ESTABLISHMENT AND MANAGEMENT OF TURFGRASS UNDER MUNICIPAL WATER RESTRICTIONS

A Thesis

by

DANIEL FRANCIS HARGEY

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	Benjamin G. Wherley
Co-Chair of Committee,	Richard H. White
Committee Members,	Ambika Chandra
	Matthew Elmore
Head of Department,	David D. Baltensperger

December 2015

Major Subject: Agronomy

ABSTRACT

Drought has become and continues to be a major concern throughout many areas of the United States. To better manage water supplies, municipalities are constantly in search of ways to conserve and ration water. In this process, they must identify the areas of importance to continue to allocate sufficient water and others in which to make reductions. Home lawns and turfgrass in general have been viewed as luxuries rather than necessities, and therefore lawns and turfgrass are the first areas to experience watering reductions. These come in the form of municipal water restrictions in which, depending on the severity of the drought, will limit the extent to which a lawn can be irrigated during conservation periods.

Limited knowledge of turfgrass maintenance under drought conditions and water restrictions has created challenges for home owners' and turf managers' inabilities to take care of turf. Selecting cultivars and management practices that result in a higher tolerance of drought can be the difference between having a healthy lawn and a dead lawn when water is decreased. Maintenance during establishment is arguably just as important as proper cultivar selection. To combat limited moisture in the upper part of the soil, deep rooting will help turf to utilize water well below the soil surface. In areas where warm-season turfgrass enters winter dormancy, cool season turfgrasses have historically been overseeded to maintain green color throughout the dormancy period. However, this practice may not be feasible under limited irrigation frequency associated with water restriction periods. Alternatives that do not require supplemental water, such as the use of colorants, have been increasingly utilized on areas that do not endure excessive wear.

The objectives of this study are to (1) evaluate establishment cultural practices on turf quality and root development of ‘Floratam’ and newly released St. Augustinegrass cultivar ‘TamStar’ during a simulated water variance period and (2) evaluate the performance of overseeded, colorant treated, and untreated ‘Tifway’ bermudagrass under water restriction and traffic.

DEDICATION

To my late friend Chris, your short life was nothing less than inspiring.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Wherley, and my committee members, Dr. White, Dr. Chandra, and Dr. Reynolds, for their guidance and support throughout the course of this research. I also want to extend my gratitude to Jon Smith and Charles Fontanier for easing my transition back into academia.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. I also want to extend my gratitude to the Texas Turfgrass Research, Education and Extension (TREEE) Endowment, which provided funding for my research.

An extra special thanks goes to Tom Seidler and Brandon Benson, without their patience and trust I would not be where I am today. I will forever be grateful of my first opportunity as professional sports turf manager.

Finally, thanks to my mother, father, sister and uncle for their encouragement and undying love. I could not ask for a better support group through the tough times.

NOMENCLATURE

PGR	Plant growth regulator
TE	Trinexapac-ethyl
VWC	Volumetric water content

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Municipal Water Restrictions

Over the last 50 years, drought-like conditions have been ever increasing throughout the United States. Due to lack of precipitation and growing demand for potable water in areas extending throughout the southern and western portions of the United States, municipalities have forced to enact water usage restrictions in an effort to conserve limited water supplies. As the population grows, the demand for water increases, which leads to greater importance of allocating water usage toward necessities. Between the years 2010 and 2030, Texas is expected to see an increase in population by 36.6% (Census, 2005). Without proper regulations from municipalities, water consumption will eventually exceed supply. In fact, given our current growth rate, an estimated 8.3 million acre feet of additional water supply would be needed by 2060 if demand remains unchanged (Texas Water Development Board, 2012).

Prioritizing water usage has become vital to maintaining an adequate supply without completely depleting water reserves. Currently, depending on the month, irrigation accounts for up to 60% of total residential water demand in Texas, and is expected to remain the highest category until 2060 (Texas Water Development Board, 2012). Irrigation for residential and commercial landscapes has become an area in which stricter restrictions have been placed to reduce the amount of water waste. In Texas, approximately 1,000 of the roughly 4,600 total public water systems already has or is currently imposing restrictions (Combs, 2012). Depending on water supplies and severity of drought, municipalities have enacted regulations that limit the duration of watering to particular days in order to balance water demands. The San Antonio Water System (SAWS), as well as other municipal water purveyors in Texas have developed a stage-based system to determine the frequency of irrigation in accordance to the severity of drought. All stages from 1 to 3 limit residents to irrigate before 11:00 am or after 7:00 pm (San Antonio Water System 2013). As the stage increases, the frequency at which residents can use irrigation systems decreases. For example in the San Antonio area, stages 1 and 2 allow for irrigation once a week, stage 3 once every other week and stage 4 prohibits the use of irrigation systems entirely, whereas in Allen Texas, homeowners can water up to twice a week during stage 1 before cutting back to similar restrictions from stages 2 to 4 (San Antonio Water System 2013, City of Allen, TX 2015).

Variance Periods

Variance requests during drought are often submitted for areas such as newly planted lawns or athletic facilities. Per request, municipalities will determine whether the variance is warranted and will only be considered if the current drought stage doesn’t exceed stage 2 (San Antonio Water System, 2013). Newly planted residential lawns that have had the variance request approved will be allowed to water daily for up to 5 weeks (San Antonio Water System, 2013). Athletic facilities often aren’t able to maintain a safe and playable surface under strict water restrictions because of an inability to sustain turfgrass density under the combined effects of drought, traffic and wear. Variance requests can be submitted for athletic facilities and irrigation frequency will be determined after the completion of an irrigation audit (San Antonio Water System, 2013).

Landscape water restrictions present unique challenges in terms of turfgrass management, and little research has focused on best establishment and management practices under these conditions. Difficulties in the establishment of warm-season turfgrasses have become more pronounced depending on the type of installation. While sodding is most common, techniques such as plugging or sprigging are cheaper options but require 60 days of optimal care to become fully established with total ground cover (Chalmers and McAfee, 2010). These methods become unfavorable under any stage of drought since irrigation would presumably become limited after the 5-week variance period. Additionally, to enable for optimal care during the variance period, proper installation of irrigation systems becomes vital. Often, irrigation systems are not properly installed or adjusted, which can lead to as much as a 50% of water lost as runoff.

As rapid population growth and droughts continue, water conservation throughout the southern and western portions of the United States will become increasing more important. As water restrictions are imposed more frequently, turf managers must become increasingly familiar with proper establishment and management techniques which promote turf health and survival.

St. Augustinegrass Sod Establishment During Water Restrictions

St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Kuntze) is a widely used turfgrass throughout the southern United States, found as far east as the Carolinas and as far west as California. St. Augustinegrass is the primary lawn grass in Texas due to its tolerance to high summer temperatures as well as shade tolerance and ability to keep its color at lower temperatures than bermudagrass (*Cynodon dactylon L.)* (Duble, 2013). St. Augustinegrass is commonly established by sodding, but in areas where water is highly accessible it can also be established by sprigging or plugging. Ideal establishment time is mid-spring through mid-summer when soil temperatures range from 18 to 24 °C (Goatley et al., 2009). Although not the most commonly used cultivar in Texas, 'Floratam' St. Augustinegrass has become widely used across the southeastern U.S. for home lawns, largely due to its above average drought tolerance and its resistance to the St. Augustine Decline (SAD) virus as well as chinch bugs (Duble, 2013).

Establishment

Homeowners with newly planted lawns are often challenged with establishing a strong stand during the variance period, commonly lasting 35 days. Once water restrictions are again imposed following this variance period, homeowners are likely to see the quality of their lawn diminish drastically under drought stress. During the first three month after planting, fertilization is critical. Contingent on soil test results, an application of a complete fertilizer should be applied during the planting and up to 4.9 g nitrogen m^{-2} may be required every 4-6 weeks during the growing season (Trenholm et al., 2000; Duble, 2013).. Atrazine is also commonly recommended during establishment as a pre-emergent herbicide without causing early growth retardation (Johnson, 1973). The application of a pre-emergence herbicide will allow the St. Augustinegrass to utilize all available water and nutrients without competition from weeds. Proper watering frequency and duration during establishment will allow the newly planted St. Augustinegrass to maintain moisture without becoming too wet or too dry. Frequent, light watering during the first 7 to 10 days is recommended to allow the sod to rapidly establish roots before reducing irrigation frequency further for the following 10 days (Trenholm et al., 2000). Ideally, during the last 10 days of the variance period 0.635 to 1.27 cm of water should be applied two to three times weekly or as needed (Trenholm et al., 2000).

Rooting

Due to the potentially abrupt change in irrigation frequency following the variance period, drought-resistant mechanisms become vital to the long term success of the St. Augustinegrass. Rooting depth has been shown to be a key factor contributing to the survival of the turfgrass under drought conditions (Marcum et al., 1995; Carrow, 1996; Steinke et al., 2011; Levitt, 2012). The majority (~91%) of St. Augustinegrass roots occur in the top 30 cm of the soil profile (Peacock and Dudeck, 1985). The percentage of rooting at depths greater than 30 cm is minimal compared to that in the upper 30 cm. During drought conditions, however, these deeper roots allow St.

Augustinegrass to survive (or avoid drought altogether) by extracting the deeper water reserves as water becomes limiting in the top 30 cm as soils dry.

In order to promote deeper rooting within established turf, it has been recommended to raise the height of cut and to mow less frequently (Madison, 1962). Wright (1962) found in a study involving Blue Panicgrass (*Panicum antidotale* Retz.), that raising the height of cut significantly increased root weight. Standard recommendations for managing St. Augustinegrass turf are to mow within the range of of 8.89-10.16 cm. Frequent mowing at lower heights has generally contributed to more shallow root development (Salaiz et al., 1995; Trenholm et al., 2000; Liu and Huang, 2002).

Plant Growth Regulators

While mowing height and frequency can impact root development, another potential chemical option for affecting root development of sod may be the use of plant growth regulators (PGRs), specifically gibberellic acid inhibitors, either prior to or after sodding. PGRs are divided into two groups, type I and type II, depending on their specific effects on plant growth regulation. Type I PGRs are foliar absorbed and inhibit cell elongation while type II PGRs are root absorbed and interfere with gibberellic acid biosynthesis (McCarty and Whitwell, 2006). Trinexapac-ethyl (TE) (4-[Cyclopropyl-a-hydroxymethylene]-3,5-dioxo-cyclohexanecarboxylic acid ethylester) is commonly used on turfgrass to limit shoot growth by inhibiting gibberellin acid synthesis which ultimately allowed a reduction in mowing frequency (Adams et al., 1992; Fagerness and

Penner, 1998; Ervin and Koski, 2001). McCarty et al. (2004) conducted an experiment to examine the effects of plant growth regulators on St. Augustinegrass and found that mowing frequency could effectively be reduced by 50% with the use of TE. In this same study, authors also reported a minimal decrease in seed head production from a single application of TE. Not only will TE help in the reduction of leaf elongation but can also have secondary benefits on rooting and tillering of turfgrasses (Ervin and Koski, 1998; Beasley et al., 2005). A study from Beasley (2005) on 'Moonlight' Kentucky bluegrass (*Poa pratensis*) showed a significant increase in the number of tillers 3 weeks after application of TE at a rate of0.27 kg ha^{-1}. In the same study, root length and root surface area also increased in response to TE. The use of TE could help homeowners or sports field managers decrease the frequency of mowing. Limited information is currently available regarding plant growth regulator effects on St. Augustinegrass. Thus, more data is needed to determine if they have positive benefits particularly during early establishment.

Overseeding During Winter Bermudagrass Dormancy

Hybrid bermudagrass (*Cynodon dactylon x C. Transvaalensis* Burtt-Davey) is the most common warm-season grass to be overseeded during winter dormancy due to its wide usage on sports fields and golf courses across the transition zone and southern U.S.. The transition zone extends from the east coast to the west coast in areas in which winter temperatures are too cold for warm-season grass growth and summers too hot for cool-season grass growth. Regions where mean temperatures during winter months range from 4 to 24 °C are well suited for overseeding of dormant warm season turf (Trlica, 2013). Most turf managers overseed to improve the playability of the field during the winter months and also for aesthetic purposes (Willis et al., 2007). On golf courses, it is common for greens to be overseeded with cool-season grasses including red fescue (*Festuca rubra*), creeping bentgrass (*Agrostis stolonifera*), annual ryegrass (*Lolium multiflorum*), or perennial ryegrass (*Lolium perenne*) (Ward et. al, 1974).

For sport complexes and golf courses that are expected to support a high level of play and provide superior playability during the winter dormancy of the warm-season grass, it is vital for turf managers to establish a stand of cool-season grass to withstand the usage and help protect the playability of the surface (Mazur and Rice, 1999; Thoms et al., 2011). The time required to reach full establishment will be determined by the usage schedule. For instance, a multi-use field may only have 2-3 weeks to establish a stand of ryegrass due to a short transition between football and soccer. Mazur and Rice (1999) determined that overseeding with higher rates of 'Gator' perennial ryegrass ranging from 150 to 180 g·m^{-2} resulted in an established ryegrass stand capable of holding up to traffic within 30 days of planting, while rates of 120 g·m^{-2} required 60 days. Even lower rates of 90 g·m^{-2} required 120 days for full establishment. Thus, it is not uncommon for perennial ryegrass to be overseeded at rates as high as 150 to 200 g·m^{-2}, however, these plants will remain in a much more juvenile stage of maturity during the winter period (Ward et al., 1974; Duble, 1978; Schmidt and Shoulders, 1980). Duble (1978) found that lower seeding rates resulted in more tillering and overall stronger plants which became an issue when the bermudagrass started coming out of dormancy in spring, resulting in delayed transition and unacceptable turf quality. Athletic field managers, who are increasingly concerned with the transition period, tend to overseed at rates between 49 to 73 $g \cdot m^{-2}$ (Powell and Bergstrom, 2009). Of course, cost may ultimately dictate seeding rates, as higher rates can result in costs of $5,000 per acre for seed, preparation and application (Liu et al., 2007).

Compaction

During the dormancy period, bermudagrass is not actively growing, and thus, has a limited capacity to recover from wear damage. For this reason, turf managers who manage athletic surfaces receiving high wear during the winter months often turn to overseeding to maintain playability (Mazur and Rice, 1999). Previous research has shown both intra and interspecific differences in performance and wear tolerance of the cool-season grasses used for overseeding. For instance, Shearman and Beard (1975) found that 'Manhattan' perennial ryegrass (*Lolium perenne*) ranked 1st and 2nd, respectively, in wear tolerance under both wheel-induced and sled-induced traffic compared to six other cool season grasses. While injury or wear is the most common visual symptom of traffic, soil compaction from traffic is another serious factor that can cause stress, especially to turfgrass roots (O'Neil and Carrow, 1983). Carrow (1980) found that visual quality was directly correlated to bulk density and aeration porosity, two soil attributes directly impacted by compaction. In this particular study involving cool-season grasses, it was also reported that perennial ryegrass and Kentucky bluegrass (*Poa pratensis L.*) only slightly declined in quality with increased compaction, while the quality of tall fescue decreased greatly. Furthermore, shoot density effects varied among species and density decreased in Kentucky bluegrass, and tall fescue (*Festuca arundinacea* Schreb.) as compaction increased. Density in the perennial ryegrass actually increased at 12x compaction before ultimately decreasing at 24x compaction.

Overseeding with Ryegrass

While overseeding athletic turf with perennial ryegrass is very common, annual ryegrass is also commonly used, yet differs in many aspects. Cockerham et al. (1990) found that perennial ryegrass cultivars displayed a higher traffic tolerance than annual ryegrass and tall fescue cultivars when overseeded into common bermudagrass. Although, the use of two higher quality perennial ryegrass cultivars ‘Caliente’ and ‘Elka’, resulted in poor spring transition of bermudagrass. Recently, a ryegrass hybrid, known as intermediate ryegrass (*Lolium hybridum* Hausskn*)*, was introduced to the overseeding market as an alternative to perennial ryegrass and annual ryegrass. Perennial ryegrass tends to persist into the warmer spring months because of its heat and disease tolerance. Intermediate ryegrass has similar aesthetic characteristics to perennial ryegrass but transitions more similar to an annual ryegrass (*Lolium rigidum* Gaud.) (Richardson, 2004). Data are limited on traffic tolerance differences between annual, perennial, and intermediate ryegrasses. Richardson (2004) evaluated 2 intermediate ryegrass cultivars, ‘Froghair’ and ‘Transist’, and observed that Froghair had more similar physical and morphological characteristics to an annual ryegrass compared to Transist. Froghair established as quickly as annual ryegrass and had a similar color to annual ryegrasses. Transist did not establish as quickly as Froghair but was quicker than perennial ryegrass. Typically, perennial ryegrasses are slower to establish compared to annual ryegrasses (Dudeck and Peacock, 1981).

There are many qualities that athletic turf managers focus on when preparing and maintaining turf surfaces. Three of these qualities are safety, playability, and aesthetics. While all three are important in their own respects, the safety of the athlete is arguably of utmost importance. According to Harper et al. (1984) in a study comparing injuries between practice and game fields for high school football in Pennsylvania, about 20% of injuries could have been prevented or less severe with more favorable field conditions. Factors such as poor turf coverage and density resulted in less than desirable playing surfaces and an increase in injury. Thus, because warm-season grass dormancy can potentially occur from October through April in many parts of the transition zone, winter overseeding has been considered to offer a safer environment for the athletes (Harper et al., 1984).

Preparation and Management

Maintenance practices such as nutrient management, weed and pest control, water management, and mowing are all critical in establishing and maintaining the ryegrass (Duble, 1978). Before overseeding with ryegrass, turf managers often prepare the area for overseeding. This may consist of practices such as verticutting or aerification along with lowering the height of cut of the bermudagrass to allow for the seeds to come in direct contact with the soil and allow more favorable conditions for germination (Duble, 1978; Polomski et al., 1999). Also fertilizer may need to be applied depending on the soil results and the newly overseeded site should be kept moist (Duble, 1978). Once the ryegrass reaches a height between 2.54 and 5.08 cm, it should be mowed, and then mowed regularly once the ryegrass reaches 6.35 cm (Polomski et al., 1999). Once established, ryegrass on athletic fields should ideally be maintained between 2.54 and 3.81 cm.

Given the increasing demand for exceptional playability and aesthetically pleasing athletic fields and golf courses, turf managers are relying heavily on the use of ryegrass and other cool-season grasses during winter dormancy of warm-season turfgrasses. Advanced cultivars and hybrids such as intermediate ryegrasses, along with proper management techniques allow turf managers to accomplish those goals while creating a smoother spring transition after winter dormancy (Richardson, 2004). At this time, the use of intermediate ryegrasses has not become widely adopted, and data on their comparative performance relative to annual and perennial ryegrasses are limited. Therefore, closer examination of intermediate ryegrasses characteristics would be beneficial to professional turf managers and homeowners alike.

Colorants During Winter Dormancy

While overseeding warm-season turf during the winter months has been fairly common in past decades, declining budgets and water availability at many facilities have led turf manager to explore other options to accommodate winter play. In response to continued desire by athletes for green playing surfaces, products have emerged in recent years which are used to mask the dormancy of the warm season turfgrass. Colorants have seen rapid market growth in recent years, used primarily as an alternative to overseeding, while turf paints, which are commonly seen on athletic fields, are used primarily for emblems, designs, or outlines. Although each contains various pigments, there are slight differences with regards to the chemical make-up of colorants and turf paints. Colorants have lower levels of heavy metals such as zinc and copper, as well as less resin and a lower viscosity.

Budgetary Restrictions

Budget is often the major driver for use of colorants during winter dormancy. For example, Liu et al. (2007) reported the cost of painting dormant bermudagrass for two applications per acre to be $1,600 to $1,800, considerably lower cost than overseeding, which may be between $2,500 and $5,000 depending on the seeding rate. These costs were similar to those reported by Carson (2004), who estimated overseeding would cost twice as much as using turf colorants. It should also be mentioned this does not take into account cost for maintenance of overseeded stands, such as fertilization, mowing and irrigation. Whether a single colorant application may be adequate to last through the entire dormancy period is likely influenced by application rate, amount of traffic, and/or environmental conditions such as temperature and rainfall.

Spring Transition

A major challenge for turf managers during the spring period is the process of transitioning out of the cool-season overseed stand while encouraging regrowth of the bermudagrass without sacrificing playability or aesthetics. Since perennial ryegrass has the ability to tolerate warming conditions as bermudagrass initiates growth in spring, it can essentially become a problematic weed once weather is conducive for spring green-up of bermudagrass (Horgan and Yelverton, 2001). The most favorable conditions for spring transition back to bermudagrass have been found to occur once nighttime soil temperatures are consistently above 18°C for 5 straight days (Duble, 1978). At this time, turf managers who are looking to transition with the aid of herbicides to remove cool season grasses will typically lower the height of cut and apply a herbicide such as ‘Revolver’ (foramsulfuron), ‘Tranxit’ (rimsulfuron), and ‘Monument’ (trifloxysulfuron)(Horgan and Yelverton, 2001). This process generally takes between 2 to 4 weeks (Yelverton, 2005). The use of colorants as an alternative to overseeding may allow for managers to avoid this annual challenge of spring transition following overseeding. Additionally, colorants may actually enhance the rate of spring bermudagrass green-up and growth. For example, Liu et al. (2007) found that application of turf colorants, Green Lawnger, Titan, or Regreen, to dormant bermudagrass golf greens resulted in higher surface temperatures, which significantly enhanced bermudagrass green-up. These results were consistent with those found by Long et al. (2005) and Shearman et al. (2005) on buffalograss (*Boutelous dactyloides* (Nutt.) Engelm.).

Traffic Tolerance

The looming question for many turf managers in regards to using colorants during winter dormancy is how well the dormant bermudagrass will hold up to traffic. Although delayed bermudagrass transition may result, ryegrass and other overseeded cool-season grasses are thought to help protect the crowns of the dormant bermudagrass under traffic stress during dormancy. Dunn et al. (1994) reported that ‘Midiron’ bermudagrass quality declined greatly during October and November under simulated traffic, compared to non-trafficked bermudagrass. The authors reported nearly a 50% reduction in turfgrass quality (~5 to ~2.5) due to traffic in the study. Furthermore, trafficked plots were reported to have considerably greater exposed bare soil and increased weed incidence. This decreased turf quality response emphasizes the inability of bermudagrass to withstand heavy traffic during fall and winter months. This is commonly seen in conditions of non-overseeded bermudagrass football fields, which, due to decreased solar radiation and suboptimal temperatures, often succumb to traffic after repeated football games and frequent vehicular traffic during fall months. Turf managers may also need to take in consideration the amount of use a facility will receive before determining whether overseeding or colorant application is most appropriate. It is possible that lower-usage facilities such as a football stadia receiving only one game per week for the first couple months of dormancy, or golf courses that receive lower rounds during fall/winter months may be better positioned for using colorants for maintaining aesthetic appearances with limited bermudagrass damage. Heavy bermudagrass damage during dormancy can also lead to reduced recuperative potential during spring (Dunn et al., 1994; Deaton and Williams, 2010; Thoms et al., 2011). This can result in delayed spring green-up and a lack of uniformity due to areas damaged beyond recovery.

Heavy Metal Toxicity

Long-term toxicity from the copper and zinc content in colorants may also be a concern, especially where reported applications are made over successive year. Concentrations of zinc in the shoots of bermudagrass turf are considered high at levels greater than 250 mg kg^{-1} (McCarty, 2011). Zinc toxicity levels may differ from one cultivar to another but long-term effects from repeated applications need to be observed. Copper is also commonly found in turfgrass colorants and paints. Copper has a low mobility and thus accumulates near the soil surface over time (McBride, 1994). In a study conducted by McCarty et al. (2014), turfgrass colorant, Evergreen (Milliken and Company, Spartanburg, SC) significantly increased the concentration of copper in the tissue of creeping bentgrass. While this did not create an immediate problem, the effects of long-term exposure and repeated applications need to be studied to evaluate potential issues.

It is also not uncommon for turf managers to use a combination of colorants and overseeding. Turf managers will overseed at very minimal rates to allow for protecting and cushioning for the dormant bermudagrass, as well as increased wear tolerance during events. In situations where overseeding has been done at relatively low rates, aesthetic uniformity may be lacking. Therefore, turf managers may apply a colorant to achieve a more uniform appearance. This process has become common for professional sports venues, where increased pressure to achieve aesthetic perfection during televised events occurs (Van Dam and Kurtz, 1971). The question that remains is whether repeated applications of colorants year after year on the same areas result in residual effects over time. The longevity and color quality of several colorants has been examined, but closer examination of soil effects in regards to metal toxicities should also be considered.

This research was carried out in order to provide supporting data relating to many questions regarding establishment and maintenance of turfgrasses under water restrictions. Results of the research will benefit homeowners, athletic turf managers, sod producers and lawn care specialists in areas of the country currently or have been prone to drought conditions

CHAPTER II

EFFECTS OF MOWING AND PLANT GROWTH REGULATOR ON ST. AUGUSTINEGRASS SOD ESTABLISHMENT DURING A 35-DAY WATER VARIANCE PERIOD

During drought induced irrigation restriction periods, municipal water purveyors often limit irrigation for established lawns to once every 7 to 14 days, although a 4 to 6 week variance to these restrictions is often permitted for turfgrass establishment. Therefore, establishment practices promoting rapid development of a deep and expansive root system during this time may support long-term success of the turf once irrigation is scaled back. Sod producers and turf managers could benefit from information on the influence of mowing practices and plant growth regulator applications on turf root development during this initial establishment period. The objectives of this greenhouse study were to 1) evaluate the effects of mowing and trinexapac-ethyl application on final turf quality and root development characteristics (mass, total length, and extension rate) of St. Augustinegrass (*Stenotaphrum secundatum* (Walter) Kuntze)) sod during a 35-day establishment period, and 2) compare the quality and rooting potential of ‘TamStar’ St. Augustinegrass, a newly released, cultivar possessing good drought resistance, with ‘Floratam’, the current industry standard for drought resistance. Weekly mowing dramatically reduced both total (2.5-90 cm deep) and deep (45-90 cm deep) root mass and root length in both cultivars. Trinexapac-ethyl had no effect on visual quality of TamStar, but decreased turf quality in Floratam. Trinexapac-ethyl reduced clipping yields of both cultivars but did not improve root

development for either cultivar. Depth of maximal root extension during establishment was unaffected by cultivar, mowing, or trinexapac-ethyl treatment. At the conclusion of the 35-day establishment period, TamStar exhibited superior turf quality and root mass relative to Floratam, but also produced higher rates of shoot growth. Results emphasize the importance of withholding mowing during St. Augustinegrass establishment, particularly for improving total root length and deep root production, and also show that trinexapac-ethyl does not improve root development of St. Augustinegrass during establishment.

Introduction

Due to recurring drought and increased demands for potable water throughout the southern and western United States, municipalities are enacting landscape irrigation restrictions to conserve water. Homeowners and turf managers are often the first to be affected by restrictions on landscape irrigation. Commonly, these restrictions include a variance period of approximately 35-days post-planting, during which the homeowner or turf manager may water as needed to facilitate establishment (San Antonio Water System, 2015; Southwest Florida Water Management District, 2015). During this time, establishment practices promoting rapid development of a deep and expansive root system may help ensure long-term success of the turf as irrigation is reduced.

Within Texas and across the southeastern U.S., St. Augustinegrass [*Stenotaphrum secundatum* (Walter) Kuntze] is a predominant warm-season turfgrass utilized for lawns due to its ability to withstand heat and shade Duble, 2013). St.

Augustinegrass cultivar Floratam is widely used throughout the southeastern U.S. for home lawns due to its good drought resistance (Siefers and Beard, 1999; Duble, 2013). Steinke et al. (2010) reported that Floratam exhibited significantly delayed leaf firing as well as superior turfgrass quality and green ground cover relative to other St. Augustinegrass cultivars during a 60-day drought in San Antonio, TX. In the same study, Floratam also demonstrated superior recovery attributes as compared to other cultivars following resumption of irrigation.

Genetic variation in St. Augustinegrass manifests in morphology, adaptability, and stress tolerance (Chandra et al., 2015). Such genetic variation is observed to be partitioned between ploidy levels. Diploids tend to exhibit superior turfgrass quality due to their finer leaf texture, color and compact growing habits, whereas polyploids such as Floratam have been shown to exhibit increased resistance to insect, disease and drought stress (Busey, 1986; 2003). Genovesi et al., (2009) reported the use of embryo rescue technique to develop interploid hybrids between polyploid and diploid germplasm of St. Augustinegrass to facilitate gene exchange between different ploidy levels. ‘TamStar’ (formerly tested under the experimental name ‘DALSA0605’), is the first and only reported embryo rescue-derived interploid cultivar of St. Augustinegrass and was recently released by Texas A&M AgriLife Research (Genovesi et al., 2009; Chandra et al., 2015).

Much of the research involving drought resistance in turfgrasses highlights the importance of rooting depth and density as factors contributing to drought avoidance

(Marcum et al., 1995; Carrow, 1996; Miller and McCarty, 1998; Steinke et al., 2011; Levitt, 2012). Busey (2003) reported that drought resistance in St. Augustinegrass is not due to reduced evapotranspiration but rather due to wilt avoidance resulting from deeper and more extensive root systems. Huang and Gao (2000) examined developmental characteristics of roots of tall fescue (*Lolium arundinaceaum* (Schreb.) Darbys.) and reported that a general root decline occurred in the upper 20 cm of soil as the drought stress ensued. However, drought resistant cultivars in the study developed increased root length within the 40-60 cm depth, which reportedly aided plants by increasing water uptake from greater depths and compensated for decreased water uptake near the soil surface. Similar observations have been reported by Huang et al. (1997) as well as Sharp and Davies (1985) for warm-season turfgrasses and maize (*Zea mays* L.). To promote deeper and more extensive root systems it has generally been recommended to increase the height of cut in managed turfgrass situations. As mowing height is reduced, the development of the root system is reduced through a root-shoot compensatory effect (Madison, 1962; Salaiz et al., 1995; Trenholm et al., 2000; Liu and Huang, 2002). While increasing the mowing height during a 35-day establishment period would likely encourage increased root development, withholding mowing altogether could conceivably produce even greater and more rapid benefits, so long as turf quality was not significantly sacrificed once mowing commenced at the end of the establishment period.

Plant growth regulators (PGRs) are widely used in turf management for reducing shoot growth and frequency of mowing and/or seedhead suppression. Trinexapac-ethyl

(TE) (4-[Cyclopropyl-a-hydroxymethylene]-3,5-dioxo-cyclohexanecarboxylic acid ethylester) is a commonly used PGR that reduces turfgrass shoot growth by inhibiting the production of biologically active forms of gibberellins (King et al, 1997; Turgeon, 2002) but has shown little to no effect on seedhead suppression in St. Augustinegrass (McCarty et al., 2004). Trinexapac-ethyl has been shown to have little to no effect on photosynthesis (Qian et al., 1998) and leads to reduced rates of maintenance respiration (Heckman et al., 2001). As such, it is believed that greater net photosynthesis may occur in TE-treated plants, with excess photosynthate not used for leaf elongation allocated to other organs (Ervin and Zhang, 2008). In fact, Fagerness et al. (2004) found that hybrid bermudagrass (*Cynodon dactylon x C. transvaalensis* Burtt-Davey) allocated 50% more ^{15}N-labelled ammonium nitrate to roots and rhizomes when treated with TE. This suggests that the altered allocation of nonstructural carbohydrates may promote greater rates of tillering, stem growth, or rooting during the period of TE suppression (Ervin and Zhang, 2008). While it is currently labeled for use on a range of warm-season turfgrasses including St. Augustinegrass, limited published information is available regarding the effects of TE on St. Augustinegrass growth and development. Weinbrecht and Miller (2009) reported the growth responses of St. Augustinegrass to five commercial PGRs and noted that root length density was unaffected by PGR application. Information on the effects of TE application and mowing practices during early establishment of St. Augustinegrass would be of interest to sod producers and turf managers as tools for potentially improving success of newly planted sod in the context of tight establishment timelines.

The objectives of this greenhouse study were to 1) evaluate the effects of mowing and TE application on shoot growth, final turf quality, and root development characteristics (mass, total length, and extension rate) of St. Augustinegrass sod during a 35-day establishment period, and 2) compare the quality and rooting potential of TamStar and Floratam.

Materials and Methods

This research was conducted at the Texas A&M University Department of Soil and Crop Science greenhouses in College Station, Texas. The experiment was initiated on April 4th, 2012 (hereafter referred to as ‘study 1’) and repeated May 29, 2013 (hereafter referred to as ‘study 2’), with each study lasting 35 days. Greenhouse temperatures were set to 30/23°C (day/night) temperatures for both studies. The greenhouse caused a 12% reduction in photosynthetic photon flux relative to ambient solar radiation. The study was arranged as a completely randomized block design with four replicates. A factorial arrangement with all possible combinations of cultivar (Floratam vs. TamStar), mowing (unmowed vs. mowed weekly at 6.3 cm); PGR (no PGR vs. TE-applied at day 0 and 21) was used. Trinexapac-ethyl (Primo Maxx, Syngenta, Greensboro, NC) was applied to select treatments using a CO_2 powered backpack sprayer with XR Teejet 8002VS nozzles (Spraying System Co., Wheaton, IL) at 40 psi, at a rate of 28 mg m^{-2} active ingredient diluted in 81.5 mL of H_2O m^{-2}. Applications were made immediately after transplant and at day 21. During applications, non-PGR-treated plants were covered with paper bags to prevent off target movement of TE.

Plant materials of Floratam and TamStar were obtained from the Texas A&M AgriLife Research and Extension Center, Dallas, TX. Six weeks prior to the start of study 1, sod plugs were established for both studies in 58 cm^2 diameter pots using washed stolon segments (6 single node stolons per pot). Stolons were allowed to establish into potting soil (Sunshine Mix, Sungro Horticulture, Bellevue, WA) and provided an initial fertilization using a 21:7:14 ($N:P_2O_5:K_2O$)granular starter fertilizer (Green Diamond Supreme Lawn Food, BCF Products, Greenville, TX) at a rate of 7.4 g N m^{-2}. Sprigged pots were watered twice daily, and trimmed twice weekly to maintain a 6.3 cm tall canopy height using scissors. After approximately 4 weeks, grasses had fully grown into pots with a well-developed root system.

Established plugs were then removed from pots, trimmed and washed free of soil to produce a 58 cm^2 x 2.5 cm deep sod plug. To initiate both studies, washed sod plugs were planted atop clear walled, extruded acrylic plastic (81 cm^2 x 90 cm deep) cylinders (Boedeker Plastics, Inc, Shiner, TX) filled with potting soil (Sunshine Mix, Sungro Horticulture, Bellevue, WA) and capped at the base with a polyvinyl chloride endcap. Holes were drilled into the cap and covered with a 2.5 cm pea gravel layer and screen to facilitate drainage. Efforts were made to uniformly tamp and saturate the potting soil before planting to prevent soil from settling during the experiment. Two layers of white polyester spandex material were used to encase the outside of the cylinders to prevent light penetration into the clear columns. The previously mentioned 21-7-14 granular was thoroughly mixed into the upper 10 cm of soil at a rate of 7.4 g N m^{-2} just prior to planting sod pieces. During the initial week of both studies, 80 ml (1 cm) of water was applied to each treatment on a daily basis. From weeks two through five, 175 ml (2.2 cm) of irrigation was applied three times weekly.

Clippings from mowed treatments were collected weekly and when pots were trimmed at 6.3 cm during both studies using scissors and a ruler. Overhanging shoots and stolons extending beyond the perimeter of the column were also clipped and included in clipping samples. Clippings were oven dried at 65°C for 72 hours before being weighed. Visual quality assessments of each treatment were made on a weekly basis during the study immediately following mowing, rated on a scale from 1 to 9 with 1 = dead and 9 = best with minimum acceptable ≥5. Turfgrass visual quality was taken for all treatments immediately after clippings were collected each week. At the conclusion of the study, all treatments (including unmowed) were trimmed to 6.3 cm, following which a final visual quality rating was then obtained for the previously unmowed treatments.

No seedheads became apparent during study 1. However, during study 2 seed head production became apparent in the treatments, most notably in unmowed treatments. Therefore, seedhead production was visually evaluated during the final two weeks of study 2. Seedhead evaluations were made on a 0 to 5 scale, with 0= no seedheads present and 5 = high density of seedheads visible.

Weekly measurements of depth of maximal root extension were also noted within treatments similar to that previously reported by Wherley et al. (2011). Measurements were made by temporarily removing white polyester sleeves to expose the clear cylinder so that the depth of the two deepest roots could be measured and marked with tape on columns. These two readings were then averaged for each measurement date. Readings were recorded throughout the study or until two roots had reached the bottom of the 90 cm deep cylinders. Data were then plotted over time to calculate rate of root extension for the treatments.

Following each 35-day study, roots were removed from the cylinders and washed thoroughly to analyze total root length and root weight. Roots were divided into two categories, upper (2.5-45 cm depth) and lower (45-90 cm depth) to allow for characterization of root development within shallow vs. deep soil depths. Total root length of these samples was measured using WinRhizo software (Regent Instruments, Ontario, Canada). Immediately after root length analysis was complete, the roots were dried at 65^{o} C for 72 hours then weighed.

Data for each parameter were subjected to analysis of variance using the general linear model, univariate test procedure using SPSS ver. 21.0 (IBM Corp, Armonk, NY) to determine statistical significance of the results. Where analysis of variance indicated a significant study effect, parameters were presented separately by study. Mean separation procedures were performed using Fisher's Least Significant Difference test at $P \leq 0.05$ level.

Results and Discussion

Turfgrass Visual Quality

Delaying mowing for 35-days did not significantly reduce final turf quality relative to weekly-mowed treatments in either study (Table 2.1). There was a significant cultivar x PGR interaction on visual quality at the conclusion of study 1, although no significant differences on quality were observed for study 2 (Table 2.1, Figure 2.1). Trinexapac-ethyl application resulted in a lower final turf quality of Floratam, but had no effect on the quality of TamStar (Figure 2.1). Final visual quality ratings for Floratam decreased from 7.9 to 6.9 due to TE application, while final quality of TamStar exhibited a slight but non-significant increase from 8.4 to 8.8 following addition of TE.

The observation that TE application resulted in decreased quality in Floratam in study 1 is consistent with findings of McCarty et al (2004), who reported that TE decreased visual quality in ‘Floralawn’ St. Augustinegrass over a 5-week period in late June. However, by the completion of their 12-week study, both TE-treated and untreated Floralawn exhibited similar visual quality ratings.

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Table 2.1. Analysis of variance for the 35-day establishment study factors. Where significant study main effect or interactions occurred, studies have been presented separately.

	P-values										
	Final Turf Quality		Clippings		Maximal Root Extension Depth	Total Root Mass		Deep Root Mass		Total Root Length	Deep Root Length
	Study 1	Study 2	Study 1	Study 2		Study 1	Study 2	Study 1	Study 2	Study 2	Study 2
Cultivar (C)	***	ns	***	ns	ns	*	ns	ns	ns	ns	ns
PGR (P)	ns	ns	***	ns	ns	*	ns	ns	ns	*	ns
Mowing (M)	ns	ns	---	---	ns	***	***	**	**	***	**
Week (W)	---	---	***	ns	***	---	---	---	---	---	---
C x P	***	ns	***	ns	ns	ns	ns	ns	ns	ns	ns
C x M	ns	ns	---	---	ns	*	ns	ns	ns	ns	ns
C x W	---	---	**	ns	ns	---	---	---	---	---	---
P x M	ns	ns	---	---	ns	ns	ns	ns	ns	ns	ns
P x W	---	---	***	ns	ns	---	---	---	---	---	---
C x P x W	---	---	ns	ns	ns	---	---	---	---	---	---
C x P x M	ns	ns	---	---	ns	ns	ns	ns	ns	ns	ns

ns, *, **, *** not significant, significant at $P \leq 0.05$, 0.01, or 0.001, respectively

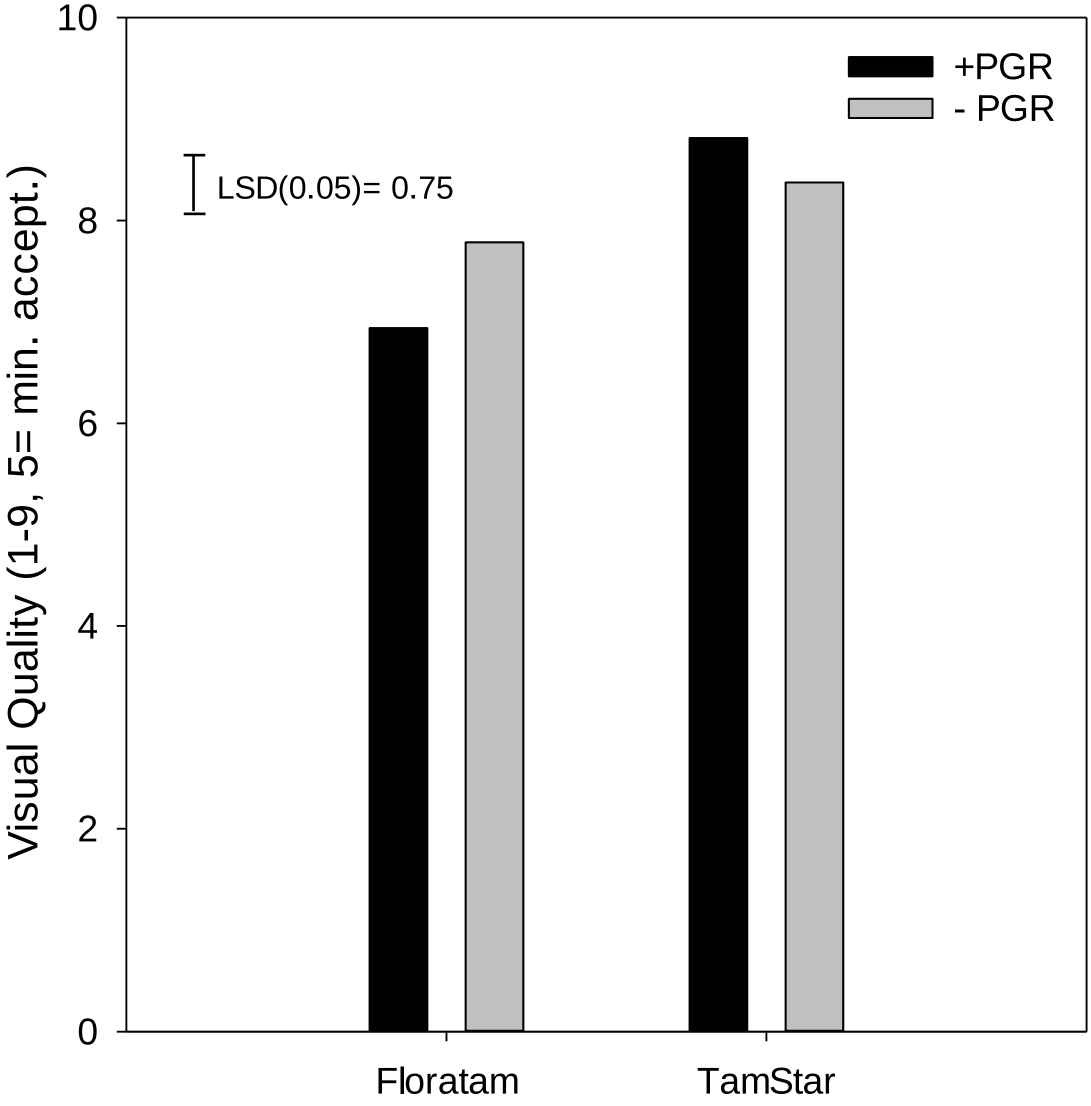

Figure 2.1. Final visual turf quality of Floratam and TamStar at day 35 as influenced by application of PGR trinexapac-ethyl for study 1. Data are pooled across mowing treatments.

Clippings

Similar to visual quality, although numerous significant treatment effects and interactions were noted for study 1, no significant differences were detected for study 2. During study 1, there was a significant cultivar x PGR interaction on clipping dry weights (Figure 2.2). Trinexapac-ethyl application to TamStar resulted in 47% (734 mg vs. 388 mg) reduction in clipping dry weight. Mean clipping reductions due to TE applications were slightly less substantial in Floratam (39% reduction; 346 mg vs. 210 mg). While no significant differences due to TE were observed in study 2, there were again decreased clipping yields observed with the use of TE in both cultivars.

TE is commonly used on turfgrass to reduce mowing requirements. This occurs through inhibition of gibberellin acid synthesis, which reduces cell elongation and ultimately clipping yields and mowing frequency (Adams et al., 1992; Fagerness and Penner, 1998; Ervin and Koski, 2001). Our growth suppression data for St. Augustinegrass for study 1 (39-47% suppression) are consistent with McCarty et al. (2004), who reported that TE reduced clipping production by 50% on Floralawn. The slightly lower levels of suppression we observed could be related to the relatively high amounts of irrigation that were applied for the newly establishing sod.

There was a significant cultivar by week interaction on clippings in study 1 (Figure 2.3). As such, rates of shoot growth for both cultivars dramatically increased over the 35 day period, from less than 100 mg per week at week 1 to greater than 600 mg per week by week 5. TamStar clippings were nearly twice those of Floratam for each week, with the largest difference observed after week 3, where average clipping mass of TamStar was 2.5 times that of Floratam. The apparent differences between cultivars may be related to morphological growth habit differences. Based on our observations, TamStar appears to possess a denser and upright growth habit compared to Floratam. Cultivar differences in shoot growth rates have been previously noted within St. Augustinegrass (Atkins et al., 1991).

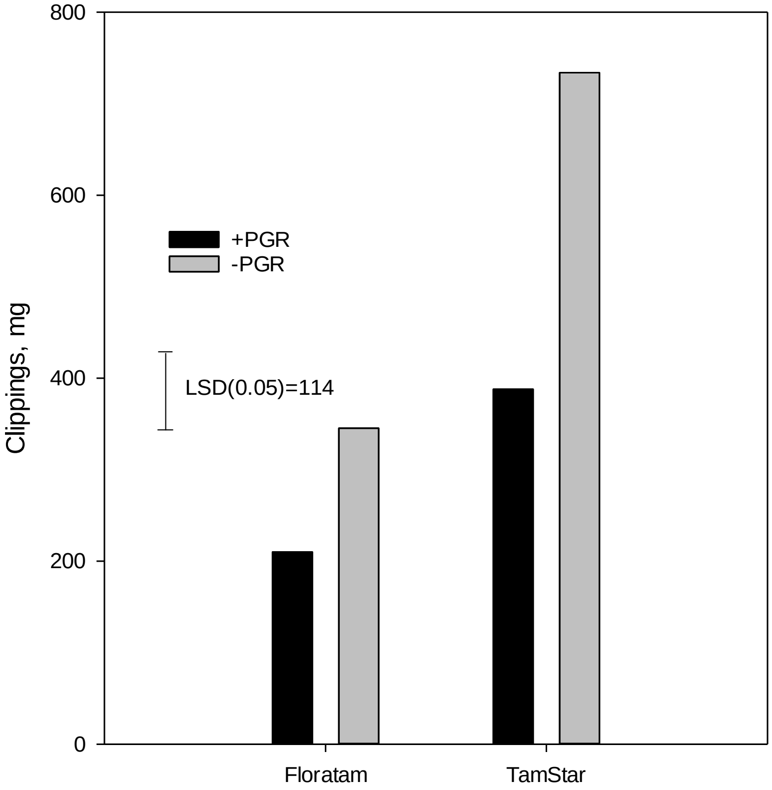

Figure 2.2. Effect of trinexapac-ethyl on mean weekly clipping dry weights for study 1. Data are pooled across mowing treatments. Error bar denotes LSD(0.05).

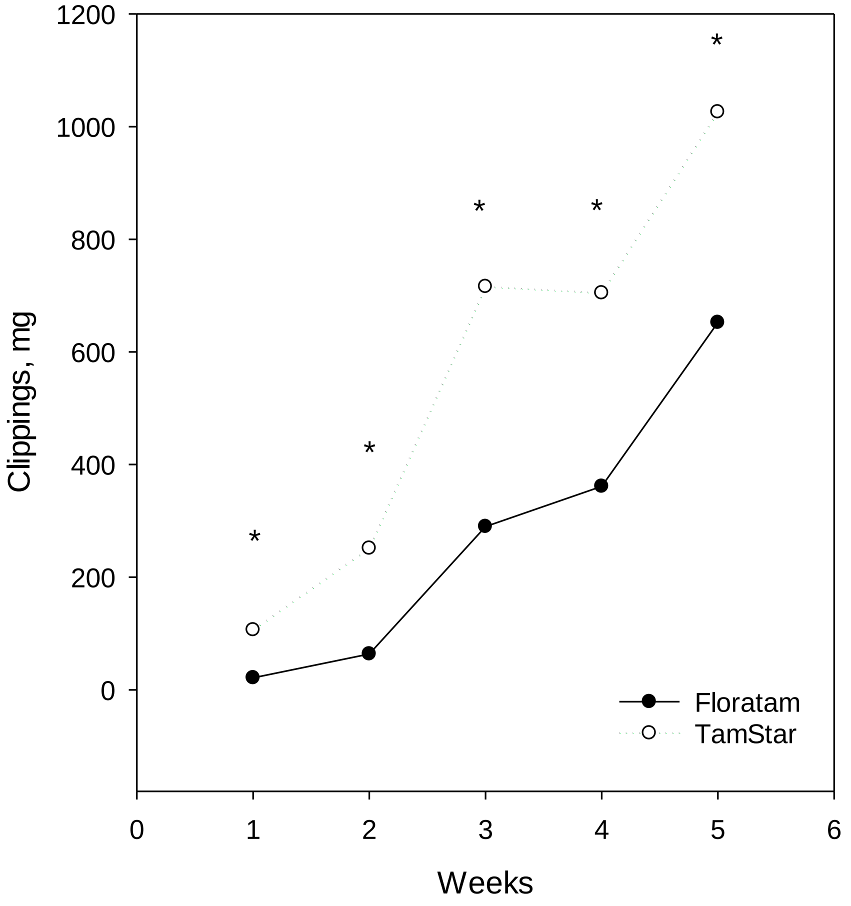

Figure 2.3. Weekly clipping dry weights for study 1 as influenced by cultivar. Data are pooled across PGR treatments. Asterisks denote significance based on LSD(0.05).

A PGR by week interaction was also observed for clippings in study 1 (Figure 2.4). Clipping mass increased weekly for plants not receiving TE application. However, in TE-treated plants, greater shoot growth was observed at week 3. Although total clippings increased in both TE-treated and untreated plants, the level of growth suppression offered by the second TE application was slightly less than that observed from the first application. Weinbrecht et al. (1998) reported St. Augustinegrass growth suppression by TE of up to four weeks.

The overall reduced efficacy of TE in affecting clipping production and visual quality for study 2 may have been partially due to greater metabolism within the plant during the summer months (Lickfeldt et al., 2001; Beasley et al., 2007; Wherley et al., 2009; Kreuser and Soldat, 2011). Although greenhouse temperatures for both studies were set to produce similar conditions, the longer days and more intense solar radiation of study 2 likely resulted in greater energy loading and plant temperatures. Furthermore, a developmental shift to reproductive seedhead development in plants was observed in all treatments midway into study 2. Consistent with previous research on PGR induced seedhead suppression (McCarty et al., 2004); we observed no suppression in seedhead numbers with TE application (data not shown). The fact that clipping collections included any growth (shoots and seedheads) occurring above a height of 6.3 cm apparently negated effects of TE on measured clippings during study 2.

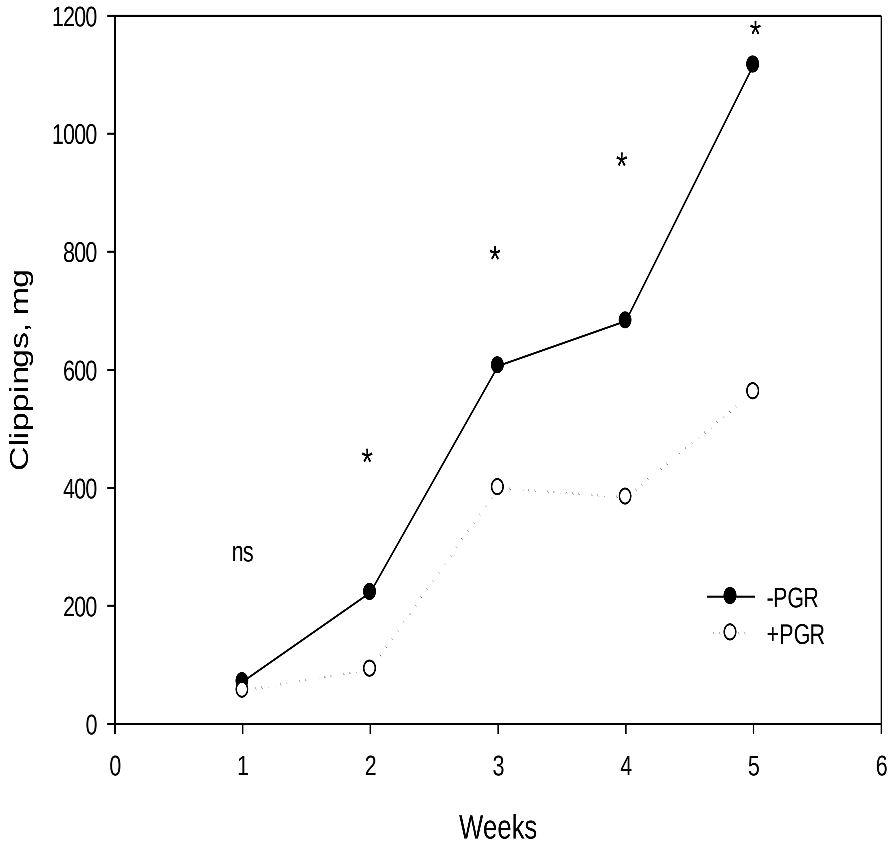

Figure 2.4. Weekly clipping dry weights as influenced by PGR for study 1. Data are pooled across cultivar. Asterisks denote significance based on LSD(0.05).

Maximal Root Extension Depth

Neither cultivar, mowing, nor PGR treatments had any effect on depth of maximal root extension, and there were no differences detected between studies (Table 2.1). As such, only week main effect was found to be significant for rooting depth. Therefore, data were pooled across studies, cultivar, and treatment (Table 2.1). Average depth of the two deepest roots at the conclusion of the study approached 80 cm over the 35-day period for both studies, resulting in an average root extension rate of ~2.3 cm d^{-1} (Figure 2.5). Turf having a deeper root system is more likely to survive periods of drought stress (Marcum et al., 1995; Carrow, 1996; Steinke et al., 2010; Steinke et al., 2011; Levitt, 2012). In a similar type of study, Wherley et al. (2011) found that St. Augustinegrass, bahiagrass, and zoysiagrass root extension rates during establishment were unaffected by mowing heights. The authors reported root extension rates between 1 and 1.8 cm d^{-1}, but also reported that increasing nitrogen fertility during establishment of these grasses resulted in accelerated root extension into deep soil for all species.

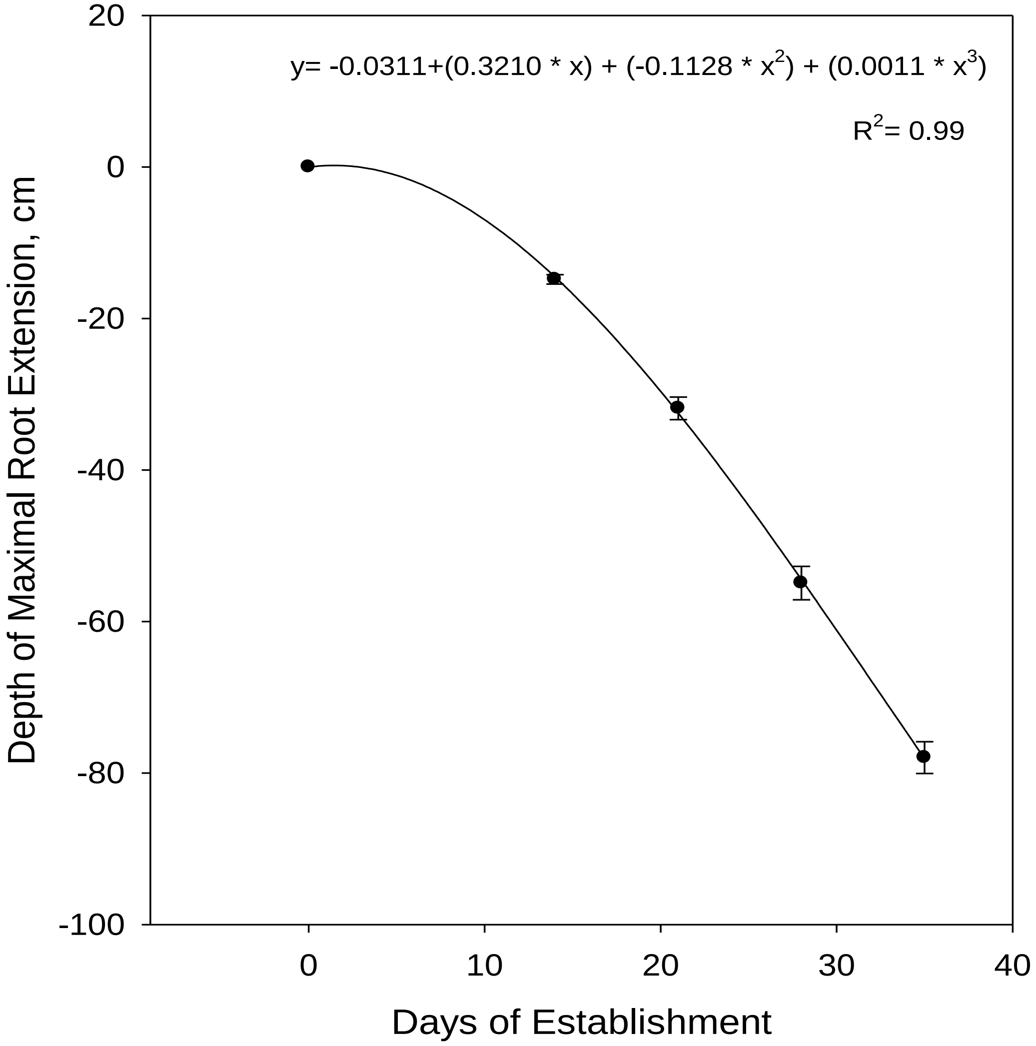

Figure 2.5. Depth of maximal root extension both St. Augustinegrass cultivars over the 35-day establishment period. Data are pooled across study, cultivars, and treatments. Error bars denote standard error.

Root Mass

Weekly mowing had profound negative impacts on total root mass measured at the conclusion of both studies. Although ANOVA detected a PGR main effect on total root mass for study 1, subsequent LSD (0.05) analysis revealed this was not in fact significant. There was a cultivar by mowing interaction on total root mass during study 1, and a mowing main effect detected for both studies (Table 2.1). Weekly mowing resulted in significant decrease in total root mass for both cultivars (Figure 2.6). For Floratam and TamStar, 53 and 71% reductions in total root mass occurred due to weekly mowing. For study 2, reductions in total root mass due to mowing were substantially greater (~85% reductions), but were similar among cultivars (Figure 2.7).

While total root mass is important, deep root production is arguably of even greater importance in terms of drought resistance. A significant effect of weekly mowing on deep root mass (45-90 cm) was observed in both studies, although noticeably greater differences between mowed and unmowed treatments occurred in study 2 (Figure 2.8). Bonos and Murphy (1999) examined rooting responses of Kentucky bluegrass cultivars under summer heat/drought stress and found that the more tolerant entries produced greater root mass at deeper soil depths (65% greater root mass at 30 to 45 cm depth) compared to less intolerant entries. They also noted that within shallower (0 to 15 cm) depths, stress tolerant entries exhibited an 18% greater root mass. Although mowing heights were not evaluated in their study, the results emphasize the benefits of increased root mass within deeper soil depths to heat and drought stress.

While limited published data are available to compare rooting differences between mowed and unmowed turf, similar results were observed in terms of mowing height by Wherley et al. (2011), where significantly greater total (0-90 cm) and deep (45-90 cm) root mass for St. Augustinegrass, bahiagrass, zoysiagrass, and bermudagrass occurred with high as opposed to low mowing heights. While not measured under establishment conditions, similar results are reported for cool-season putting green turf. Fagerness and Yelverton (2001) reported that root biomass was 32% and 36% greater when cool-season ‘Penncross’ creeping bentgrass was maintained a cutting height of 4.8 mm or 4.0 mm as opposed to 3.2 mm.

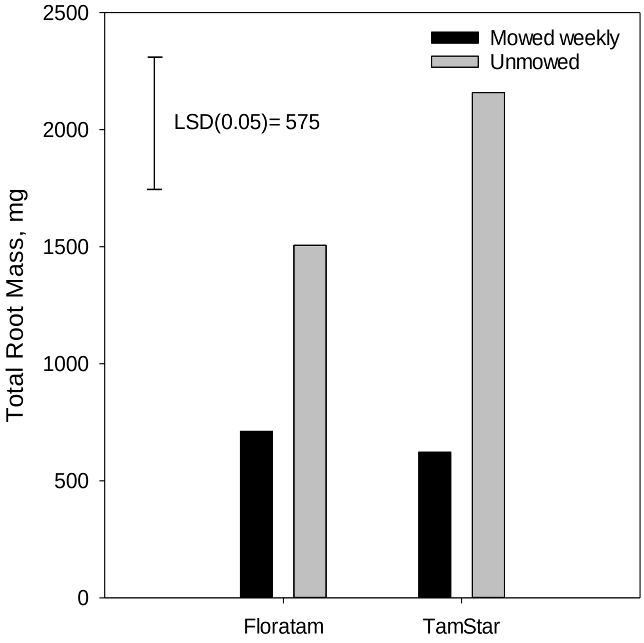

Figure 2.6. Total (2.5-90 cm) root mass at the conclusion of study 1 for Floratam and TamStar as affected by weekly mowing vs. unmowed conditions. Data are pooled across PGR treatments. Error bar denotes LSD(0.05).

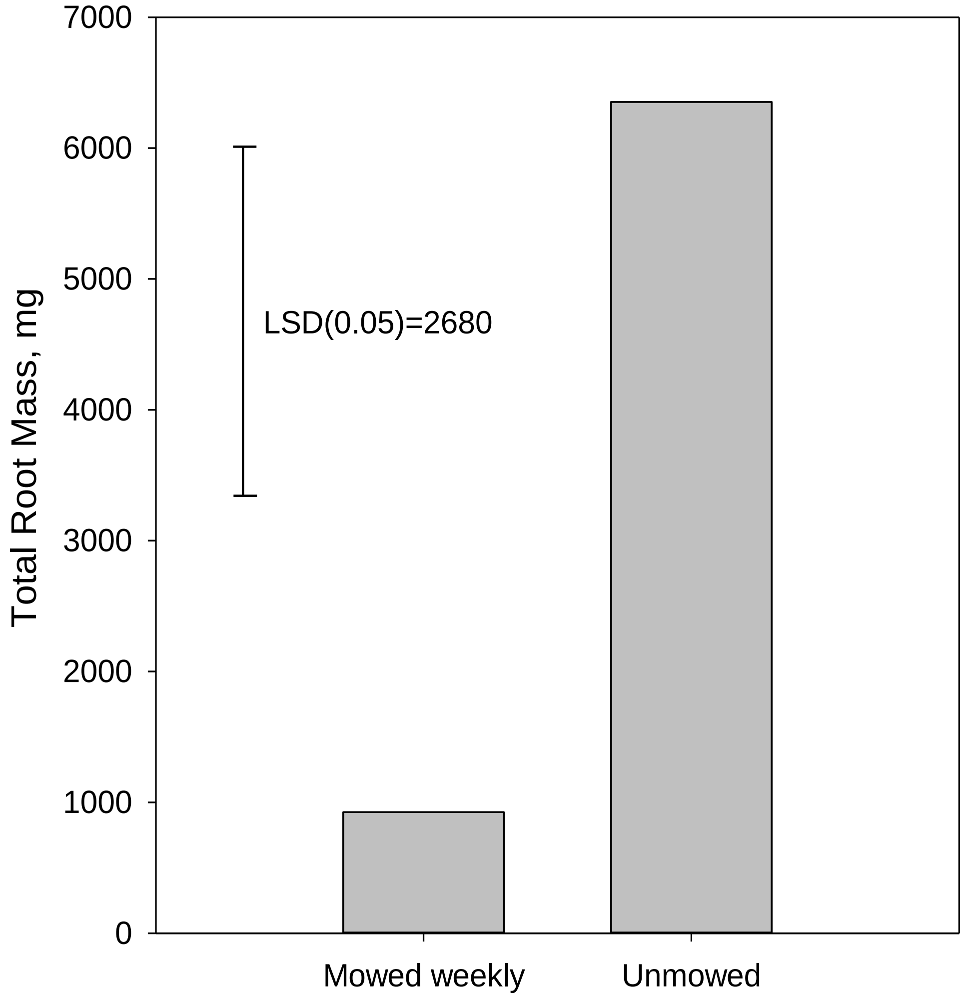

Figure 2.7. Total (2.5-90 cm) root mass at the conclusion of study 2 as affected by weekly mowing vs. unmowed conditions. Data are pooled across cultivar and PGR treatments. Error bars denote LSD(0.05).

Total Root Length Effects

The effects of cultivar, mowing, and PGR applications on total root length are also of interest because increased root proliferation within soil contributes to more efficient absorption of water and nutrients during establishment. In our study, mowing caused significant effects on total root length (2.5-90 cm) and deep root length (45-90 cm) in study 2 (Table 2.1), but neither cultivar nor TE significantly impacted root length in either study. It should be noted that although ANOVA detected a significant (P = 0.05) effect of PGR on total root length for study 2 (Table 2.1), subsequent LSD analysis revealed this reduction in root length caused by TE was not significant. Weekly mowing significantly reduced both total root length (20,433 and 8,478 cm for unmowed and mowed, respectively) and deep root length (7,513 and 3,597 cm for unmowed and mowed, respectively) (Figure 2.9). Qian et al. (1997) reported correlations between wilting of warm-season grass species and root length density within bermudagrass and zoysiagrass. Furthermore, PGRs such as TE inhibit gibberellin production and reduce cell elongation, and therefore, could conceivably influence elongation of both turfgrass shoots and roots. Carrow (1996) evaluated rooting responses to soil dry-down in a range of warm- and cool-season grasses in Georgia and found the largest decrease in root length and density occurred in the top 10 cm of soil. In deeper (20 to 60 cm depth) soil, total root length and density increased in all turfgrasses during dry-down. A relationship was noted between total root length within the deeper 20-60 cm soil depth and delayed leaf firing under drought stress. Interestingly, although ‘Raleigh’ St. Augustinegrass was noted to have similar rooting depth, but significantly lower root length density than

‘Tifway’ bermudagrass within deep soil, it exhibited excellent tolerance to soil dry down with minimal leaf firing. This may suggest that rooting depth alone is as important a factor relating to drought resistance as root length density.

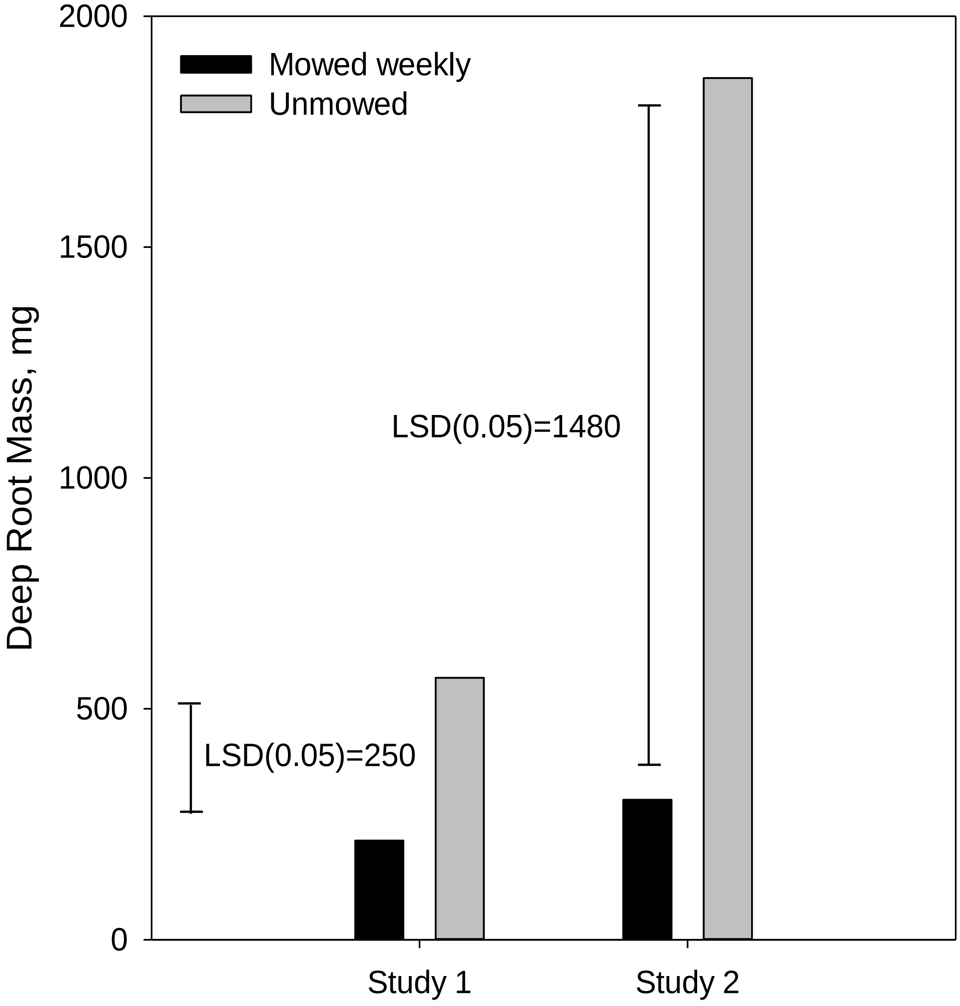

Figure 2.8. Deep (45-90 cm) root mass at the conclusion of studies 1 and 2 as affected by weekly mowing vs. unmowed conditions. Data are pooled across cultivar and PGR treatment. Error bars denote LSD(0.05).

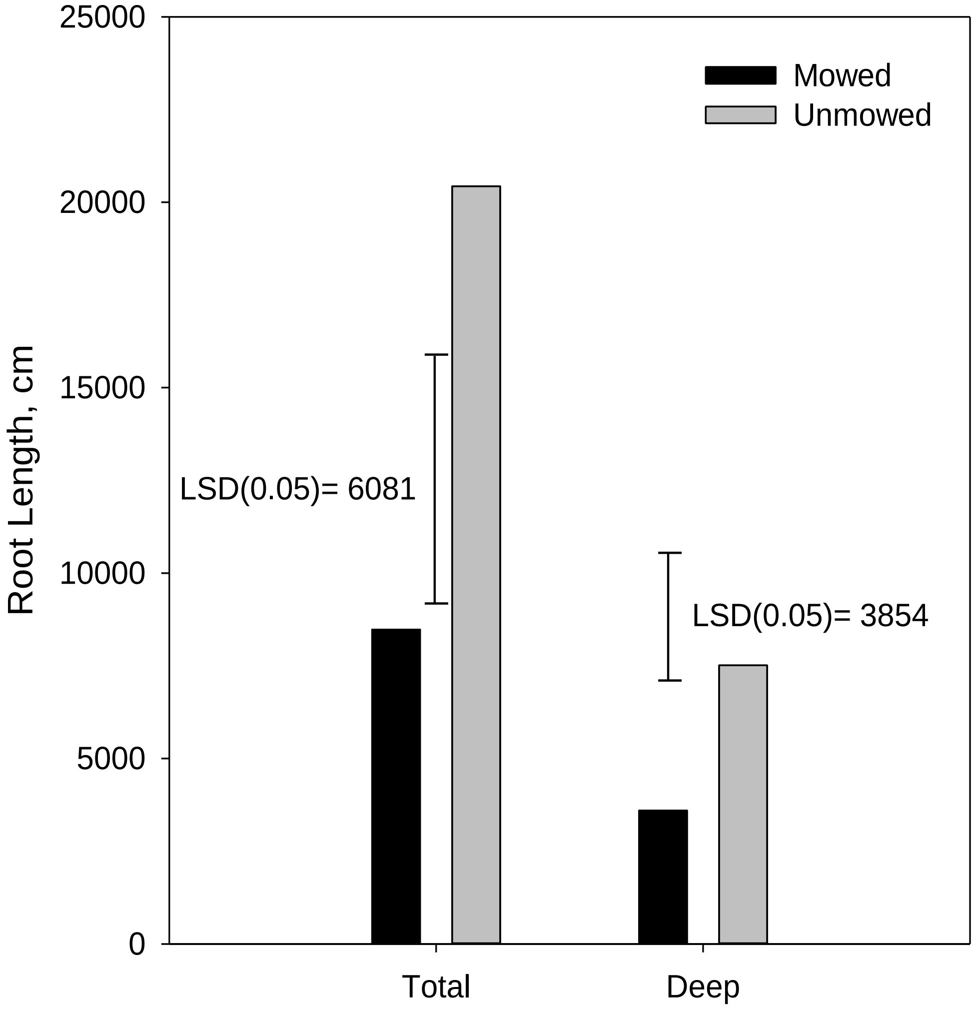

Figure 2.9. Total root length as affected by weekly mowing vs. unmowed conditions for study 2. Data are pooled across cultivars and PGR treatments. Error bars denote LSD(0.05).

Conclusions

As municipal water restrictions become more commonplace across the southern and western U.S., turf managers and homeowners will face challenges with shorter turfgrass establishment windows during water conservation periods. Thus, it has become increasingly important to examine cultural strategies for maximizing success during the early establishment period. A key component for long-term drought resistance in turfgrass is the development of a deep and extensive root system. In evaluating the effects of mowing and TE applications during this 35-day St. Augustinegrass establishment period, we observed that weekly mowing dramatically reduced total and deep root mass as well as root length characteristics in both St. Augustinegrass cultivars. Furthermore, while applications of TE slightly reduced turf quality in Floratam, and also resulted in reduced clipping yields in both cultivars, it failed to provide benefit in terms of root development for either cultivar. Neither mowing nor TE influenced depth of maximal root extension for either cultivar. TamStar exhibited superior turf quality and root mass relative to the Floratam, but also generated higher amounts of cumulative shoot growth. Collectively, the results emphasize the importance of delaying mowing during St. Augustinegrass establishment to promote enhanced root length and deep root production. Whether these observed short-term benefits would translate into actual drought resistance under subsequent mowing and water stress conditions is a question that will require further investigation

CHAPTER III

EFFECTS OF SIMULATED TRAFFIC ON PERFORMANCE OF WINTER OVERSEEDED VERSUS COLORANT-TREATED TIFWAY BERMUDAGRASS

Municipal water restrictions across the southwestern U.S. have created additional challenges for maintaining safe playing surfaces on recreational turf facilities. In recent years, many cities within the southern and southwestern U.S. have even begun to impose irrigation restrictions during winter months. Although winter overseeding has been regularly practiced in these areas, interest and use of colorants as an alternative to overseeding has grown due to decreasing water availability and budget concerns. While possibly more cost-effective than winter overseeding, the extent of traffic injury tolerable by colorant-treated versus overseeded dormant turf has not been fully explored. The objectives of this 2-year field study were to evaluate performance, tolerance to simulated traffic, and spring transition of ‘Tifway’ bermudagrass (*Cynodon dactylon x C. transvaalensis* Burtt-Davy) winter treatments under a 1-day per week irrigation schedule. Treatments included 1) untreated bermudagrass, 2) fall colorant-treated bermudagrass, 3) perennial ryegrass (*Lolium perenne* L.) overseeded bermudagrass, and 4) turf-type annual ryegrass (*Lolium multiflorum* Lam.) overseeded bermudagrass. In both years, highly significant treatment differences were detected for percent green cover, soil volumetric water content, percent visual injury, surface hardness, and percent bermudagrass transition. Percent green cover and visual injury levels were similar between annual and perennial ryegrass stands in year 1, however, loss of green cover and greater injury were noted in annual ryegrass during spring of year 2. Residual benefits of fall colorant application extended into February of year 1, but dissipated by late December of year 2, likely due to substantially greater rainfall. Overseeding reduced bermudagrass spring transition by 40 to 50% compared to untreated and colorant-treated plots, however, no acceleration of bermudagrass transition resulted from fall colorant treatment. Results of the study demonstrate that environmental differences from season to season can impact the relative benefits derived from overseeding or colorant application.

Introduction

In the transition zone and southern U.S., winter overseeding of dormant bermudagrass athletic turf has become a common practice. Winter overseeding provides an actively growing cool-season turfgrass stand that offers protection of the underlying dormant turf as well as green coverage throughout winter dormancy. However, maintaining a healthy stand of overseeded turf requires regular irrigation or precipitation, and therefore has become more of a challenge in some areas of the country where municipal water restrictions may now limit winter irrigation to once per 7 to 14 days, or prohibit the practice entirely (City of Allen, TX, 2015; San Antonio Water System, 2013). Little is known regarding the potential for perennial or annual ryegrass overseed stands to persist under these infrequent irrigation schedules. In light of tightening water restrictions and reduced budgets, many turf managers have begun to explore turf colorants as an alternative to overseeding.

Turfgrass colorants have become more widely used as an alternative to winter overseeding in recent years, particularly on warm-season golf course greens, tees, and fairways (Van Dam and Kurtz, 1971; Sheffer, 1987; Hartwiger and O'Brien, 2013) as well as athletic turf fields (Miller and Pinnix, 2014). The rise in colorant use may be partially related to water conservation efforts, but has likely also been driven by reduced operating budgets. The cost of colorant application has been shown to be 2 to 3 times less than overseeding (Carson, 2004; Liu et al., 2007). Some turf managers have reported more rapid and consistent spring green-up due to colorant application, likely a result of elevated canopy temperatures of colorant-treated turf during the early spring green-up period (Liu et al., 2007; Long et al., 2005; Shearman and Beard, 1975; Shearman et al., 2005). While there are advantages to using colorants as an alternative to overseeding, there could also be disadvantages. Non-overseeded warm-season turfgrass that are under heavy winter traffic may benefit more from overseeding due to the protection offered by the actively growing cool-season turfgrass. Significantly reduced quality of non-overseeded dormant 'Midiron' bermudagrass during October and November was reported due to simulated winter traffic, with injury disrupting uniformity and delaying green-up during spring (Dunn et al., 1994; Deaton and Williams, 2010; Thoms et al., 2011). Additionally, improper dilution, application, and/or accumulation of turf colorants in plant tissues or soil are other potential concerns, particularly in relation to heavy metal toxicity. Turfgrass colorant applications significantly increased Cu concentration in creeping bentgrass leaf tissues, although concentrations did not reach toxic levels (McCarty, 2011). Application of colorants may also interfere with or block absorption of photosynthetically active radiation and thus reduce photosynthesis and/or stomatal conductance, which could potentially lead to decreased plant health over time (McCarty et al., 2013; Reynolds et al., 2013).

While perennial ryegrass has been a primary cool-season turfgrass used for winter overseeding of athletic turf, turf-type annual ryegrasses have been developed in recent years which possess finer texture and improved color relative to older annual ryegrass cultivars such as ‘Gulf’, and improved spring transition relative to perennial ryegrass. Nelson et al. (2005) compared the performance and quality of ‘Axcella’ and ‘Panterra’ annual ryegrass (*Lolium multiflorum*) with perennial ryegrass (*Lolium perenne*) cultivars and reported more rapid (~1 month earlier) transition with turf-type annual ryegrasses, although turf quality was reportedly slightly inferior to perennial ryegrass. Data are currently lacking regarding comparative performance of turf-type annual ryegrass and perennial ryegrass cultivars used for overseeding under limited irrigation frequency and traffic. Such data would be useful for guiding appropriate species selection as restrictions on winter time irrigation become more prevalent in the future.

The objectives of this 2-year field study were to evaluate performance, tolerance to simulated traffic, and spring transition of Tifway bermudagrass winter treatments under a 1-day per week irrigation schedule. Treatments included 1) untreated bermudagrass, 2) colorant-treated bermudagrass, 3) perennial ryegrass overseeded bermudagrass, and 4) turf-type annual ryegrass overseeded bermudagrass.

Materials and Methods

This research was conducted at the Texas A&M Agrilife Research Turfgrass Field Laboratory in College Station, Texas. The experiment was initiated on 10 October 2013 (hereafter referred to as ‘year 1’) and repeated 15 October 2014 (hereafter referred to as ‘year 2’), with each experiment lasting 7 months. For each year of the study, separate plots of established Tifway bermudagrass were used. Soils for both study sites were characterized as a Booneville series (fine, smectitic, thermic, chromic vertic Albaqualf). Based on physical analysis of the 0-15 cm soil depth, the year 1 site topsoil was characterized as sandy loam (79% sand, 12% silt, 9% clay) with pH 9.7, while year 2 site topsoil was characterized as a sand (89% sand, 8% silt, 3% clay), with pH 8.9. At both sites, the A horizon topsoil varied from a depth of 10-30 cm, and lies atop a heavy clay B horizon subsoil. The study was arranged as a split-plot design with four replicate plots per treatment.

Main plots (1.5 m x 1.5 m) consisted of winter treatments 1) untreated bermudagrass, 2) colorant-treated bermudagrass, 3) perennial ryegrass overseeded bermudagrass, and 4) turf-type annual ryegrass overseeded bermudagrass. Untreated bermudagrass entered shoot dormancy following November frosts each year, with some active green shoots visible deep within the base of the canopy throughout the winter months. Colorant treated bermudagrass received a single fall (mid-October at time of seeding) application of Greenlawnger turf colorant (Becker Underwood, Ames, IA) prior to dormancy each year using a CO_2 powered backpack sprayer equipped with XR Teejet

8002VS nozzles (Spraying System Co., Wheaton, IL) and spray pressure of 40 psi. The sprayer was calibrated to deliver 561 L ha^{-1} and a 7:1 H_2O to colorant dilution was used. In early February of each year, untreated and colorant-treated plots were selectively treated for annual bluegrass using foramsulfuron (Revolver 0.19 SC; Bayer Crop Science, Research Triangle Park, NC), at a rate of 2.8 mg a.i. m^{-2} using handheld boom sprayer equipped with XR Teejet 8005VS nozzles and calibrated to deliver 610 L ha^{-1}.

Overseeded treatments were seeded 10 October of year 1 and 15 October of year 2. Prior to overseeding, plots were mowed to their maintenance height of 2.5 cm. Perennial ryegrass plots were seeded using ‘Futura 2000’ perennial ryegrass blend (Pickseed, Tangent, OR), while annual ryegrass plots were seeded using ‘Panterra V’ annual ryegrass blend (Barenbrug USA, Tangent, OR). Plots of both species were overseeded via hand shaker jars at a rate of 49 g m^{-2}. A 29-0-5 (N-P_2O_5-K_2O) granular starter fertilizer (Sta-Green All Season Lawn Fertilizer, Infinity Lawn and Garden, Milan, IL) was applied to the entire study area at the time of overseeding using a broadcast spreader delivering a rate of 4.9 g N m^{-2}. The fertilizer was again applied 2 and 4 months after overseeding, resulting in a total of 14.7 g N m^{-2} applied to the study area during the 7-month period.

Newly seeded plots were established under well-watered conditions during the initial 30 days of each year (mid-October through mid-November). During this time, all treatment plots received 6 mm irrigation 5 to 7 days weekly. After the 30-day establishment period, plots received 2 cm irrigation once weekly. This irrigation amount was estimated to be the volume required to return the 0 to 15 cm soil depth root zone in plots to field capacity. Weekly irrigation amounts were adjusted to account for any rainfall events of 2 cm or less received during the prior 7-day period. During the study, weather data including Penman-Monteith reference evapotranspiration (ET_o), precipitation, air temperature, and solar radiation were monitored via an onsite weather station (Campbell Scientific, Logan, UT) connected to the Texas ET Network (texaset.tamu.edu). Cumulative weather data totals for each month of the study are presented in Table 2. Plots were mowed weekly during the study at 3.2 cm height of cut using a rotary walk mower with clippings removed.

After the 30-day establishment period, treatment main plots were subdivided into halves receiving either 0 (untrafficked) or 4 passes once weekly simulated traffic using a Cady Traffic Simulator (Henderson et al., 2005) equipped with rubber football cleats and operated in the forward direction. Traffic was applied immediately following each weekly mowing event. When rainfall occurred less than 24 hours prior to a scheduled traffic event, trafficking was delayed by 24 hours. Relative to other simulated traffic machines, traffic produced by the Cady Traffic Simulator has been considered to best mimic that occurring on highly trafficked athletic fields (Henderson et al., 2005). Two passes with the Cady Traffic Simulator have been reported to simulate the amount of injury equivalent to one NCAA football game (Henderson et al., 2005).

Evaluation of Winter Treatments

Percent green cover was evaluated for all treatments from plot images obtained monthly during the study. Digital images were taken of the center of plots from December through May during the study. Images were taken 2 days following mowing and traffic application using a digital camera (Canon PowerShot SX-170 IS, Tokyo, Japan) mounted on a metal 0.6 m x 0.6 m x 0.6 m cube light-box equipped with 4 compact fluorescent bulbs. Images were analyzed for percent green cover using Sigma Scan Pro (Systat Software, Inc., San Jose, CA). Hue and saturation settings of 45 to 120 and 0 to 100, respectively, were used (Richardson et al., 2001; Karcher and Richardson, 2003; Karcher and Richardson, 2005).

Visual assessment of percent injury from simulated traffic was also recorded monthly, 2 days following mowing and traffic application, in trafficked plots. Evaluations were adapted from the method described previously by Shearman and Beard (1975). Briefly, a rating of 0% indicated no injury, while 100% indicated bare soil was exposed and only stems remained in plots. Intermediate ratings were as follows: 25% = 25% of leaf blades were shredded from sheaths, 50% = 50% of leaf blades were shredded from sheaths and 75% = 75% of leaf blades were shredded from sheaths with some exposed soil.

Percentage of actively growing bermudagrass was estimated in April and May of each year. Estimates were based on the method previously described by Dunn et al. (1994), and were based on a visual estimation of the amount of green, actively growing bermudagrass evident in plots relative to dormant, straw colored bermudagrass, overseeded ryegrass, or bare soil.

Soil volumetric water content within the 0-5 cm depth was measured monthly using a soil moisture meter (Fieldscout TDR 300, Spectrum Technologies, Inc., Aurora, IL). Measurements were taken between 1-2 days prior to irrigation events and were obtained within both trafficked and non-trafficked subplots.

Canopy temperatures were also measured during cloudless afternoon periods using a handheld infrared thermometer (Spectrum Technologies, Inc., Aurora, IL), from a distance of 92 cm above the soil surface.

Surface hardness ratings (Gmax) were measured monthly within all treatments using a 2.25 kg Clegg impact soil tester (Turf-Tec International, Tallahassee, FL), which provides a measure of impact absorption (Rogers and Waddington, 1990). Gmax is defined as the ratio of maximum negative acceleration on impact in units of gravities to the acceleration due to gravity. Gmax measurements were taken 2 days after simulated traffic was applied to plots. Three Gmax values were obtained at a representative area within each plot and then averaged.

Data Analysis

Data for each parameter were subjected to analysis of variance using the general linear model, univariate test procedure using SPSS ver. 21.0 (IBM Corp, Armonk, NY) to determine statistical significance of the results. Where analysis of variance indicated a significant study effect, parameters were presented separately by study. Mean separation procedures were performed using Fisher's Protected LSD test at the $P \leq 0.05$ level.

Results and Discussion

Weather Data

The first year of the study was characterized by higher evaporative demand, less precipitation, higher monthly solar radiation, and lower mean air temperatures relative to year 2 (Table 3.2). ET_o increased from 5.6 cm in December to a maximum of 16.8 cm in May of year 1, and from 5.7 cm in December to a maximum of 13.1 cm in year 2. Solar radiation increased from 8.0 MJ m^{-2} in December to 19.6 MJ m^{-2} in May of year 1, and from 7.6 MJ m^{-2} in December to 15.1 MJ m^{-2} in May of year 2. While total precipitation for the 6-month period was greater in year 2, May of year 1 was considerably wetter than that of year 2 (21.0 vs. 13.8 cm, respectively). Nighttime temperatures were lower during year 1, which contributed to a greater degree of visible shoot dormancy in plots compared to year 2 (data not shown).

Percent Green Cover

Date, treatment, and traffic all significantly affected percent green cover in plots in both years. There was also a significant date x treatment interaction on percent green cover during both years (Table 3.1). Whereas untreated bermudagrass fell to 0% green cover by January in year 1, it declined to only ~30% green cover in February of year 2, as some green shoots persisted through the winter months deep within the canopy. This was likely due to the relatively higher (~1-4°C) mean daily and nighttime air temperatures for the December through February period of year 2, which may have prevented onset of full shoot dormancy (Table 3.2). With the exception of December of year 1, overseeded plots maintained consistently higher percent green cover compared to non-overseeded and colorant-treated plots from December through March of both years (Figure 3.1). From December through March, overseeding resulted in approximately 65 to 80% green cover in years 1 and 2, respectively. Percent green cover of perennial ryegrass remained stable through the entire period during both years, but annual ryegrass declined by 50% in April of year 2 due to excessive growth and scalping resulting from weekly mowing during the excessively cloudy and rainy March and April months. Colorant application resulted in 60% green cover ratings for December of both years. In year 1, the effects of the colorant application lasted through February; however, in year 2, they only remained through December. This is likely due to the considerably higher (more than 200% higher) rainfall amounts received in December and January of year 2 compared to year 1. By March of year 1 and January of year 2, there were no differences in percent green cover remaining between untreated and colorant treated plots. By May of year 1, all treatments exhibited similar levels (~70%) of green cover, however, at the conclusion of year 2, annual ryegrass green cover declined by 25% compared to all other treatments, which were exhibiting between 80-90% green cover levels.

Table 3.1. Analysis of variance for bermudagrass athletic turf study factors. Where significant study main effect or interactions occurred, studies have been presented separately by year.

	P-values											
	Percent Green Cover		Volumetric Water Content		Spring Canopy Temperatures		Percent Injury		GMAX		Percent Active Bermudagrass	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Date (D)	***	***	***	***	ns	ns	***	***	ns	***	***	***
Treatment (T)	***	***	***	ns	ns	ns	***	***	***	***	***	***
Traffic (Tr)	***	***	***	ns	---	---	ns	ns	***	***	***	ns
D x T	***	***	***	ns	ns	ns	***	***	ns	***	***	ns
D x Tr	ns	ns	ns	ns	---	---	---	---	ns	***	***	ns
T x Tr	ns	ns	ns	ns	---	---	---	---	ns	***	*	ns
D x T x Tr	ns	ns	ns	ns	---	---	---	---	ns	***	---	ns

ns, *, **, *** not significant, significant at $P \leq 0.05$, 0.01, or 0.001, respectively

Table 3.2. Monthly reference evapotranspiration (ET_o), precipitation, supplemental irrigation, solar radiation, and mean daily air temperature for each year of the study. Environmental data were provided through an onsite weather station linked to the Texas ET Network.

		Dec.	Jan.	Feb.	Mar.	Apr.	May
Year 1	ET_{o}, cm	5.6	8.3	6.7	10.2	14.8	16.8
	Precipitation, cm	2.9	3.5	2.7	3.8	3.0	21.0
	Irrigation, cm	5.1	5.1	4.4	5.1	7.6	2.5
	Solar radiation, MJ m^{-2}	8.0	10.6	10.3	13.7	18.4	19.6
	Mean Temperature, °C	8.9	8.3	11.4	13.3	19.4	22.5
Year 2	ET_{o}, cm	5.7	5.8	6.3	8.7	12.2	13.1
	Precipitation, cm	6.7	8.1	1.9	8.4	12.5	13.8
	Irrigation, cm	3.8	1.9	4.4	0.0	0.0	0.6
	Solar radiation, MJ m^{-2}	7.6	11.3	11.8	14.1	15.2	15.1
	Mean Temperature, °C	13.1	9.7	11.1	15.8	21.1	23.6

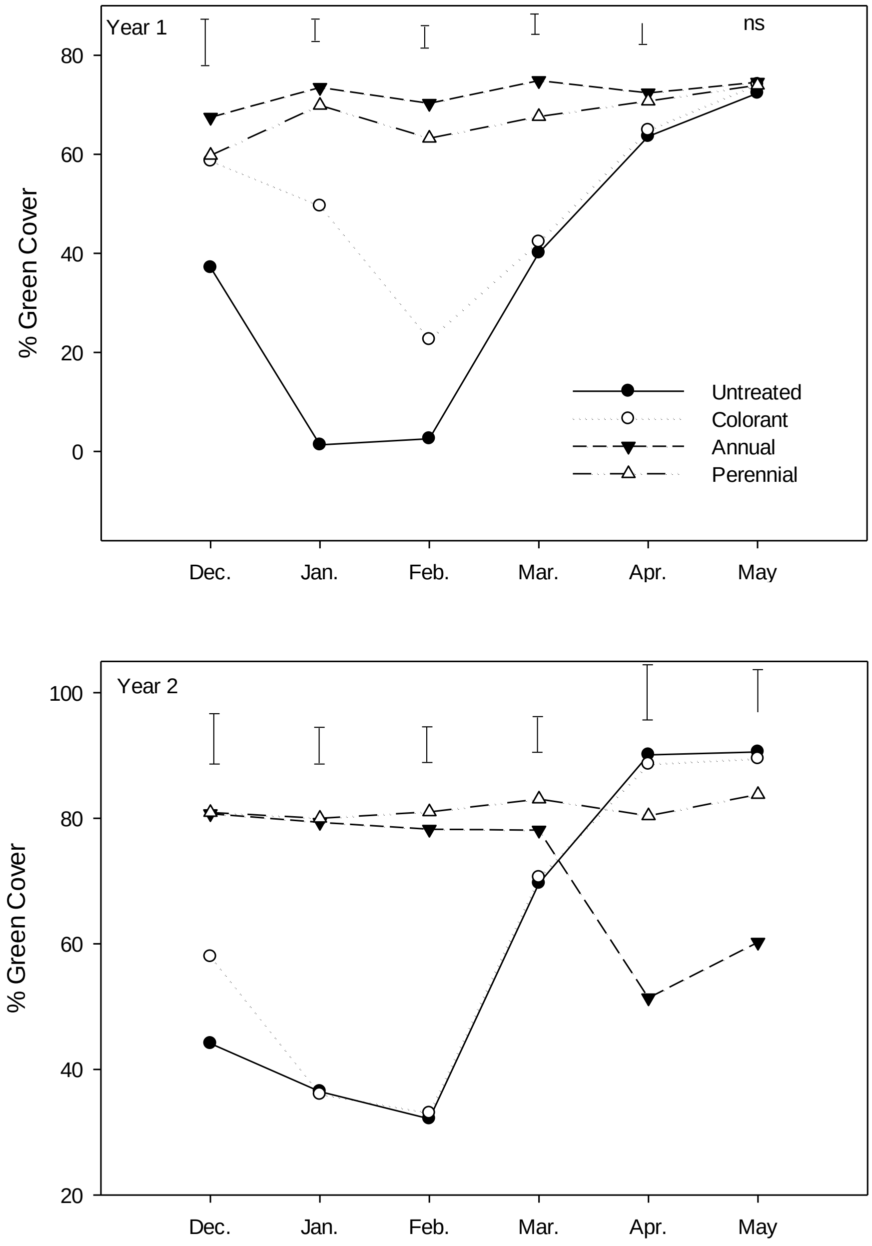

Figure 3.1. Percent green cover as influenced by treatments for years 1 (top) and 2 (bottom). Data are pooled across traffic levels. Error bars denote differences between treatments based on Fishers LSD(0.05).

A significant traffic main effect on percent green cover was also detected during both years (Table 3.1). Traffic resulted in a ~15% decrease in percent green cover in year 1, but only a ~3% decrease in year 2 (Figure 3.2). It is likely that differences by year with respect to traffic effects on percent green cover may have been attributable to bermudagrass achieving complete shoot dormancy in year 1, but retaining >30% green cover through most of year 2. This maintenance of minimal levels of bermudagrass activity may have aided in offsetting the effects of traffic. Furthermore, while cloudier conditions prevailed, the slightly elevated temperatures of year 2 were also possibly more conducive to growth of the overseeded ryegrass. Haselbauer et al. (2012) evaluated effects of repeated autumn simulated traffic on percent green cover of 5 experimental bermudagrasses as well as cultivars Tifway, ‘Tifsport’, and ‘TifGrand’ bermudagrass in Tennessee. By mid-November (after 20 simulated traffic events) of their study, percent green cover of non-overseeded plots ranged from 14 to 34% after year 1, but ranged from 58 to 79% in year 2. The increased cover observed was attributed to ~5° C higher air temperatures in year 2, which promoted greater levels of bermudagrass recovery during the second year. Similarly, Thoms et al. (2011) reported percent green cover of Tifway bermudagrass decreased from 95% to 63% after 17 autumn traffic events (August through November) in Tennessee. While there are a number of reports evaluating traffic tolerance of bermudagrass during summer and autumn months, limited to no published data are available regarding effects of repeated winter traffic on dormant bermudagrass.

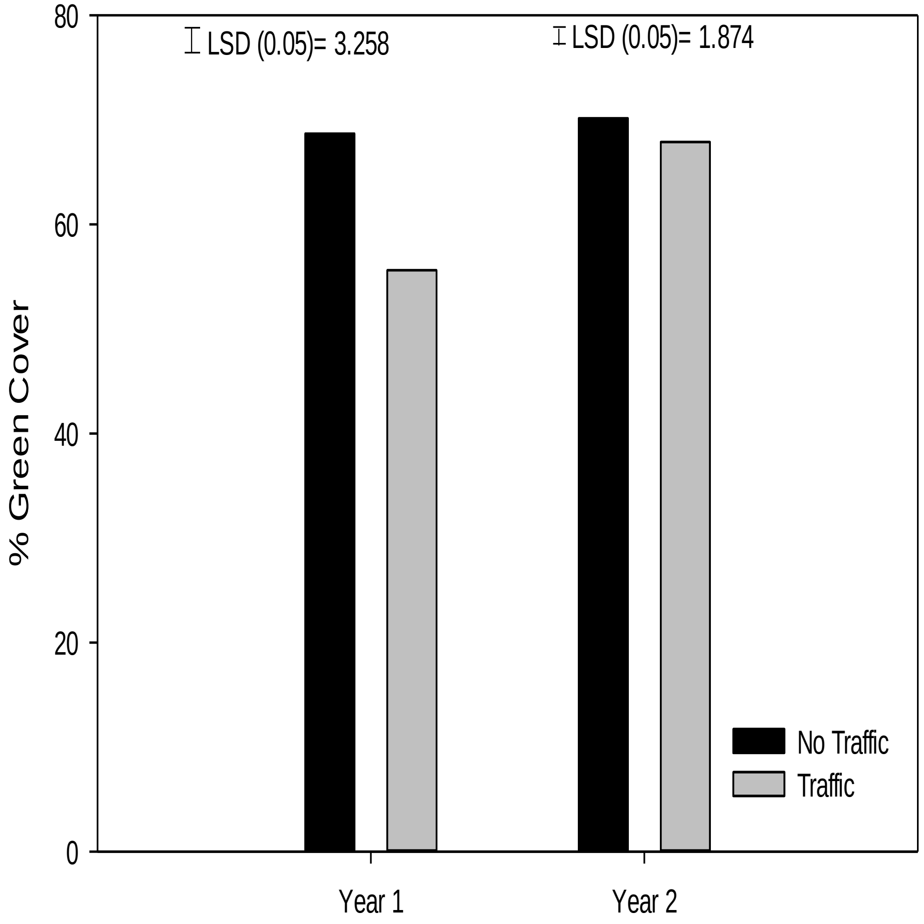

Figure 3.2. Effect of traffic on percent green cover for years 1 and 2. Data are pooled across winter treatments. Error bars denote differences between winter treatments based on Fishers LSD(0.05).

Volumetric Water Content

A significant date x treatment interaction, as well as date and traffic main effects were detected for soil volumetric water content (VWC) in year 1, however, only date significantly affected VWC during year 2 (Table 3.1, Figure 3.3). During December of year 1, no differences in VWC were detected among treatments, with all plots exhibiting VWC of ~38%. On subsequent rating dates, significant differences in VWC occurred among the treatments. For January through May ratings, overseeded treatments exhibited from ~2 to 6% lower VWC compared to untreated and colorant-treated plots. Although the slightly lower VWC within annual ryegrass plots relative to perennial ryegrass would suggest higher ET rates, these differences were minimal, and were not significant. Not surprisingly, no differences occurred between colorant-treated and untreated plots for any month. Water consumption of bermudagrass has been reported to range from 2.5 to 7.5 mm per day during active growth periods (Beard, 1972), however, the influence of bermudagrass ET on soil moisture during these winter months was likely negligible with the exception of the May rating date. Although there are little to no published data comparing water requirements or ET rates of annual and perennial ryegrass cultivars, levels of irrigation/precipitation received during this study period were sufficient to support acceptable levels of turf quality for both species through the duration of the winter growth period until onset of warmer May temperatures (data not shown). Had lower than normal amounts of precipitation occurred during the study period, it is likely that higher levels of stress may have occurred under this 1-day per week irrigation.

A significant effect of traffic on VWC was also observed during year 1 (Table 3.1). As such, plots trafficked plots exhibited a 7% decrease in VWC as compared to non-trafficked plots (data not shown). While similar effects were not observed in year 2, trafficked plots did again exhibit a slight decrease in VWC as compared to non-trafficked plots (data not shown). It is likely that these differences could be attributed to compaction caused by the simulated traffic. Compaction causes changes in soil such as altered pore size distribution and increased bulk density (Boufford and Carrow, 1980; Carrow, 1980). Agnew and Carrow (1985) also reported decreased soil moisture content with increasing traffic within the 0-3 cm soil depth, reporting soil moisture decreases of 8 and 12% for short- and long-term traffic, respectively. Similar findings have also been reported by O’Neil and Carrow (1983). Both elevated precipitation amounts as well as the sandier-textured soils used in year 2 may have limited the capacity to once again detect similar treatment differences.

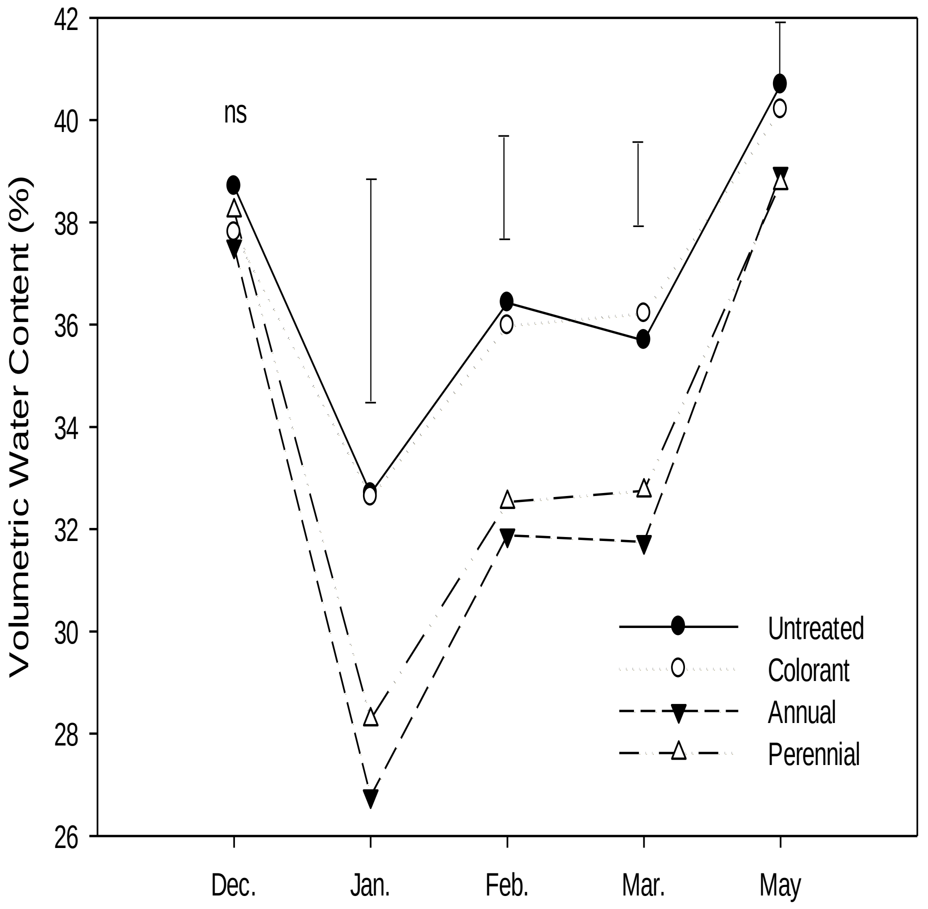

Figure 3.3. Soil volumetric water content by month for year 1. Data are pooled across traffic treatments. Error bars denote differences between treatments based on Fishers LSD(0.05).

Percent Visual Injury

A date x treatment interaction for percent visual injury occurred due to weekly traffic during both years 1 and 2 (Table 3.1, Figure 3.4). Percent injury peaked at 22% for all treatments in April of year 1, prior to recovery taking place during May. For year 2, peak injury of 28% injury was noted for untreated and colorant treated plots in February before recovery ensued. Not surprisingly, untreated and colorant-treated plots exhibited the greatest levels of visual injury from January through March rating dates, with no differences noted between the two treatments on any rating date (Figure 3.4). Visual injury of annual and perennial ryegrass overseeded plots was significantly lower than colorant-treated or untreated plots for January through March periods both years. Injury of overseeded plots gradually increased from December through April of year 1 and through May of year 2. Although no injury differences between the ryegrass species were observed in year 1, annual ryegrass overseeded plots succumbed to significantly greater injury relative to perennial ryegrass overseeded plots in year 2 (Figure 3.4), possibly related to the lower levels of solar radiation and high rainfall early spring of the second year. The lower injury levels observed in perennial versus annual ryegrass are consistent with findings of Shearman and Beard (1975), who evaluated wear tolerance of seven different winter overseeded cool-season grasses in bermudagrass and reported wear tolerance of ‘Manhattan’ perennial ryegrass to be superior to annual ryegrass, Kentucky bluegrass, tall fescue, red fescue, chewing fescue, and rough bluegrass. Similar results of comparisons of cool-season turfgrass traffic tolerance have been reported by Canaway (1978), Bourgoin and Mansat (1979), Carrow and Petrovic (1992).

While limited published data are available comparing traffic tolerance of colorant-treated and untreated dormant bermudagrass, the similar injury levels observed throughout the study period suggest that colorant application neither increased nor decreased bermudagrass traffic tolerance.

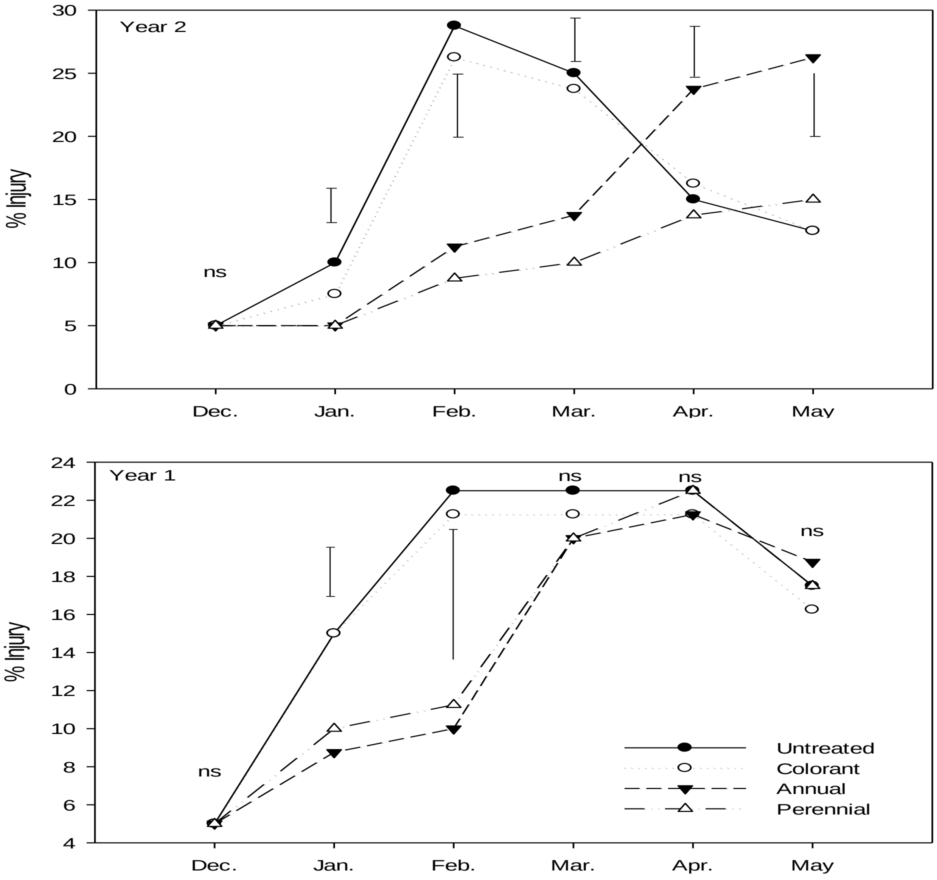

Figure 3.4. Percent visual injury by month for years 1 (top) and 2 (bottom) as affected by winter treatment. Data are for trafficked plots. Error bars denote differences between treatments based on Fishers LSD(0.05).

Surface Hardness (Gmax)

Both winter treatment and traffic main effects were detected for surface hardness in each year of the study. Year 1 Gmax measurements ranged from 60 to 72, while year 2 measurements ranged from only 50 to 67, possibly due to the higher sand content in year 2 plots (Figures 3.5 and 3.6). For year 1, overseeding reduced surface hardness relative to untreated and colorant-treated plots ~60 vs. 70, respectively), however no differences were noted between annual vs. perennial ryegrass or between untreated vs. colorant-treated plots. In year 1, Gmax was higher in trafficked vs. nontrafficked plots (74 vs. 61, respectively), regardless of treatment (data not shown). For year 2, a date x treatment x traffic interaction for surface hardness was observed (Table 3.1). During the course of year 2, surface hardness of trafficked treatments increased monthly on overseeded plots, resulting in an increase of 19% for annual ryegrass and 5% for perennial ryegrass by the final May rating date (data not shown). Untreated and colorant treated plots exhibited peak Gmax in March of year 2, just prior to bermudagrass growth resumed in spring. Traffic significantly increased Gmax across all treatments in year 2, however, perennial ryegrass showed the least change in surface hardness due to traffic (Figure 3.6). Dunn et al. (1994) reported similar to slightly elevated Gmax measurements in non-overseeded compared to perennial ryegrass-overseeded bermudagrass plots in ratings taken during early summer in a 2-year Missouri study (51 vs. 49 and 37 vs. 37 for non-overseeded and overseeded plots, respectively). These readings are somewhat lower than those reported in our study, likely due to their measurements being taken during summer months, when active growth of bermudagrass had resumed. Dunn et al. (1994) also reported 36 to 74% increases in surface hardness of bermudagrass resulting from traffic in overseeded and non-overseeded plots, respectively. The greater increase in Gmax ratings observed in their study could be a result of a substantially greater number of weekly traffic simulator passes made (10 passes 3 times weekly) compared to the 4 passes provided once weekly in our study. Stoloniferous grasses such as bermudagrass tend to produce greater amounts of thatch and biomass compared to bunch-type turfgrasses such as perennial ryegrass, and therefore may also provide more cushion to the impact of the Clegg tester (Waddington, 1990). Canaway et al. (1990) has suggested that Gmax ratings for athletic turf should ideally fall between 20 and 80 while acceptable ratings could range from 10 to 100. Although all treatments in our study exhibited Gmax measurements of less than 100, it is possible that more intensive traffic may have produced these levels. While we are not aware of any existing standards for youth or recreational athletic fields, the National Football League field testing program currently requires playing surface hardness of both natural and synthetic turf fields to be lower than 100 Gmax (Sports Turf Managers Association, 2015).

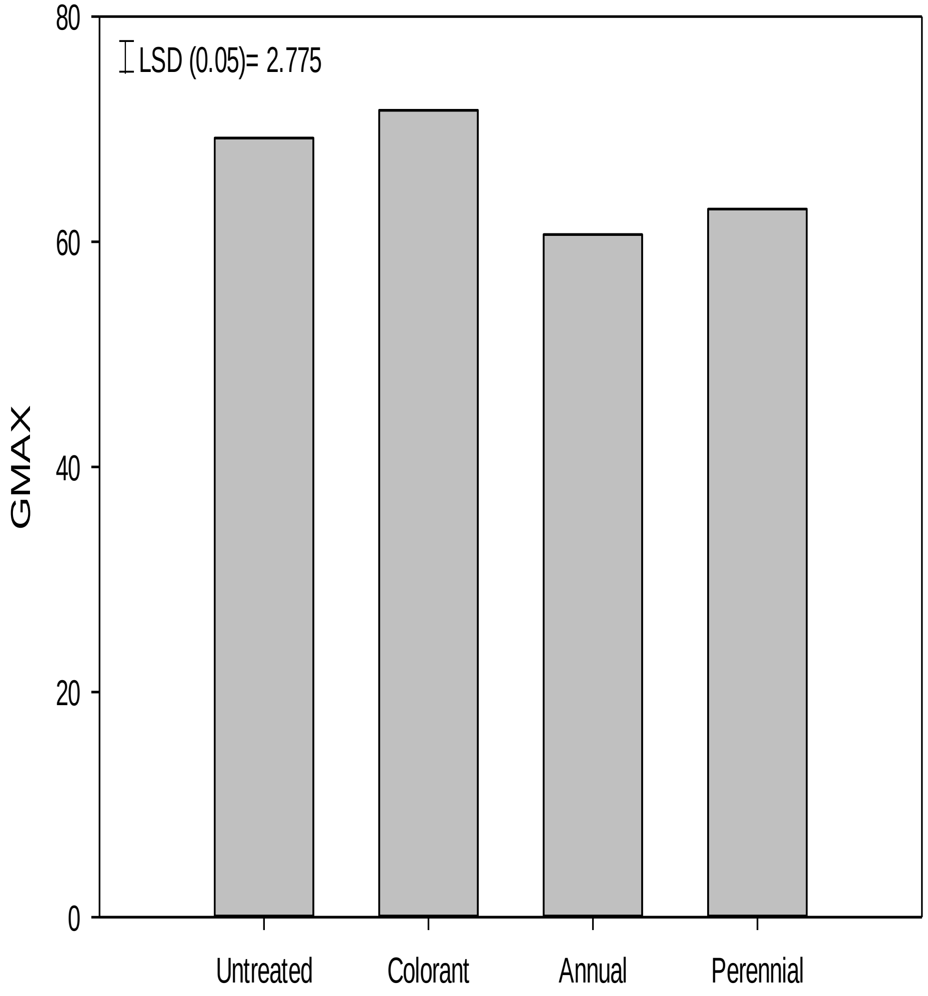

Figure 3.5. Surface hardness (Gmax) as affected by winter treatment for year 1. Data are pooled across traffic levels. Error bar denotes differences between treatments based on Fishers LSD(0.05).

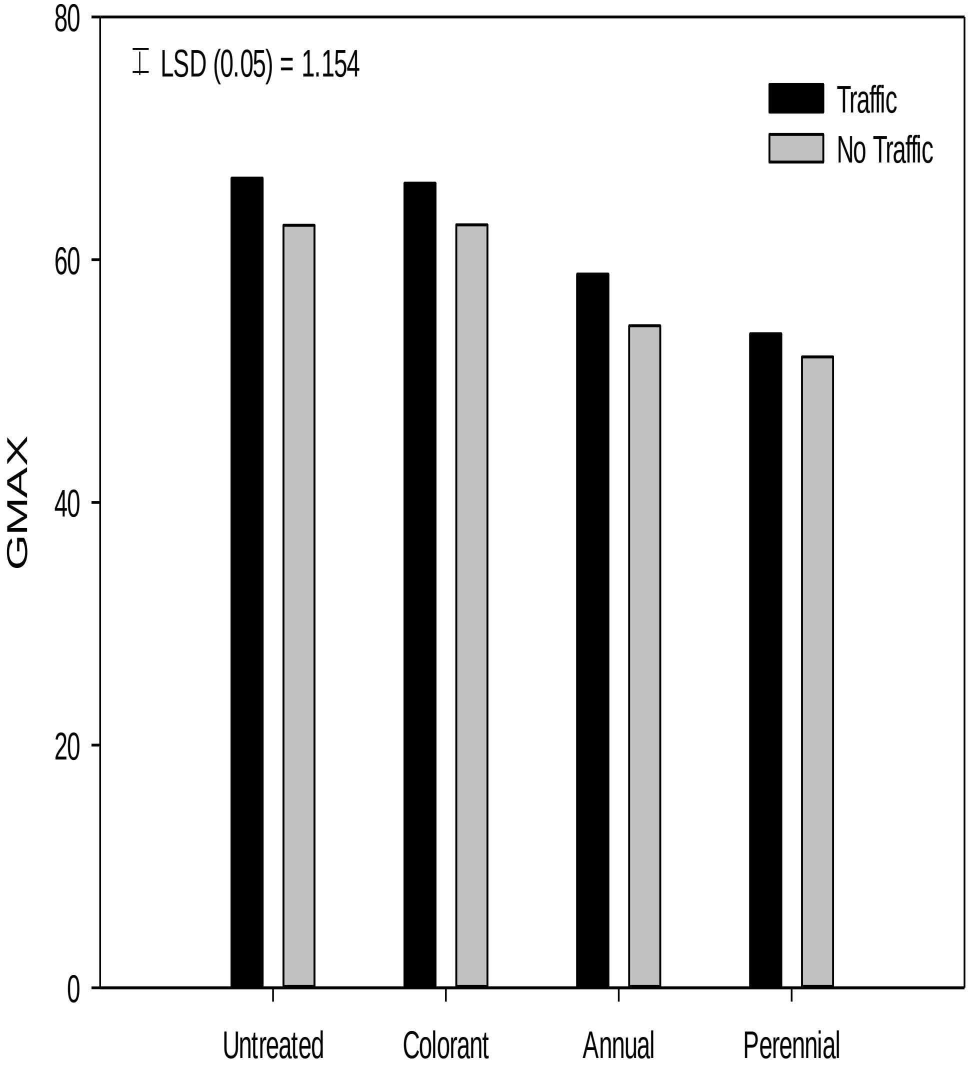

Figure 3.6. Surface hardness (Gmax) as affected by winter treatment and traffic for year 2. Error bar denotes differences between treatments based on Fishers LSD(0.05).

Percent Active Bermudagrass

A significant treatment x traffic interaction on percent active bermudagrass occurred in year 1 but not for year 2 (Table 3.1, Figure 3.7). As such, overseeding of either species resulted in a significant (~40 to 50%) decrease in visible active bermudagrass in plots compared to non overseeded plots (Figure 3.7). Percent active bermudagrass was also similar between annual and perennial ryegrass overseed plots. Furthermore, whereas traffic reduced active bermudagrass by ~10% in colorant-treated and non-overseeded plots, it had no effect on percent bermudagrass of overseeded plots. Interestingly, although there have been anecdotal observations of enhanced spring bermudagrass growth due to fall colorant application, we observed no significant differences between colorant-treated and untreated plots in terms of April and May bermudagrass evaluations. Spring canopy temperature measurements taken during March, April, and May also did not significantly differ between colorant-treated and untreated plots (Table 3.1), which may further substantiate this lack of apparent spring bermudagrass stimulation resulting from fall colorant application. For year 2, percent active bermudagrass was affected only by treatment, with no effect or interaction due to traffic observed (Table 3.1, Figure 3.8). Consistent with year 1, overseeding significantly reduced percent active bermudagrass in plots, however, reductions were again similar between annual vs. perennial overseed stands.

Our results are in agreement with those of Cockerham et al. (1990) who reported 42% and 61% reductions (untrafficked and trafficked plots, respectively) in bermudagrass transition due to overseeding of perennial ryegrass. It should be noted that percent active bermudagrass ratings in their work was observed at the conclusion of the study following chemical transition of perennial ryegrass. However, our observations of bermudagrass transition differs somewhat with that of Cockerham et al. (1990), who reported similar amounts of bermudagrass in annual ryegrass-overseeded and non-overseeded plots during spring transition evaluations. Richardson (2004) also compared spring transition of annual and perennial ryegrasses in Arkansas and reported that annual ryegrass-overseeded plots exhibited 46% and 55% ryegrass in late May, whereas perennial ryegrass-overseeded plots still had from 95 to 100% ryegrass. Differences between this and our study are likely due to our use of an improved turf type annual ryegrass as well as the high rainfall and elevated spring temperatures occurring in our study.

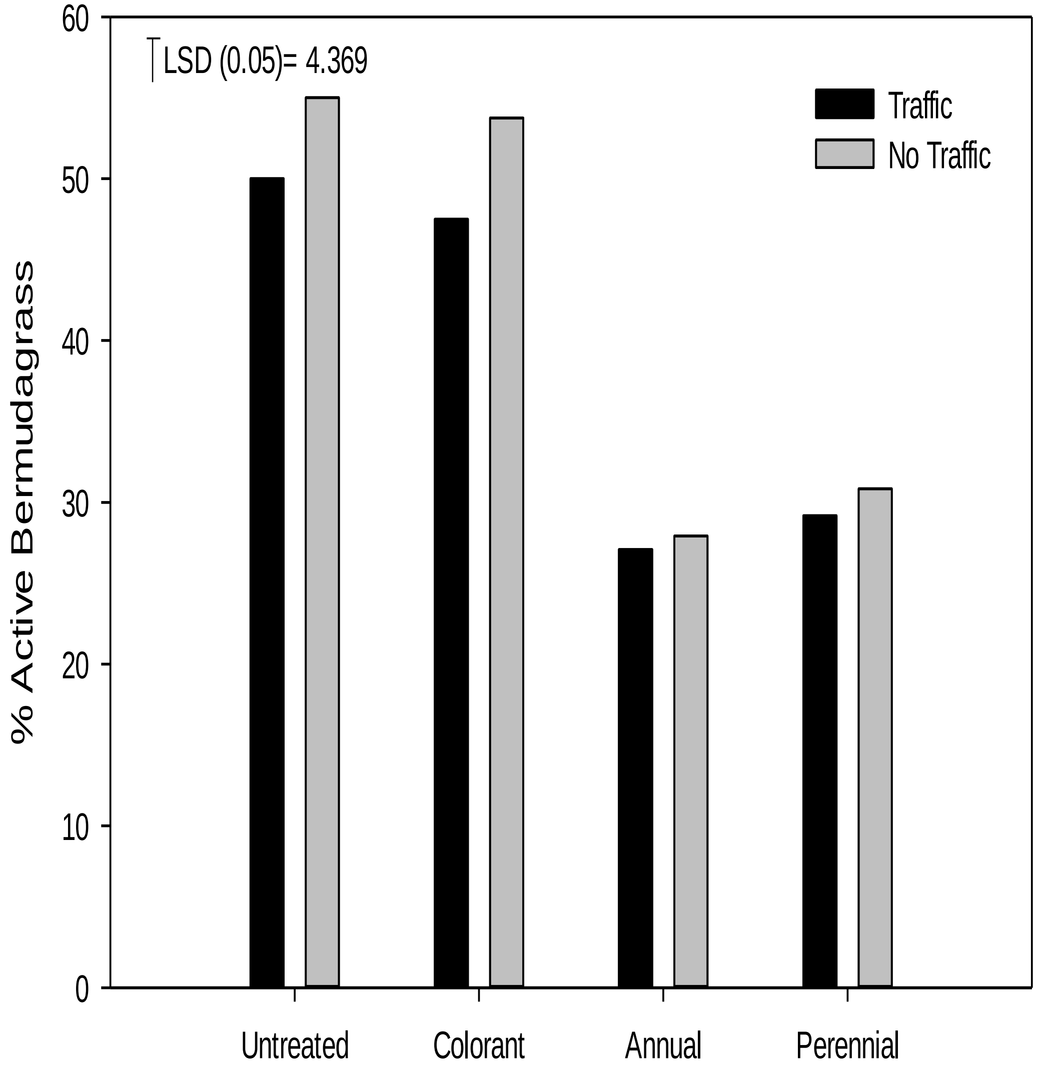

Figure 3.7. Percent active bermudagrass as influenced by winter treatment and traffic for year 1. Error bars denote LSD(0.05).

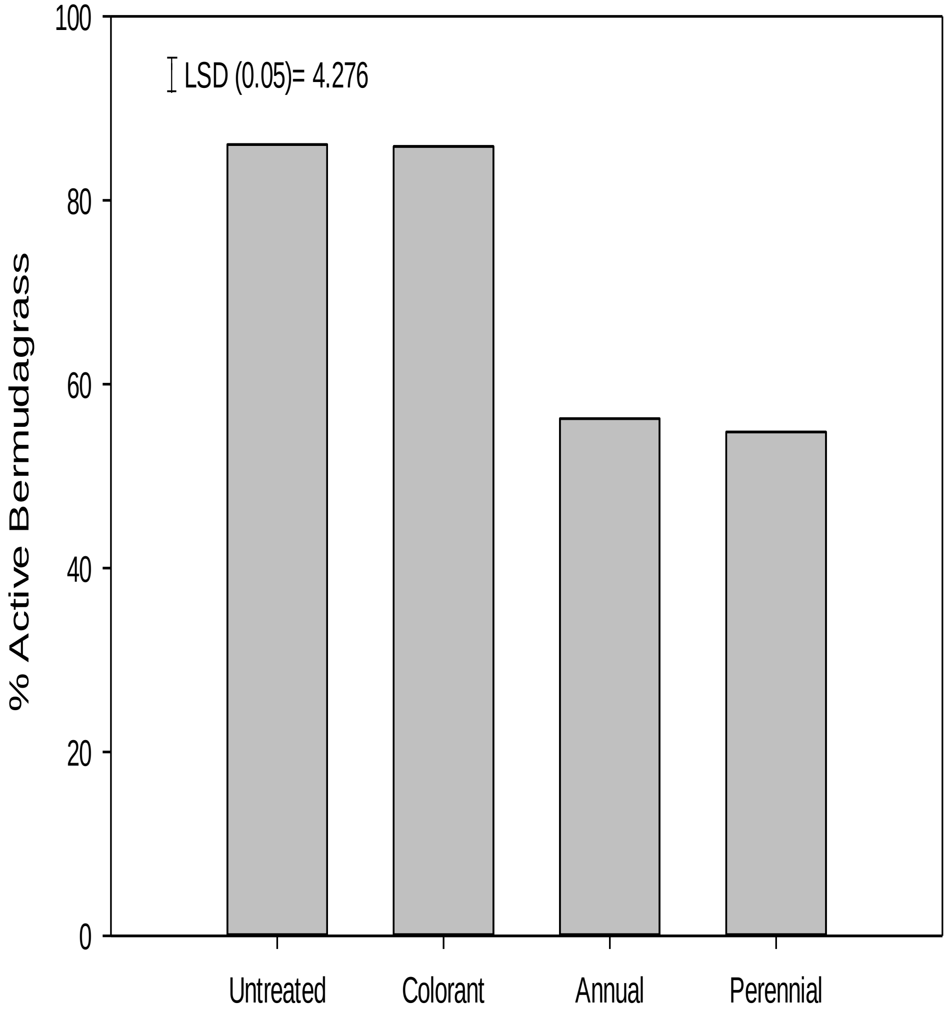

Figure 3.8. Percent active bermudagrass as influenced by winter treatment for year 2. Data are pooled across traffic levels. Error bars denote LSD(0.05).

Conclusions

Given the need for increased urban water conservation and reduced operating budgets, southern and transition zone turf managers will need to continue to evaluate options for and alternatives to winter overseeding of trafficked, dormant warm-season turf. Improved ‘turf-type’ annual ryegrasses may offer improved turf quality relative to older cultivars, however, there is concern that they may be less tolerant of traffic or infrequent irrigation. Also, while use of turf colorants is an alternative that has seen growing adoption within golf and athletic turf management, the practice may not be practical for areas that are subjected to larger amounts of wear from traffic. This research compared performance, tolerance to simulated traffic, and spring transition of Tifway bermudagrass winter treatments under a 1-day per week supplemental irrigation schedule. Based on our results, both improved turf-type annual ryegrass and perennial ryegrass overseed stands maintained acceptable levels (60 to 80%) of green cover both years of the study. While tolerance to simulated traffic (4 passes weekly) did not differ between the two species in year 1, the higher precipitation and cloud cover of year 2 may have contributed to greater injury levels within annual ryegrass in year 2. Additionally, residual benefits of fall colorant application were variable, extending into February of year 1, but dissipating by late December of year 2. These results indicate repeat applications may be required during the winter months, depending on environmental conditions. Overseeding, regardless of species, reduced bermudagrass spring transition by 40 to 50% compared to untreated and colorant-treated plots, with no stimulation of bermudagrass transition resulting from the single fall colorant application.

CHAPTER IV

CONCLUSION

As drought becomes more severe and widespread, the necessity for turf managers to more effectively conserve water resources will continue to increase. Research further examining methods and alternatives to existing management practices will be important to the sustainability of the turfgrass industry. These greenhouse and field projects identified cultural management techniques that result in development of a deep and expansive root system in newly establishing St. Augustinegrass sod, which may be beneficial to long term success of the sod. We also examined the use of turf colorants as an alternative to overseeding during restricted irrigation practices.

In the greenhouse study, we evaluated how the use of PGRs and weekly mowing affect root development during the establishment of St. Augustinegrass during a 35-day water variance period. In this study, we also evaluated a new St. Augustinegrass cultivar, TamStar, in relation to the industry standard for drought tolerance, Floratam. Our findings demonstrated that, during establishment, mowing could be withheld during a 35-day variance period in St. Augustinegrass to ensure more extensive development of root systems. The use of PGRs reduced the quality of Floratam, as well as the clipping yield from both cultivars, but no benefits were realized in terms of rooting. We also found that the new St. Augustinegrass cultivar, TamStar, exhibited improved quality and root mass compared to Floratam.

Our field study focused on options for managing trafficked bermudagrass during winter dormancy and infrequent irrigation. Specifically, we evaluated the effects of traffic on overseeded and non overseeded Tifway bermudagrass during a stage 2, or once weekly, irrigation restriction. Our findings showed that, the benefits of turf colorants as an alternative to overseeding differed by year and environmental conditions, also, we found that both perennial and annual ryegrasses exhibited a similar quality during the first year of the study. However, with higher rainfall and cloud cover in year 2, annual ryegrass quality declined considerably relative to perennial ryegrass. Traffic also increased the surface hardness of all treatments with the non-overseeded plots becoming harder than those overseeded. Future research should address the benefits of repeated colorant applications, as well as the impacts of colorants on heavy metals in soil and plant tissue.

As turf management practices change due to declining water availability in coming decades, findings of both the greenhouse and field studies provide practical information for turfgrass professionals on the establishment and maintenance of turfgrasses during water restriction periods.

REFERENCES

Adams, R., E. Kerber, K. Pfister and E. Weiler 1992. Studies on the action of the new growth retardant CGA 163'935 (cimectacarb). Progress in plant growth regulation. Springer.

Agnew, M. L. and R. N. Carrow 1985. Soil compaction and moisture stress preconditioning in Kentucky bluegrass. I. Soil Aeration, Water Use, and Root Responses. Agronomy Journal 77: 872-878.

Atkins, C., R. Green, S. Sifers and J. Beard 1991. Evapotranspiration rates and growth characteristics of ten St. Augustinegrass genotypes. HortScience 26: 1488-1491.

Beard, J. B. 1972. Turfgrass: Science and culture, Englewood Cliffs, N.J., Prentice Hall.

Beasley, J. S., B. E. Branham and L. M. Ortiz-Ribbing 2005. Trinexapac-ethyl affects Kentucky bluegrass root architecture. HortScience 40: 1539-1542.

Bonos, S. A. and J. A. Murphy 1999. Growth responses and performance of Kentucky bluegrass under summer stress. Crop Science 39: 770-774.

Bouffford, R. W. and R. Carrow 1980. Effects of intense, short-term traffic on soil physical properties and turfgrass growth. Transactions of the Kansas Academy of Science 1903: 78-85.

Bourgoin, B. and P. Mansat 1979. Persistence of turfgrass species and cultivars. Journal of the Sports Turf Research Institute 55: 121-140.

Busey, P. 1986. Morphological identification of St. Augustinegrass cultivars. Crop Science 26: 28-32.

Busey, P. 2003. St. Augustinegrass, Stenotaphrum secundatum (Walt.) Kuntze. Biology, breeding, and genetics of turfgrasses. John Wiley and Sons, Inc., Hoboken, New Jersey: 309-330.

Canaway, P. 1978. Trials of turfgrass wear tolerance and associated factors--a summary of progress 1975-1977. Journal of the Sports Turf Research Institute 54: 7-14.

Canaway, P., M. Bell, G. Holmes, and S. Baker. 1990. Standards for the playing quality of natural turf for association football. Natural and artifical playing fields: Characteristics and safety features 1073: 29-47

Carrow, R. N. 1980. Influence of soil compaction on three turfgrass species. Agronomy Journal 72: 1038-1042.

Carrow, R. N. and A. M. Petrovic 1992. Effects of traffic on turfgrasses. Turfgrass. Agron. Monogr 32: 285-330.

Carrow, R. N. 1996. Drought resistance aspects of turfgrasses in the southeast: Root-shoot responses. Crop Science 36: 687-694.

Carson, T. 2004. Overseed or paint. Golf Course Management 72: 22.

Census, United States of America 2005. Change in the total population for regions, divisions, and states: 2000 to 2030.

Chalmers, D. and J. Mcafee. 2010. Turfgrass Establishment for Texas. AgriLIFE Extension. http://galveston.agrilife.org/files/2011/05/B-6239-Turfgrass-Establishment-for-Texas-6-2010.pdf.

Chandra, A., A. Genovesi, B. Wherley, S. Metz, J. Reinert, Y. Wu, P. Skulkaew, M. Engelke, D. Hargey and L. Nelson 2015. Registration of 'DALSA 0605'St. Augustinegrass. Journal of Plant Registrations 9: 27-34.

City of Allen, TX. 2015. Stage 2 water restrictions Available at http://allentx.swagit.com/play/08302011-155 (Acessed 3 Sept. 2015)

Cockerham, S. T., V. A. Gibeault, J. Van Dam and M. K. Leonard 1990. Tolerance of several cool-season turfgrasses to simulated sports traffic. Natural and Artificial Playing Fields: Characteristics and Safety Features 1073: 85.

Combs, S. 2012. The impact of the 2011 drought and beyond. Texas Controller of Public Accounts 96: 1704

Deaton, M. T. and D. W. Williams 2010. Overseeding and trinexapac-ethyl effects on tolerance to simulated traffic of four bermudagrass cultivars grown as a sand-based athletic field. HortTechnology 20: 724-729.

Duble, R. L. 1978. Overseeding bermudagrass turf. Southern Golf 9: 20-23.

Duble, R. L. 2013. St. Augustine Grass. Aggie Horticulture. http://aggie-horticulture.tamu.edu/archives/parsons/turf/publications/staug.html

Dudeck, A. and C. Peacock. Effects of several overseeded ryegrasses on turf quality, traffic tolerance, and ball roll. Proc. 4th Int. Turfgrass Res. Conf., Guelph, ON, Canada, 1981. 19-23.

Dunn, J. H., D. D. Minner, B. F. Fresenburg and S. S. Bughrara 1994. Bermudagrass and cool-season turfgrass mixtures: Response to simulated traffic. Agronomy journal 86: 10-16.

Ervin, E. H. and A. Koski 1998. Growth responses of Lolium perenne L. to trinexapac-ethyl. HortScience 33: 1200-1202.

Ervin, E. H. and A. Koski 2001. Trinexapac-ethyl increases Kentucky bluegrass leaf cell density and chlorophyll concentration. HortScience 36: 787-789.

Fagerness, M. J. and D. Penner 1998. Spray application parameters that influence the growth inhibiting effects of trinexapac-ethyl. Crop science 38: 1028-1035.

Fagerness, M. J. and F. H. Yelverton 2001. Plant growth regulator and mowing height effects on seasonal root growth of Penncross creeping bentgrass. Crop science 41: 1901-1905.

Genovesi, A. D., R. W. Jessup, M. C. Engelke and B. L. Burson 2009. Interploid St. Augustinegrass [Stenotaphrum secundatum (Walt.) Kuntze] hybrids recovered by embryo rescue. In Vitro Cellular & Developmental Biology-Plant 45: 659-666.

Goatley, M., S. Askew, D. S. Mccall and P. B. Schultz 2009. Spring and summer lawn management considerations for warm-season turfgrasses.

Harper, J., C. Morehouse, D. Waddington and W. Buckley 1984. Turf management, athletic field conditions, and injuries in high school football. Agric. Exp. Stn. Prog. Rep 384.

Hartwiger, C., and P. O'Brien. 2013. Fall green-up: Turf Colorants are redefining winter playing conditions. USGA Green Section Course Care. Available at http://www.usag.org/course-care/2013/09/fall-greenup-turf-colorants-are-redefining-winter-playing-conditions-21474860082.html (Accessed 3 Sept 2015)

Haselbauer, W.D., A.W. Thoms, J.C. Sorochan, J.T. Brosnan, B.M. Schwartz, and W.W. Hanna. 2012. Evaluation of experimental bermudagrasses under simulated athletic field traffic with perennial ryegrass overseeding. HortTech 22(1):94-98.

Henderson, J.J., J.L. Lanovaz, J.N. Rogers III, J.C. Sorochan, and J.T. Vanini. 2005. A new apparatus to simulate athletic field traffic: The Cady Traffic Simulator. Agron J. 93:1153-1157.

Horgan, B. P. and F. H. Yelverton 2001. Removal of perennial ryegrass from overseeded bermudagrass using cultural methods. Crop Science 41: 118-126.

Huang, B., R. R. Duncan and R. N. Carrow 1997. Drought-resistance mechanisms of seven warm-season turfgrasses under surface soil drying: II. Root Aspects. Crop Science 37: 1863-1869.

Huang, B. and H. Gao 2000. Root physiological characteristics associated with drought resistance in tall fescue cultivars. Crop Science 40: 196-203.

Johnson, B. 1973. Establishment of centipedegrass and St. Augustine grass with the aid of chemicals. Agronomy Journal 65: 959-962.

Karcher, D.E. and M.D. Richardson. 2003. Quantifying turfgrass color using digital image analysis. Crop Sci. 43:943-951.

Karcher, D.E. and M.D. Richardson. 2005. Batch analysis of digital images to evaluate turfgrass characteristics. Crop Sci. 45:1536-1539.

Levitt, J. 2012. Chilling, freezing, and high temperature stresses. Vol. 1. Elsevier.

Liu, H., B. Mccarty, C. M. Baldwin, W. G. Sarvis and S. H. Long 2007. Painting dormant bermudagrass putting greens. Golf Course Manage 75: 86-91.

Liu, X. and B. Huang 2002. Mowing effects on root production, growth, and mortality of creeping bentgrass. Crop Science 42: 1241-1250.

Long, S. H., H. Liu, L. Mccarty and J. Thackston 2005. If it’s winter, it must be time to put on a coat (of green paint). Turfgrass Trends 61: 56-58.

Madison, J. H. 1962. Turfgrass ecology. Effects of mowing, irrigation, and nitrogen treatments of Agrostis palustris Huds.,‘Seaside’and Agrostis tenuis Sibth.,‘Highland’on population, yield, rooting, and cover. Agronomy Journal 54: 407-412.

Marcum, K. B., M. Engelke, S. J. Morton and R. H. White 1995. Rooting characteristics and associated drought resistance of zoysiagrasses. Agronomy Journal 87: 534-538.

Mazur, A. and J. Rice 1999. Impact of overseeding bermudagrass with various amounts of perennial ryegrass for winter putting turf. HortScience 34: 864-866.

Mcbride, M. B. 1994. Environmental chemistry of soils, Oxford university press.

Mccarty, L. B., J. S. Weinbrecht, J. E. Toler and G. L. Miller 2004. St. Augustinegrass response to plant growth retardants. Crop science 44: 1323-1329.

Mccarty, B. and T. Whitwell 2006. Plant Growth Regulators for Fine Turf.

Mccarty, L. B. 2011. Best golf course management practices. 2nd ed. Pearson Prentice Hall, Upper Saddle River, NJ.

Mccarty, L. B., J. R. Gann, C. E. Wells and P. D. Gerard 2014. Creeping Bentgrass Field Response to pigment-containing products. Agronomy Journal 106: 1533-1539.

Miller, G. and L. Mccarty 1998. Turfgrass rooting characteristics of ‘Palmetto’,‘FX-10’, and ‘Floratam’St. Augustinegrasses and ‘Pensacola’bahiagrass. Root Demographics and Their Efficiencies in Sustainable Agriculture, Grasslands and Forest Ecosystems. Springer.

Miller, G. and D. Pinnix. 2014. Green sports fields using turf colorants. Sports Turf Magazine Online. Available at http://sportsturfonline.com/2014/10/09/green-sports-fields-using-turf-colorants/6170/ (Accessed 3 Sept. 2015)

Nelson, L., J. Crowder, and H. Pemberton. 2005. Performance and transition date of a turf-type annual ryegrass in comparison to perennial ryegrass and fine fescues. HortTechnology 15: 304-308

O'neil, K. J. and R. N. Carrow 1983. Perennial ryegrass growth, water use, and soil aeration status under soil compaction. Agronomy Journal 75: 177-180.

Peacock, C. H. and A. Dudeck 1985. Effect of irrigation interval on St. Augustinegrass rooting. Agronomy Journal 77: 813-815.

Polomski, B., B. Mccarty and D. Shaughnessy 1999. Overseeding with ryegrass. Clemson Cooperative Extension.

Powell, A. and D. Bergstrom 2009. Overseeding bermudagrass sports fields. Online. Ext. Publ. Univ. of Kentucky, Lexington, KY.

Reynolds, W. C., G. L. Miller, and T. W. Rufty. 2013. Athletic field paint color differentially alters light spectral quality and bermudagrass photosynthesis. Crop Science 53: 2209-2217.

Richardson, M. 2004. Morphology, turf quality, and heat tolerance of intermediate ryegrass. HortScience 39: 170-173.

Rogers, J. N. and D. V. Waddington. 1992. Impact absorption characteristics on turf and soil surfaces. Agronomy Journal 84: 203-209.

San Antonio Water System Conservation. 2013. SAWS Conservation Ordinance. Available at http://www.saws.org/Conservation/Ordinance/download.cfm (Accessed 3 Sept. 2015).

Salaiz, T., G. Horst and R. Shearman 1995. Mowing height and vertical mowing frequency effects on putting green quality. Crop science 35: 1422-1425.

Schmidt, R. and J. Shoulders. Seasonal performance of selected temperate turfgrasses overseeded on bermudagrass turf for winter sports. Proceedings of the Third International Turfgrass Research Conference, 1980. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, 75-86.

Sharp, R. and W. Davies 1985. Root growth and water uptake by maize plants in drying soil. Journal of Experimental Botany 36: 1441-1456.

Shearman, R. and J. Beard 1975. Turfgrass wear tolerance mechanisms: I. Wear tolerance of seven turfgrass species and quantitative methods for determining turfgrass wear injury. Agronomy journal 67: 208-211.

Shearman, R., L. Wit, S. Severmutlu, H. Budak and R. Gaussoin 2005. Colorant effects on dormant buffalograss turf performance. HortTechnology 15: 244-246.

Sheffer, K., J. Dunn and D. Minner 1987. Summer drought response and rooting depth of three cool-season turfgrasses. HortScience 22: 296-297.

Siefers, S. and J. B. Beard 1999. Drought resistance in warm-season grasses. Golf Course Manage 67: 67-70.

Sports Turf Managers Association. 2015. Field Hardness Testing. Available at: http://www.stma.org/sites/stma/files/STMA_Bulletins/Field_Hardness%20FINAL.pdf. (Accessed 21 Sept. 2015).

Steinke, K., D. Chalmers, J. Thomas and R. White 2011. Bermudagrass and buffalograss drought response and recovery at two soil depths. Crop Science 51: 1215-1223.

Steinke, K., D. Chalmers, J. Thomas, R. White and G. Fipps 2010. Drought response and recovery characteristics of St. Augustinegrass cultivars. Crop science 50: 2076-2083.

Texas Water Development Board. 2012. State water plan. Available at: http://www.twdb.texas.gov/waterplanning/swp/2012/index.asp. (Accessed 20 Oct. 2014)

Thoms, A. W., J. C. Sorochan, J. T. Brosnan and T. J. Samples 2011. Perennial ryegrass and grooming affect bermudagrass traffic tolerance. Crop Science 51: 2204-2211.

Trenholm, L., J. Cisar and J. B. Unruh 2000. St. Augustinegrass for Florida lawns. Available at: http://edis.ifas.ufl.edu/lh010 (Accessed 10 Oct. 2015)

Trlica, M. J. 2013. Grass Growth and Response to Grazing. Colorado State University Extension. Available at: http://www.ext.colostate.edu/pubs/natres/06108.html. (Accessed 3 Sept. 2015)

Van Dam, J. and K. Kurtz 1971. A turfgrass colorant study. California Turfgrass Cult. 22: 26-28.

Waddington, D. V. 1990. Effects of management practices on impact absorption and shear resistance in natural turf. Natural and artificial playing fields: Characteristics and safety features 1073: 136.

Ward, C., E. Mc Whirter and W. Thompson. 1974. Evaluation of cool-season turf species and planting techniques for overseeding bermudagrass golf greens. Proceedings of the Second International Turfgrass Research Conference. American Society of Agronomy, Crop Science Society of America, 480-495.

Weinbrecht, J., L. Mccarty, M. Kane, G. Miller and G. Best 1998. St. Augustinegrass root growth response following plant growth retardant application. Root Demographics and Their Efficiencies in Sustainable Agriculture, Grasslands and Forest Ecosystems. Springer.

Weinbrecht, J. S. and G. L. Miller 2009. St. Augustine growth responses to various plant growth retardents. Available at: http://turf.ufl.edu/research_stauggro.shtml (Accessed 15 Aug. 2015)

Willis, J. B., S. D. Askew and B. W. Compton 2007. Cold influences overseeded perennial ryegrass control. Golf Course Management 75: 118-120.

Wright, N. 1962. Root weight and distribution of blue panicgrass, Panicum antidotale Retz., as affected by fertilizers, cutting height, and soil-moisture stress. Agronomy Journal 54: 200-202.

Yelverton, F. 2005. Spring transition: Going, going, gone. USGA Green Section Record 43: 22-23.