a total of 25 traffic events occurred over the traffic season).

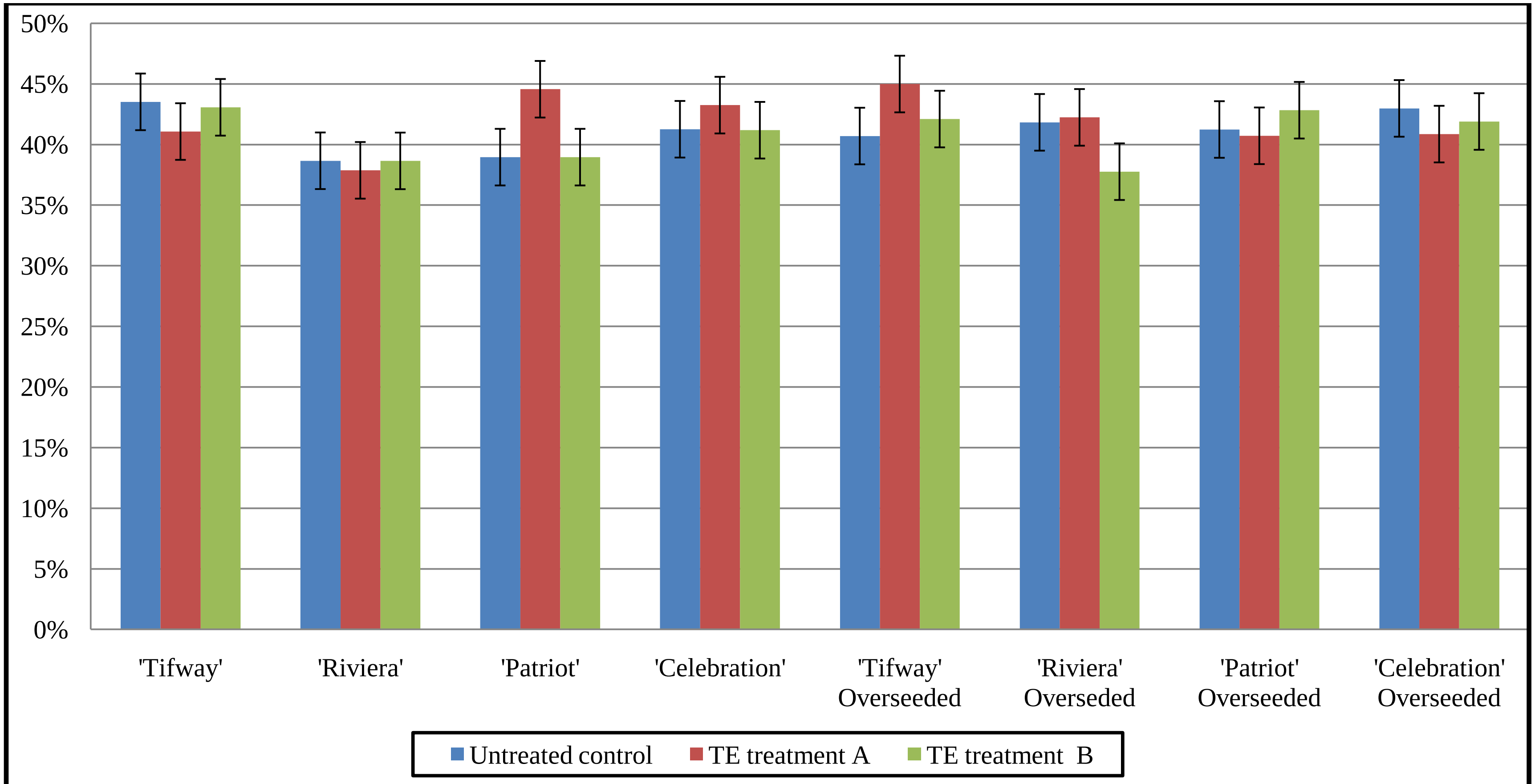

Figure 3. Effects of cultivar by trinexapac-ethyl (TE)† by overseeding‡ on total soil porosity§ in 2009 in Knoxville, TN.

† Overseeding TE applications consisted of untreated Control, TE A=TE applied every 14 days until 14 days before traffic at 76.3 g ha^{-1}, and TE B= TE applied every 14 days until 14 days after traffic at 76.3 g ha^{-1}.

‡ Overseeding occurred at 670 kg ha^{-1} occurring on 22 September 2008 (after 7 simulated games) and 21 October 2009 (after 6 simulated games).

§ Total porosity is the saturated weight of soil subtracted from the oven dried weight of the soil over its volume.

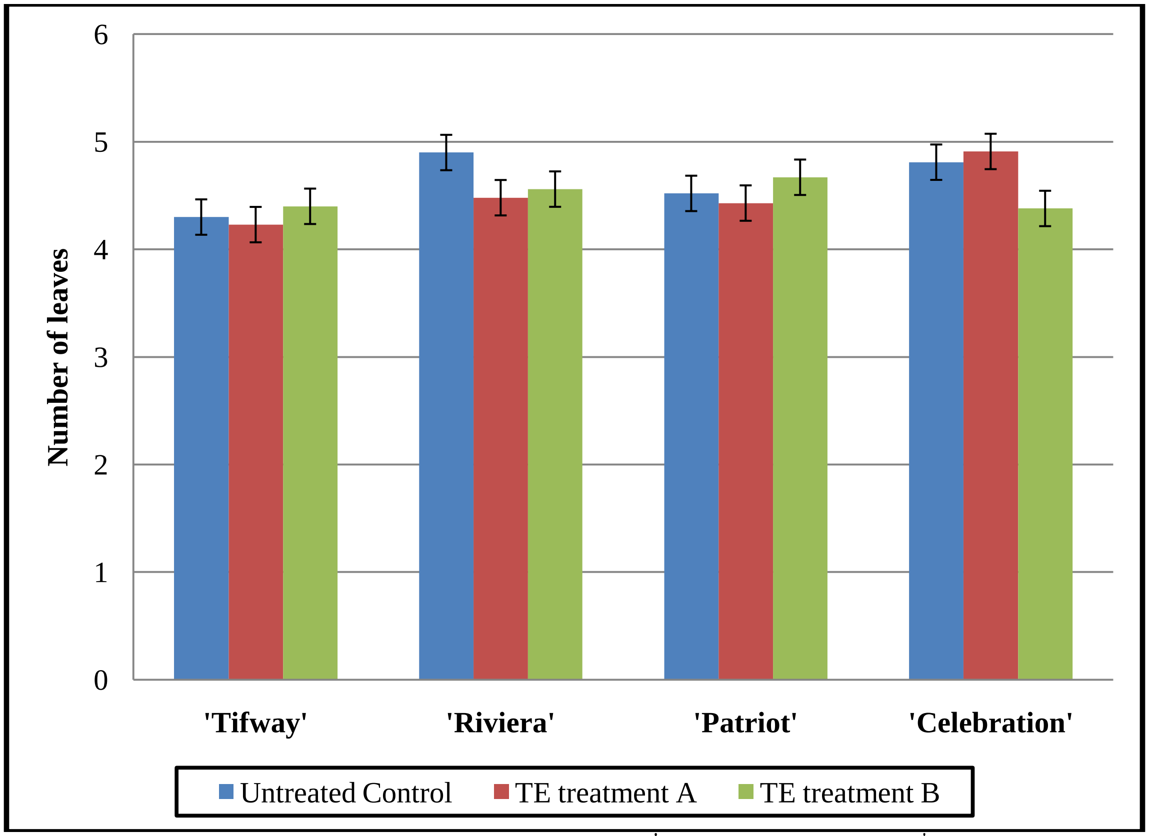

Figure 4. Effect of cultivar by trinexapac-ethyl (TE)[†] on number of leaves[‡] in 2008 in Knoxville, TN.

[†] TE applications consisted of untreated TE, TE applied at 76.3 g a.i. ha^{-1} every 14 days for three total applications, and TE applied at 76.3 g a.i. ha^{-1} every 14 days for five total applications.

[‡] Number of leaves was the total number of leaves measured off of the youngest shoot of the stolon.

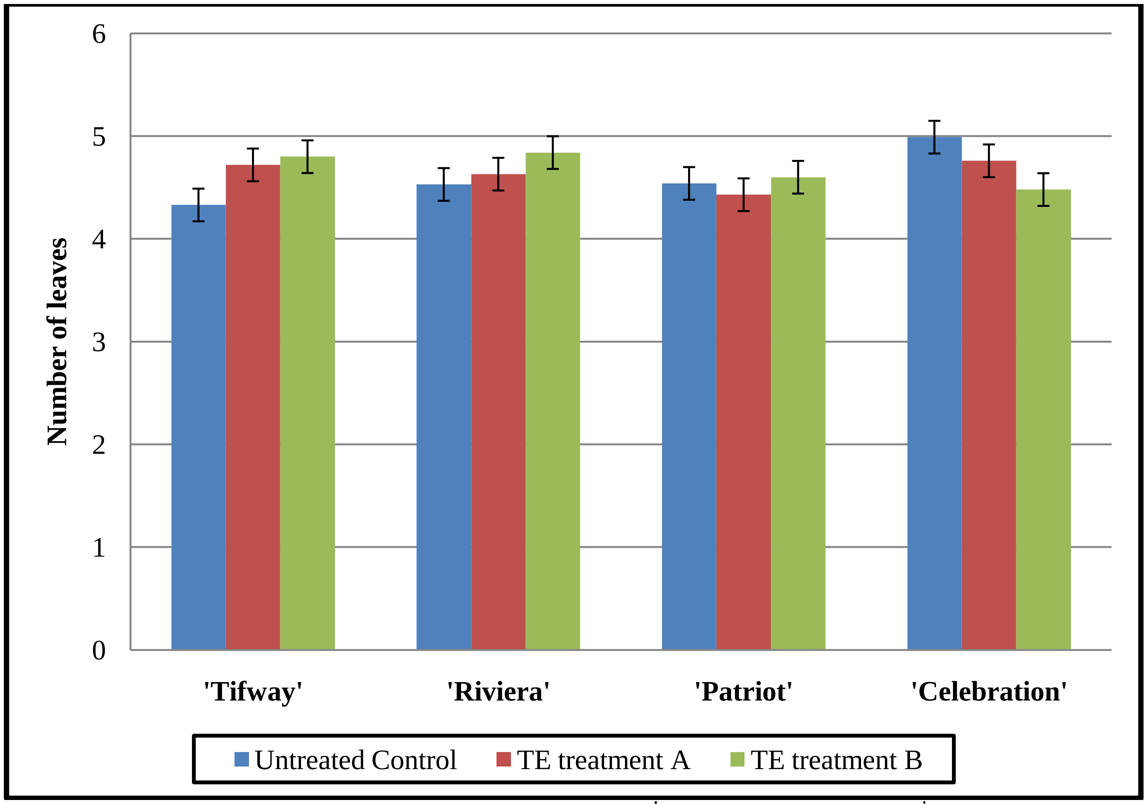

Figure 5. Effect of cultivar by trinexapac-ethyl (TE)† on number of leaves‡ in 2008 9 in Knoxville, TN.

† TE applications consisted of untreated TE, TE applied at 76.3 g a.i. ha^{-1} every 14 days for three total applications, and TE applied at 76.3 g a.i. ha^{-1} every 14 days for five total applications.

‡ Number of leaves was the total number of leaves measured off of the youngest shoot of the stolon.

VITA

William Haselbauer was born in Minneapolis, MN on June 13, 1984. He grew up in south Minneapolis and attended high school at De La Salle High School, graduating in 2002. After graduation he pursued a bachelors of science degree from the University of Minnesota in horticulture with an emphasis on turfgrass management. He graduated in the spring of 2007. In the spring of 2008 William accepted a graduate research position at the University of Tennessee in Plant Sciences under the direction of Dr. John Sorochan. Upon graduation William plans to move to Chicago and pursue an industry position in turfgrass science.