Evaluation of novel techniques to establish and transition overseeded grasses on bermudagrass sports turf

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ABSTRACT

Most professional turf in Virginia is comprised of bermudagrass (*Cynodon dactylon* L.) or (*Cynodon dactylon x C. transvaalensis* Burtt Davy) as a monoculture in summer and overseeded with perennial ryegrass (*Lolium perenne* L.) (PR) in winter, during bermudagrass dormancy. Two transitions are required in an overseeding program, fall establishment of PR and spring control of PR. During each transition, turf quality suffers as one grass dies or enters dormancy while another grass is promoted to fill voided areas. Field studies at various locations in Virginia were conducted to investigate methods of improving spring and fall transition. Bermudagrass green cover in August was influenced by duration of PR competition variably between three bermudagrass cultivars. For example, 'Midiron', 'Patriot', and 'Riviera' bermudagrass required 218, 139, and 327 cumulative growing degree days at base 18.3 C (GDD) to reach 95% cover. Bermudagrass biomass was also positively correlated with increasing duration of noncompetitive GDD. Total nonstructural carbohydrates were not correlated to duration of PR competition. Novel application methods were invented and tested at Virginia Tech. Drip, sponge, and strip application methods were used to create patterns of PR control using selective herbicides. Controlling a portion of PR with these methods maintained acceptable turfgrass quality throughout the spring transition and improved bermudagrass cover 12 to 20%, speeding transition by 20 or more days. Efforts to improve PR establishment in dense bermudagrass suggest chemicals that injure existing bermudagrass can improve PR establishment, but cause unacceptable turf discoloration. Mechanical methods to disrupt the bermudagrass canopy had less effect on PR establishment than chemical treatments.

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Chapter 1.

Introduction

Bermudagrass (*Cynodon dactylon* L.) and (*Cynodon dactylon x C. transvaalensis* Burtt Davy) are warm season turfgrasses that are commonly used in the transition zone and southern climates on golf courses, athletic fields, and home lawns (Patton et al. 2008). Warm-season turfgrasses are adapted to favorable growth during warm portions (26.7 ° to 35° C) of the growing season and utilize C_4 carbon fixation in photosynthesis (Turgeon 1996). Bermudagrass is used for athletic fields and high use areas because it tolerates wear and recuperates quickly after injury. Furthermore, heat tolerance, drought stress tolerance, and a broad pest resistance are other positive characteristics of bermudagrass that make it suitable for the transition zone and southern climates (Richardson et al. 2007; Schmidt and Shoulders 1980). However, bermudagrass enters a dormant period in the winter during which pigment loss in stems and leaves results in a light tan to whitish-tan appearance (Beard 1973). Discoloration usually occurs at the end of the growing season, when average temperatures drop below 10° C (Pessarakli 2008). As a result, bermudagrass is commonly overseeded with a cool-season grass to provide a green surface during the winter months.

Cool-season turfgrasses are adapted for favorable growth during cool portions (15.6 ° to 23.9° C) of the growing season and utilize C_3 carbon fixation in photosynthesis via the Calvin cycle (Turgeon 1996). Species best adapted for overseeding are those that rapidly establish, provide good density and color during winter, tolerate traffic, and exhibit declining spring competitiveness with underlying bermudagrass (Watschke and Schmidt 1992). Perennial ryegrass (*Lolium perenne* L.) is most commonly used for winter overseeding (Richardson et al. 2007; Schmidt and Shoulders 1980). Its dark green color, fine texture, and speed of establishment make it a desirable grass for overseeding (Morris 2004). Perennial ryegrass has been shown to perform better than annual ryegrass, rough bluegrass, or red fescue for winter overseeding (McWhirter and Ward 1970). Furthermore, perennial ryegrass tolerates a low mowing height which is desirable for golf greens and fairways (Ward et al. 1974).

Perennial ryegrass forms a dense canopy that shades underlying bermudagrass. Bermudagrass density declines over time if perennial ryegrass continues to compete with post-dormant bermudagrass into the summer. Plants generally compete for space, light, nutrients, carbon dioxide, and water. Overseeding is typically practiced on professionally managed turf that receives adequate water, nutrients, and carbon dioxide. Thus, light and space are the two factors most responsible for competitive displacement of bermudagrass by perennial ryegrass (Yelverton 2005). When bermudagrass receives less than 60% full sunlight the leaves become narrow and elongated, stems become thin and upright with elongated internodes, and rhizomes decline (Yelverton 2005). A study was conducted by Jiang et al. (2004) in Griffin, GA during the 2001 and 2002 growing seasons to determine the light tolerance of seashore paspalum and hybrid bermudagrass. The two cultivars of bermudagrass tested were ‘Tifsport’ and ‘Tifeagle’. Significant differences were seen in turf quality, density, color, canopy photosynthetic rates, leaf dry weight, canopy chlorophyll index, and canopy spectral reflectance. Turf quality of ‘Tifsport’ and ‘Tifeagle’ bermudagrass was reduced 9 to 22% when maintained at 70% of normal solar radiation. Canopy photosynthetic rate and normalized difference vegetative index also decreased significantly with decreasing solar radiation.

Removing overseeded perennial ryegrass from bermudagrass in the spring is frequently referred to as spring transition (Green et al. 2004). The difficulty in transitioning from perennial ryegrass to bermudagrass has been increased due to more recent development of heat tolerant perennial ryegrass varieties and variable weather conditions in spring and early summer. New varieties of perennial ryegrass provide a better playing surface for the winter months, but result in a more difficult spring transition (Horgan and Yelverton 2001). Successful spring transition depends on climate, perennial ryegrass seeding rate, perennial ryegrass and bermudagrass cultivar, and management practices. Increasing perennial ryegrass seeding rate increases fall establishment rates (Askew et al. 2007; Goddard et al. 2009; Mazur and Rice 1999), but has variable influence on perennial ryegrass control with chemical and cultural methods the following spring (Askew et al. 2007; Mazur and Rice 1999). The displacement of perennial ryegrass during spring transition was slowed by increasing fall perennial ryegrass seeding rate on golf putting greens and not effected by fall seeding rate on golf fairways (Askew et al. 2007; Kopec 2001; Mazur and Rice 1999). Askew et al. (2006) concluded that bermudagrass cultivar was the most influential factor affecting the success of spring transition. Aggressive cultivars of bermudagrass such as ‘Patriot’ transition more efficiently and will require a less aggressive approach to transitioning when compared to less aggressive cultivars such as ‘Midiron’ (Askew et al. 2006).

Competition for light between perennial ryegrass and bermudagrass results in injury to bermudagrass (Jiang et al. 2004). Therefore, perennial ryegrass must be removed during the spring to allow for healthy bermudagrass in the summer. Relying on perennial ryegrass to transition naturally typically is not a sound approach for spring transition due to varieties of perennial ryegrass that have better heat and drought tolerance (Horgan and Yelverton 2001). Horgan and Yelverton (2001) conducted experiments in 1995-1996 and 1996-1997 to evaluate cultural methods for removal of perennial ryegrass from overseeded bermudagrass. They hypothesized that various cultural treatments would promote bermudagrass growth while adversely affecting the perennial ryegrass. Treatments were biweekly vertical mowing, scalping, core cultivation, vertical mowing combined with scalping, and two application timings of NH_4NO_3. Results from this study indicate perennial ryegrass can not be controlled consistently using cultural treatments alone. While perennial ryegrass cover was reduced during the spring and early summer, ultimately it was not effectively controlled. Therefore, it can be determined that chemical removal of perennial ryegrass is needed for a successful spring transition in the transition zone. However, cultural treatments control perennial ryegrass better in extreme southern climates (Yelverton 2004).

Pronamide was the first herbicide used to control perennial ryegrass without harming bermudagrass during the 1970’s (Johnson 1976). Other chemicals that have been assessed for the control of perennial ryegrass are diclofop, dithiopyr, metribuzin, ethephon, mefluide, maleic hydrazide, oxadiazon, butralin, MSMA, methazole, benefin, oryzalin, glyphosate, paraquat, pendimethalin, chlorosulfuron, metsulfuron, rimsulfuron, foramsulfuron, flazasulfuron, and trifloxysulfuron (Askew et al. 2006; Barker et al. 2003; Johnson 1994; Johnson 1988; Johnson 1977; Johnson 1976; and Mazur 1988). Foramsulfuron accounts for most of the market share in the U.S transition market owing to effective perennial ryegrass control and bermudagrass safety (Prs. Comm. Larry Norton, Bayer Crop Science). Other commonly used transition-assisting herbicides include trifloxysulfuron sodium, rimsulfuron, and metsulfuron (Prs. Comm.. Patrick Connelly, Landscape Supply Inc.). These herbicides, including foramsulfuron, are employed more often to control perennial ryegrass during spring transition than any other products. All are members of the sulfonylurea herbicide family and inhibit the enzyme acetolactate synthase which produces branched chain amino acids isoleucine, leucine, and valine (Zabalza et al. 2007). Plant death eventually occurs due to the inhibition of these amino acids, but the sequence of phytotoxic processes is unclear (Senseman 2007).

In the transition zone, perennial ryegrass must be controlled with chemicals to prevent injury to desirable bermudagrass as a result of perennial ryegrass competition. However, questions still remain about when chemical treatments should be applied. Bermudagrass most efficiently photosynthesizes when temperatures and light intensities are high. Therefore, summer is when bermudagrass is most productive at producing carbohydrate reserves (Howard 2006). In highly maintained turf such as golf courses and athletic fields, light is the limited resource for bermudagrass when perennial ryegrass competition exists (Yelverton 2005). Thus, it is apparent that perennial ryegrass should be eliminated (preventing competition for light) prior to summer when bermudagrass photosynthesizes most efficiently and light is of great importance. It has been stated that in most climates, bermudagrass needs about 100 days of competition free growth (Yelverton 2004 and 2005). While this is a viable claim, it has not been tested scientifically. Hutto et al. (2008) used soil temperature as an indicator for perennial ryegrass control. Six sulfonylurea herbicides were applied at three different soil temperatures; waiting until soil temperatures reached 26 C improved perennial ryegrass control and overall turf quality.

The amount of carbohydrates that bermudagrass has in reserve is considered to be one of the major factors for winter survival (Zhang et al. 2006). Lateral stems of bermudagrass supply most of the carbohydrates required for new growth until energy is available through photosynthesis in the new shoots (Sifers and Beard 2001). It is unknown how perennial ryegrass competition affects accumulation of total nonstructural carbohydrates (TNC). Zhang et al. (2006) showed that TNC increased 85% in ‘Riviera’ bermudagrass due to cold acclimation. However, ‘Princess-77’ had no increase in TNC over the same time period. ‘Riviera’ is a variety of bermudagrass that is well known for its cold tolerance and ‘Princess-77’ is known for being sensitive to the cold (Zhang et al. 2006).

In colder climates where bermudagrass is grown, spring dead spot disease and cold injury lead to decline in bermudagrass population density during the winter (Butler and Tredway 2006). When overseeded perennial ryegrass is controlled, bermudagrass must fill voids in the turf canopy, often during periods of suboptimal growing conditions (Howard 2006). Voids in the turf canopy are unacceptable from the standpoint of visual appeal and playability and turf density must be improved as rapidly as possible. As density of surviving bermudagrass decreases, the time needed to achieve complete turf density after perennial ryegrass control increases. Turf managers are often pressured to allow perennial ryegrass to persist longer into the season to preserve aesthetics and use of turf, further exacerbating the decline of bermudagrass (Howard 2006). Choosing which herbicide to use as a transition aid can affect the quality of underlying bermudagrass.

Fast acting herbicides such as foramsulfuron and trifloxysulfuron sodium should be applied when bermudagrass is actively growing allowing bare areas to fill in and improve underlying bermudagrass quality (Yelverton 2004). Attempts to slow the activity of herbicides through low-rate sequential applications often either kill the perennial ryegrass with the first treatment or cause no more than slight injury following each successive treatment (Askew et al. 2003). Non-chemical cultural practices often transition perennial ryegrass slowly in the south but do not control perennial ryegrass in the north (Horgan and Yelverton 2001). Allowing perennial ryegrass to persist into the summer improves turf aesthetics and playability but causes bermudagrass density to decline and reduces time allowed for bermudagrass to recover from perennial ryegrass competition. The challenges involved with overseeding bermudagrass have caused some to stop overseeding all together and resort to painting dormant bermudagrass green (Liu et al. 2007). However, paint showed tendencies of turning a somewhat blue when not applied correctly, and can result in a streaked appearance (Liu et al. 2007).

A potential solution that allows for slow perennial ryegrass transition, improved turf quality, and improved long-term bermudagrass density was recently invented at Virginia Tech. “Partial control” is a new application method that uses selective herbicides applied to turf in patterns rather than as a uniform spray (Compton et al. 2007). Inspiration for the idea came from research conducted at Kansas State University (Fry et al. 2007). A strip seeder was developed to aid in the establishment of slow-germinating zoysiagrass and Kentucky bluegrass by tilling a narrow strip along the seeded row to reduce competition from existing turf (Zuk and Fry 2005).

Overseeded bermudagrass has an additional transition period separate from the aforementioned spring transition. It is called the fall transition and deals with the establishment of perennial ryegrass or other cool-season grasses into bermudagrass as it enters dormancy. Askew et al. (2006) found that bermudagrass cultivar had inverse effects on transition success in spring versus fall. Dense, aggressive cultivars were difficult to transition in fall (i.e. establish perennial ryegrass) and easy to transition in spring (i.e. control perennial ryegrass). Establishing perennial ryegrass in the fall is often more important to athletic field managers because many athletic events are hosted in the fall and winter. Furthermore, athletic fields are subjected to more wear stress than other types of turf and require aggressive, dense turfgrasses to withstand heavy traffic and recover quickly. These factors combine to make fall transition a serious problem for athletic field managers. Establishment of perennial ryegrass in the fall is of paramount importance and dense bermudagrass cultivars negatively impact perennial ryegrass establishment.

‘Patriot’ bermudagrass produces a dense dark green surface and has cold hardiness (Taliaferro et al. 2006). Furthermore, relative to other cultivars of bermudagrass, it displays a vigorous growth habit (Taliaferro et al. 2006). These characteristics make ‘Patriot’ bermudagrass a popular turfgrass species for athletic field use in the transition zone. ‘Patriot’ bermudagrass is used on professional, college, high school, and parks and recreation fields. ‘Patriot’ bermudagrass’ dense surface and vigorous growth habit presents the same challenge of establishing a winter overseeding of cool-season turfgrass. Seedbed preparation is essential for overseeding establishment and must occur at the right time or stand failures may result at any seeding rate (Mazur and

Rice, 1999; Gill et al., 1967; Ward et al., 1974). Previous research indicates removing thatch and aeration combined with topdressing performed 4 to 6 weeks prior to overseeding were the most effective when establishing winter overseeding (Mazur and Rice, 1999; Schmidt, 1970; Ward et al., 1974). However, vertical mowing just prior to overseeding removes thatch and reduces competition from bermudagrass allowing for improved seedling stands (Mazur and Rice, 1999; Duble, 1978; Gill et al., 1967). Furthermore, it has been stated that optimal soil temperatures for perennial ryegrass establishment are between 22 and 26 C (Mazur and Rice, 1999; Batten et al., 1980; Beard and Menn, 1988). Most research that has evaluated fall transition was conducted on golf putting greens. Creeping bentgrass (*Agrostis stolonifera* L.), rough stalk bluegrass (*Poa trivialis* L.), and perennial ryegrass establishment were promoted by vertical mowing, topdressing, and applying trinexapac ethyl (Sifers and Beard 2001). In a separate study, Mazur and Rice (1999) found perennial ryegrass establishment increased with topdressing and increasing perennial ryegrass seeding rate.

RESEARCH OBJECTIVES

1. Measure how duration of perennial ryegrass competition influences bermudagrass cover, biomass accumulation, and total nonstructural carbohydrate accumulation.
2. Determine if partial kill of overseeded perennial ryegrass in May will increase bermudagrass cover when remaining ryegrass is killed in June or July.
3. Evaluate three methods of herbicide application in turfgrass to give partial control of overseeded perennial ryegrass.
4. Determine if cultural and chemical treatments prior to overseeding ‘Patriot’ bermudagrass improve perennial ryegrass establishment

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Chapter 2.

Effects of Perennial Ryegrass Competition on Bermudagrass Cover, Biomass Accumulation and Total Nonstructural Carbohydrate Accumulation

INTRODUCTION

Bermudagrass (*Cynodon dactylon* L.) and (*Cynodon dactylon x C. transvaalensis* Burtt Davy) are warm season turfgrasses that are commonly used in the transition zone and southern climates on golf courses, athletic fields, and home lawns (Patton et al. 2008). Bermudagrass is used for athletic fields and high use areas because it tolerates wear and recuperates quickly after injury (Richardson et al. 2007; Schmidt and Shoulders 1980). However, bermudagrass enters a dormant period in the winter during which pigment loss in stems and leaves results in a light tan to a whitish-tan appearance (Beard 1973). As a result, bermudagrass is commonly overseeded with a cool-season grass to provide a green surface during the winter months. Perennial ryegrass (*Lolium perenne* L.) is most commonly used for winter overseeding (Richardson et al. 2007; Schmidt and Shoulders 1980). Its dark green color, fine texture, and speed of establishment make it a desirable grass for overseeding (Morris 2004). Furthermore, perennial ryegrass tolerates mowing heights conducive for golf and sports turf uses (Ward et al. 1974).

Perennial ryegrass forms a dense canopy that shades underlying bermudagrass. Bermudagrass density declines over time if perennial ryegrass continues to compete with post-dormant bermudagrass into the summer. Plants generally compete for space, light, nutrients, carbon dioxide, and water. Overseeding is typically practiced on professionally managed turf that receives adequate water, nutrients, and carbon dioxide. Thus, light and space are the two factors most responsible for competitive displacement of bermudagrass by perennial ryegrass (Yelverton 2005). Removing overseeded perennial ryegrass from bermudagrass in the spring is frequently referred to as spring transition (Green et al. 2004). The difficulty in transitioning from perennial ryegrass to bermudagrass has been increased due to heat tolerant perennial ryegrass varieties and variable weather conditions in spring and early summer. New varieties of perennial ryegrass provide a better playing surface for the winter months, but result in a more difficult spring transition (Horgan and Yelverton 2001). Successful spring transition depends on climate, perennial ryegrass seeding rate, perennial ryegrass and bermudagrass cultivar, and management practices. Askew et al. 2006 concluded that bermudagrass cultivar was the most influential factor affecting the success of spring transition. Aggressive cultivars of bermudagrass such as 'Patriot' transition more efficiently and will require a less aggressive approach to transitioning when compared to less aggressive cultivars such as 'Midiron' (Askew et al. 2006).

Competition for light between perennial ryegrass and bermudagrass results in injury to bermudagrass (Jiang et al. 2004). Therefore, perennial ryegrass must be removed during the spring to allow for healthy bermudagrass in the summer. Relying on perennial ryegrass to transition naturally typically is not a sound approach for spring transition due to varieties of perennial ryegrass that have better heat and drought tolerance (Horgan and Yelverton 2001). Horgan and Yelverton (2001) conducted experiments in 1995-1996 and 1996-1997 to evaluate cultural methods for removal of perennial ryegrass from overseeded bermudagrass. They hypothesized that various cultural treatments would promote bermudagrass growth while adversely affecting the perennial ryegrass. Treatments were biweekly vertical mowing, scalping, core cultivation, vertical mowing combined with scalping, and two application timings of NH_4NO_3. Results from this study indicate perennial ryegrass can not be controlled consistently using cultural treatments alone. While perennial ryegrass cover was reduced during the spring and early summer, ultimately it was not effectively controlled. Therefore, it can be determined that chemical removal of perennial ryegrass is needed for a successful spring transition in the transition zone. Cultural treatments will likely control perennial ryegrass better in extreme southern climates (Yelverton 2004).

In the transition zone, perennial ryegrass clearly must be controlled with chemicals to prevent injury to desirable bermudagrass. However, questions still remain about when chemical treatments should be applied. Bermudagrass most efficiently photosynthesizes when temperatures and light intensities are high. Therefore, summer is when bermudagrass is most productive at producing carbohydrate reserves (Howard 2006). In highly maintained turf such as golf courses and athletic fields, light is the limited resource for bermudagrass when perennial ryegrass competition exists (Yelverton 2005). Thus, it is apparent that perennial ryegrass should be eliminated (removing competition for light) prior to summer when bermudagrass photosynthesizes most efficiently and light is of great importance. It has been stated that in most climates, bermudagrass needs about 100 days of competition free growth (Yelverton 2004 and 2005). While this is a viable claim, it has not been tested scientifically. Therefore trials were established in Blacksburg, VA to evaluate how the duration of perennial ryegrass competition influences bermudagrass cover, biomass accumulation, and total nonstructural carbohydrate accumulation.

MATERIALS AND METHODS

Field experiments were conducted at the Turfgrass Research Center (TRC) on 'Midiron' bermudagrass (*Cynodon dactylon x C. transvaalensis* Burtt Davy) and the Glade Road Research Center (GRRC) on 'Patriot' bermudagrass (*Cynodon dactylon x C. transvaalensis* Burtt Davy) in Blacksburg, VA, in 2006 and at the Virginia Tech Golf Course (VTGC) on 'Riviera' bermudagrass (*Cynodon dactylon* (L.) Pers. var. dactylon) in Blacksburg, VA, in 2007. Bermudagrass was overseeded with perennial ryegrass at 275 kg ha^{-1} pure live seed in late September of 2005 for 2006 studies and late September 2006 for the 2007 studies. The following spring, starting April 6, a new plot was treated with foramsulfuron at 29 g ai ha^{-1} to remove perennial ryegrass every week for twenty four weeks. Foramsulfuron was applied with a CO_2-pressurized backpack sprayer delivering 280 L ha^{-1} at 276 kPa with XR8004 nozzles. A randomized complete block design was used and treatments were replicated three times. Plots were 0.9 by 1.2 m in all experiments. Plots were maintained at a height 1.5 cm, watered as needed to maintain active growth, and fertilized monthly at 50 kg N ha^{-1}.

Bermudagrass cover, bermudagrass biomass accumulation, and total nonstructural carbohydrates (TNC) were evaluated in these trials. Bermudagrass cover ratings were recorded as visually estimated percentages with 0% being no cover and 100% being complete cover. Bermudagrass biomass accumulation was determined by removing a plug from each plot using a standard 10.7 cm diameter cup cutter. Above-ground tissue was removed from each plug, washed, and dried at 75 C for 48 hours, then weighed. Biomass data were collected on October 17 for both trials in 2006 and on October 23 in

2007. TNC was determined using Hendrix's method of rapid extraction and analysis of nonstructural carbohydrates in plant tissues (Hendrix 1993). Stolons were collected for TNC analysis the same day that biomass accumulation data were collected in 2006 and 2007. In 2006, 3 samples were collected from every plot. In 2007, 3 samples were collected from every other plot. Samples were taken with a standard 10.7 cm diameter cup cutter. Above-ground tissue was removed from each plug, washed, and dried at 75 C for 48 hours. Dried tissue was then ground and used for TNC analysis.

Data were subjected to a combined analysis of variance with sums of squares partitioned to test for trial, treatment, and trial by treatment effects. The mean square of treatment effects was tested using the mean square of the interaction with trial, which was considered random (McIntosh 1983). Treatments were applied every 7 days but heat units were observed to vary greatly between study initiation and completion (Figure 1). Therefore, treatments were expressed as cumulative heat units or growing degree days with a base of 18.3 C for subsequent regressions of significant effects. Once significant treatment effects were confirmed, ANOVA was conducted with sums of squares partitioned to reflect linear, quadratic, and higher order effects so that appropriate regressions could be performed. Fitted polynomial regressions were then produced to explain relationships between heat unit accumulation and measured responses.

RESULTS AND DISCUSSION

Bermudagrass cover. A significant trial by treatment interaction was observed for bermudagrass cover at all rating dates ($p<0.0001$). Consequently, regressions of bermudagrass cover are presented separately by trial. The significant trial by treatment interaction likely occurred due to differences between heat unit accumulation between years and differences between competitiveness of the bermudagrass cultivars. Trial sites and associated bermudagrass cultivars were randomly chosen. Thus, no attempt has been made to statistically compare between bermudagrass cultivars. Analysis of variance indicates that both linear and quadratic effects were significant ($p<0.0001$) and correlation coefficients for quadratic regressions were higher than those of linear regressions (data not shown). Quadratic regressions were fitted to visually estimate bermudagrass cover data in all cases.

Intercepts of each line indicate 'Midiron' and 'Patriot' bermudagrass attained 61 and 83% cover respectively, under continuous competition with perennial ryegrass when assessed on August 16, 2006 (Figures 2A, 2B). When assessed on August 29, 2006, the same cultivars had 70 and 83% cover, respectively, under continuous competition with perennial ryegrass (Figures 2C, 2D). The number of competition free heat units required to reach 95% bermudagrass cover on August 29, 2006 was 218 for 'Midiron' and 139 for 'Patriot'. These heat unit values represent plots treated to control perennial ryegrass on June 22, 2006 and July 6, 2006 for 'Midiron' and 'Patriot' bermudagrass respectively.

In 2007, 480 growing degree days were accumulated, representing 1.6 times that of the 2006 season (Figure 1). 'Riviera' bermudagrass under continuous competition with perennial ryegrass attained 37, 32, 47, and 59 % cover on July 6, August 6, August 24, and September 27, 2007, respectively (Figures 3A, 3B, 3C, and 3D). 'Riviera' bermudagrass reached 95% cover after accumulating 327 and 360 heat units when assessed on August 24 and September 27, 2007, respectively. The requirement for more degree day accumulation by 'Riviera' in 2007 indicates either perennial ryegrass was more competitive than in 2006 or that ‘Riviera’ is less able to compete with perennial ryegrass. Given differences between years in total heat unit accumulation it may be assumed that differences in heat unit accumulation rates may explain differences in bermudagrass cover between the three trials. However, close examination of Figure 1 reveals that heat unit accumulation was equivalent between years until Julian day 240 or August 26. By comparing Figures 2B, 2D, and 3C, we observe that the heat unit accumulation needed to reach 95% bermudagrass cover in late August is 218, 139, and 327 for ‘Midiron’, ‘Patriot’, and ‘Riviera’ bermudagrass, respectively. Although cultivars cannot be compared statistically in this study, differences in bermudagrass cover appear to be cultivar related and warrant further investigation. The dates at which perennial ryegrass must be treated to reach 95% bermudagrass cover by August 24 to 29 were June 22, July 6, and April 20 for ‘Midrion’, ‘Patriot’, and ‘Riviera’ bermudagrass, respectively.

Treatment effects on bermudagrass biomass accumulation. The trial by treatment interaction was not significant (P = 0.37) for bermudagrass biomass assessed in October. The treatment main effect (P = 0.0002) and trial (P <0.0001) main effects were both significant. Each trial had a different cultivar of bermudagrass and these cultivars tended to exhibit the same relationship to duration of competition-free growth. This relationship is expressed as bermudagrass-biomass per m^2 as influenced by cumulative growing degree days at base 18.3 C (Figure 4). The data fit a quadratic polynomial with a correlation coefficient of 0.82. When averaged over trials, bermudagrass biomass was 792 g when under constant competition with perennial ryegrass and remained static for the first 100 heat units and then tended to increase, adding approximately 1 g biomass per heat unit for the next 200 heat units in a curvilinear fashion. Effects of competition-free heat units on bermudagrass biomass are similar to trends in bermudagrass cover (Figures 2 and 3). However, differences were observed between trials for bermudagrass cover response to competition and not for biomass accumulation response to competition. Thus, bermudagrass visual cover and biomass are not completely correlated. It is possible to accumulate more biomass after 100% visual cover has been reached. The trial main effect explained more error than any other term in the analysis of variance with an F-value of 1157. This effect is likely due to differences in bermudagrass cultivars at each site. Although the cultivars exhibited similar responses of biomass production to cumulative growing degree days, the magnitude of biomass production by each cultivar varied. When averaged over treatments, biomass of 'Midiron', 'Patriot', and 'Riviera' was 495, 1081, and 1172 g/m^2, respectively, with 'Patriot' and 'Riviera' statistically equivalent and greater than 'Midiron' (data not shown).

Bermudagrass total nonstructural carbohydrates accumulation. Treatment effects on bermudagrass total nonstructural carbohydrates accumulation were significant ($p = 0.005$). However, correlation between cumulative competition free heat units and total nonstructural carbohydrates accumulation was < 0.18. Due to high cost associated with this analysis a smaller than desired sampling size was used and it could have been too small to fully represent the entire plot. In addition, when collecting samples, it is difficult to select only dead tissue, thus only green stolons were chosen, introducing bias in the sampling method. Furthermore, at the time samples were collected for analysis, some plots had less bermudagrass cover than others. In plots with less bermudagrass cover, it is possible that lack of competition from other bermudagrass plants allowed for increased accumulation of total nonstructural carbohydrates. Lastly, perennial ryegrass competition may not effect total nonstructural carbohydrates accumulation in bermudagrass.

CONCLUSIONS

Our data suggest that the time of perennial ryegrass removal for optimum bermudagrass cover is a function of noncompetitive days of growth and the number of cumulative noncompetitive growing degree days. When large quantities of cumulative noncompetitive growing degree days are accumulated in a small number of days, a marginal number of non competitive growth days may still be necessary for acceptable bermudagrass cover. If noncompetitive days of growth are granted in a period of time in which cumulative noncompetitive growing degree days are being accumulated slowly, numerous days of noncompetitive growth may be necessary to reach acceptable bermudagrass cover. In addition, we determined that bermudagrass variety impacts the days of noncompetitive growth and cumulative noncompetitive growing degree days needed to obtain acceptable bermudagrass cover. More aggressively growing varieties of bermudagrass such as Patriot may be able to outcompete perennial ryegrass and need less days of non competitive growth and cumulative noncompetitive growing degree days. Furthermore, it is possible that the number of cumulative noncompetitive growing degree days has more impact on bermudagrass biomass accumulation than cover. While increased cumulative noncompetitive growing degree days does not necessarily lead to more bermudagrass cover, it appears that it leads to more biomass accumulation, depending on variety. Lastly, treatments did not have a significant impact on TNC accumulation.

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Figure 1. Heat units as total growing degree days (GDD) with a base 18.3 C accumulated in 2006 and 2007.

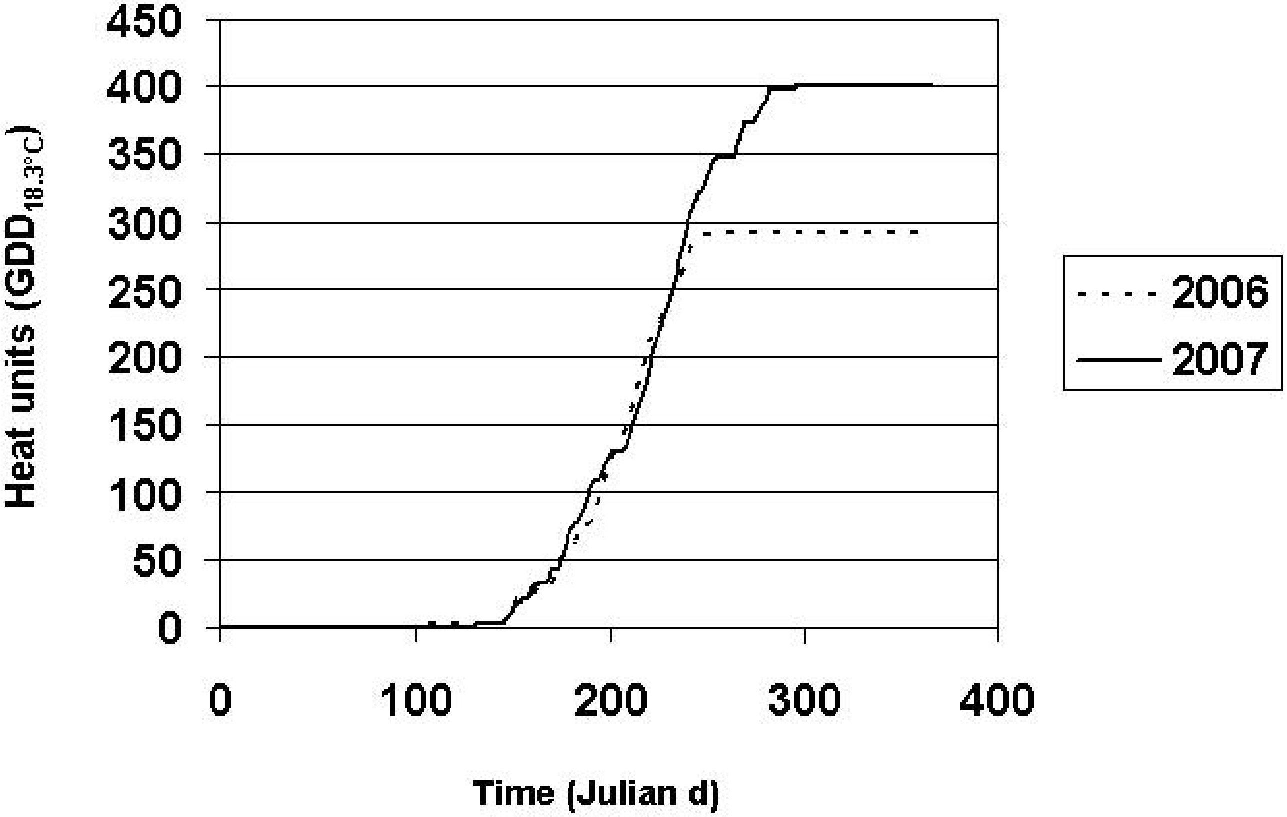
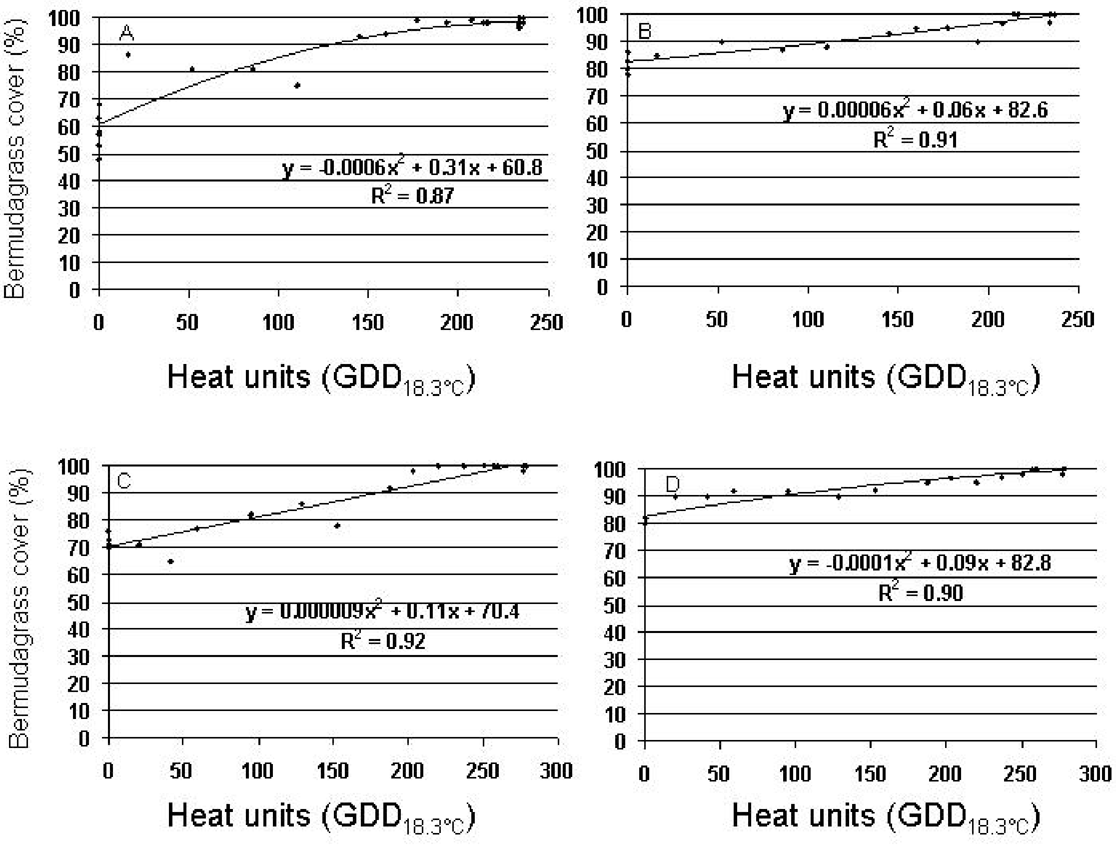
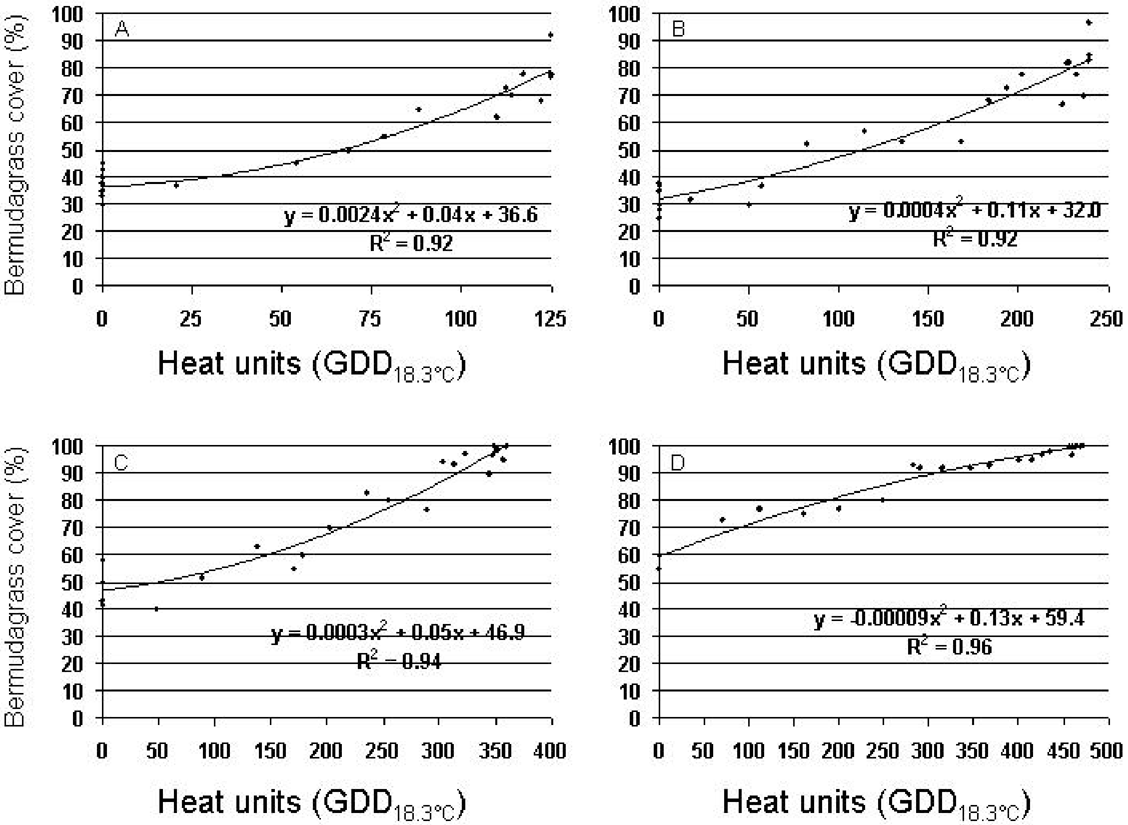


Figure 2. Midiron and Patriot bermudagrass cover in response to cumulative noncompetitive growing degree days in 2006.



A = Midiron bermudagrass cover estimated on August 16, 2006
B = Patriot bermudagrass cover estimated on August 16, 2006
C = Midiron bermudagrass cover estimated on August 29, 2006
D = Patriot bermudagrass cover estimated on August 29, 2006

Figure 3. Riviera bermudagrass cover in response to cumulative noncompetitive growing degree days in 2007.



A = Riviera bermudagrass cover estimated on July 6, 2007
B = Riviera bermudagrass cover estimated on August 6, 2007
C = Riviera bermudagrass cover estimated on August 24, 2007
D = Riviera bermudagrass cover estimated on September 27, 2007

Figure 4. Midiron, Patriot and Riviera bermudagrass combined average biomass accumulation in response to cumulative noncompetitive growing degree days.

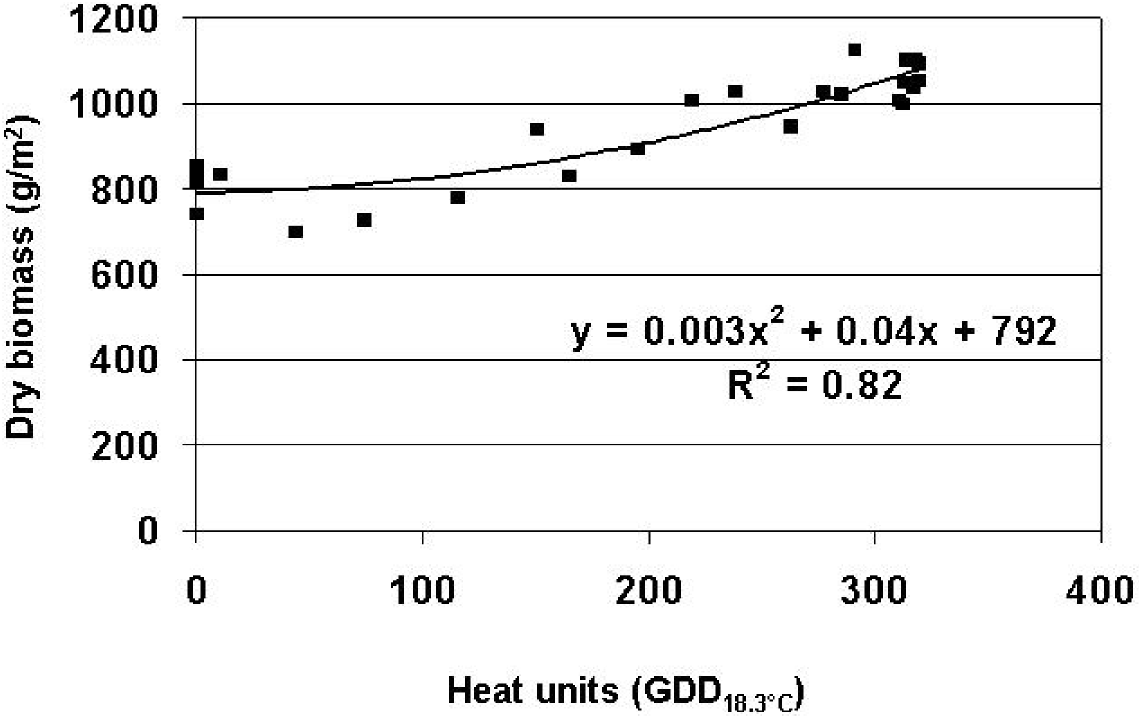
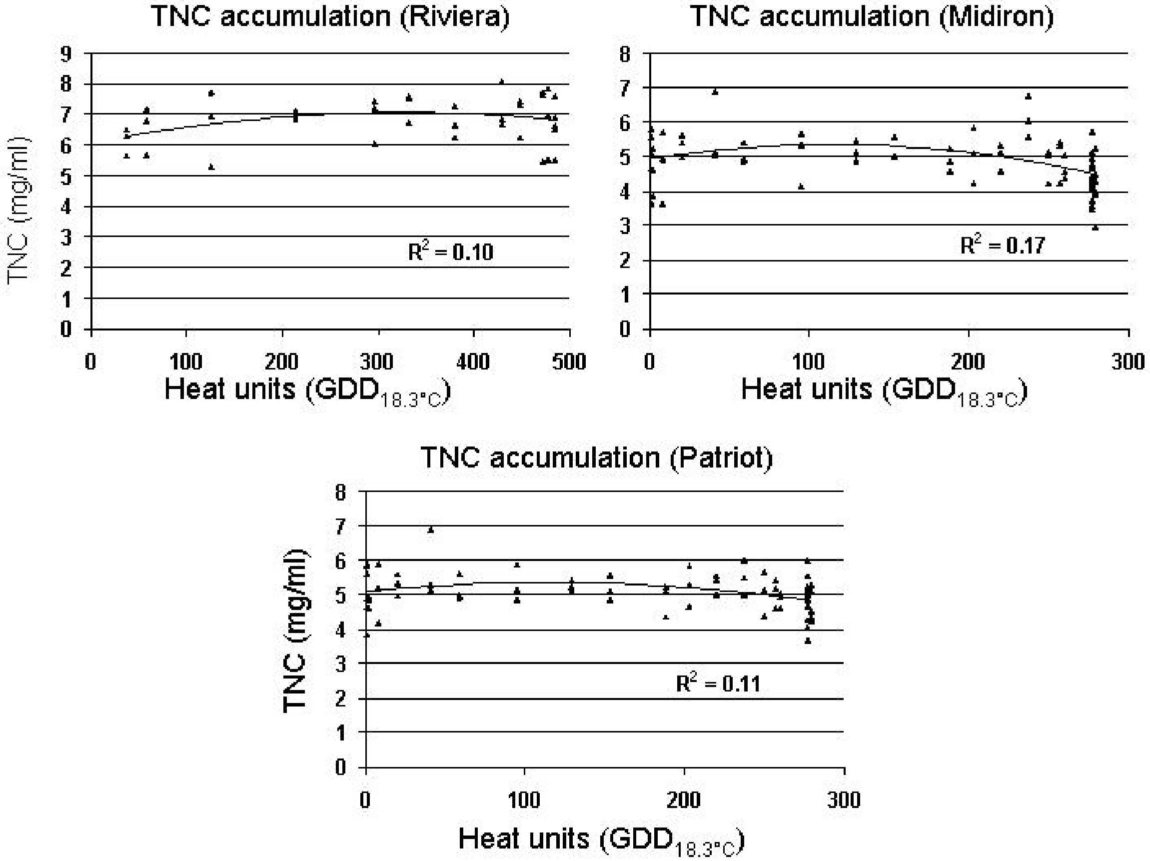


Figure 5. TNC accumulation in Riviera, Midiron, and Patriot bermudagrasses in response to cumulative noncompetitive growing degree days.



Chapter 3.

Improving Quality of Bermudagrass Post-Dormancy Transition Using Partial Control Techniques

INTRODUCTION

Bermudagrass (*Cynodon dactylon* L.) and (*Cynodon dactylon x C. transvaalensis* Burtt Davy) are warm season turfgrasses that are commonly used in the transition zone and southern climates on golf courses, athletic fields, and home lawns (Patton et al. 2008). Bermudagrass is used for athletic fields and high use areas because it tolerates wear and recuperates quickly after injury (Richardson et al. 2007; Schmidt and Shoulders 1980). However, bermudagrass enters a dormant period in the winter during which pigment loss in stems and leaves results in a light tan to a whitish-tan appearance (Beard 1973). As a result, bermudagrass is commonly overseeded with a cool-season grass to provide a green surface during the winter months. Perennial ryegrass (*Lolium perenne* L.) is most commonly used for winter overseeding (Richardson et al. 2007; Schmidt and Shoulders 1980). Its dark green color, fine texture, and speed of establishment make it a desirable grass for overseeding (Morris 2004). Furthermore, perennial ryegrass tolerates a low mowing height which is desirable for greens and fairways (Ward et al. 1974).

In colder climates where bermudagrass is grown, spring dead spot disease and cold injury lead to decline in bermudagrass population density during the winter (Butler and Tredway 2006). . When overseeded perennial ryegrass is controlled, bermudagrass must fill voids in the turf canopy, often during periods of suboptimal growing conditions (Howard 2006). Voids in the turf canopy are unacceptable from the standpoint of visual appeal and playability. Turf density must be improved as rapidly as possible. Choosing which herbicide to use as a transition aid can affect the quality of underlying bermudagrass. Fast acting herbicides such as foramsulfuron and trifloxysulfuron sodium should be applied when bermudagrass is actively growing allowing bare areas to fill in and improve underlying bermudagrass quality (Yelverton 2004). Attempts to slow the activity of herbicides through low-rate sequential applications often either kill the perennial ryegrass with the first treatment or cause no more than slight injury following each successive treatment (Askew et al. 2003). Cultural practices often transition perennial ryegrass slowly in the south but do not control perennial ryegrass in the north (Horgan and Yelverton 2001).

A potential solution that allows for slow perennial ryegrass transition, improved turf quality, and improved bermudagrass density was recently invented at Virginia Tech using “Partial control” techniques. “Partial control” is a new application method that uses selective herbicides applied to turf in patterns rather than a uniform spray (Compton et al. 2007). Inspiration for the idea came from research conducted by Dr. Jack Fry at Kansas State University (Fry et al. 2007; Zuk and Fry 2005). A strip seeder was developed to aid in the establishment of slow-germinating zoysiagrass and Kentucky bluegrass by tilling a narrow strip along the seeded row to reduce competition from existing turf (Fry et al. 2007; Zuk and Fry 2005). Trials were established to investigate partial control as a means to increase bermudagrass cover and improve aesthetics during spring transition.

MATERIALS AND METHODS

Field experiments arranged in a randomized complete block design were conducted at Farmington Country Club in Charlottesville, VA, in 2006 on ‘Vamont’ bermudagrass (*Cynodon dactylon)* and at the Virginia Tech Golf Course (VTGC) in Blacksburg, VA, in 2007 on ‘Riviera’ bermudagrass (*Cynodon dactylon* (L.) Pers. var. dactylon ‘Riviera’). Each year, bermudagrass was overseeded with perennial ryegrass in the fall at 489 kg ha^{-1}. Three partial control techniques were evaluated in this study including drip, sponge, and strip. Custom equipment was built to facilitate sponge, drip, and strip application methods. The sponge applicator consisted of 5 circular discs linked together with four 5 kg weights and contained 32, 20-ml vials each plugged with 3 cm diameter by 4 cm thick cylindrical pieces of sponge. The vials were evenly spaced around the circular discs such that when the apparatus was rolled across the turf, liquid was dispensed by contact with wet sponge, creating a pattern of evenly spaced dots every 10 cm.

The drip applicator consisted of a wooden frame holding a trigger valve linked to two stainless steel distributor blocks that supplied fluid to a 1-m boom via independent lengths of 5 mm diameter Tygon tubing. The distributors had valves to regulate flow rate to each length of tubing and tubes were spaced 10 cm apart. Furthermore, 34.5 kPa of pressure was supplied from a CO_2 canister and the flow rate of each tube was adjusted with the distributor to achieve an even drip rate. The drip rate and walking speed were calibrated to achieve approximately 1 drip every 10 cm.

Strip application was achieved by constructing two templates 2 m by 3 m with strips of plywood to shield spray in a strip fashion. Openings in the template allowed overspray to contact turf. These openings were 2.5 cm wide and spaced evenly to achieve the desired amount of treated turf. Two templates were made for 20 and 30% treatments.

The drip boom and sponge applicator were calibrated to kill 6 cm diameter circles on 10 cm centers. Calibrations were unique for each device and resulted in a solution delivery rate of 1,635 L/ha for drip, 1,402 L/ha for sponge, and 280 L/ha for strips.

A factorial treatment arrangement evaluated four scenarios of each method: foramsulfuron at 30% coverage applied early, trifloxysulfuron at 30% coverage applied early, foramsulfuron at 30% coverage applied early and late, and foramsulfuron at 20% coverage applied early and late. A comparison treatment that did not receive partial control treatment was also included. Partial control treatment dates were April 26, 2006 (early) and May 18, 2006 (late) at location 1 and May 9, 2007 (early) and May 30 (late), 2007 at location 2. A broadcast application of foramsulfuron at 29 g ai/ha was applied on July 7 each year to remove remaining perennial ryegrass from plots.

Visual ratings included percent bermudagrass cover and turfgrass quality. Percent bermudagrass cover was rated on a scale of 0 to 100%, where 0% is no bermudagrass cover and 100% is complete bermudagrass cover. Turfgrass quality was rated from 2 viewing directions, 90° and 0°, on a 1 to 9 scale, where 1 is poor and 9 is excellent and less than 6 indicates unacceptable turf. When viewed at 90° the viewer is looking down the plot or parallel to the axis of spray and when viewing at 0° the viewer is looking across the plot or perpendicular to the axis of spray.

Prior to analysis, data were transformed to the arcsine of the square root or the log compared to normal data for effects on variance homogeneity. If transformed data were used in analysis of variance, nontransformed means are presented for clarity. Data were subjected to analysis of variance with sums of squares partitioned to reflect trial effects and the factorial treatment structure. Trial was considered random and mean squares were tested as appropriate for a combined analysis of variance with random trials (McIntosh 1983). Appropriate means were separated with Fisher's protected LSD test at $p = 0.05$. Where possible, trends over time were explained with polynomial regressions in addition to mean separation.

RESULTS AND DISCUSSION

Application technique effects on turfgrass quality. The trial by application technique interaction was significant for turf quality from both viewing angles ($p < 0.0001$). In 2006 at Farmington Country Club in Charlottesville, VA, regardless of viewing angle, strip treatment significantly reduced turf quality at 22 DAT and 50 DAT (Figure 1). Drip and sponge application techniques maintained quality greater than 7 throughout the transition period. All partial control techniques significantly improved quality when compared to nontreated at 86 DAT (Figure 1).

In 2007 at the Virginia Tech Golf Course in Blacksburg, VA, the same trends were evident with respect to reduced quality by strip application early in the season. At 63 DAT all application techniques significantly improved turfgrass quality when compared to the nontreated check (Figure 1). Partially controlling perennial ryegrass seemed to eliminate interspecific competition and stimulate bermudagrass growth. When remaining perennial ryegrass was killed on July 7, quality in nontreated plots suffered.

The result was a higher turfgrass quality in plots that had been treated using different application techniques. After the blanket application of foramsulfuron, all application techniques generally improved quality when compared to the nontreated (Figure 1). Strip treatment significantly reduced quality longer than other application techniques because the strip pattern was evident when looking down the plots, thus quality was reduced. Significant bermudagrass cover must be present in the strips in order to improve quality.

Similar work by Fry et al. (2007), evaluated the effects of disturbing a percentage of a perennial ryegrass canopy to establish seeded bermudagrass on turfgrass quality. On July 2, 2002, three methods were used to disturb the perennial ryegrass canopy. First, glyphosate was applied to the entire plot and disturbed 100% of the perennial ryegrass canopy. Second, a strip seeder was used that disturbed 11% of the perennial ryegrass canopy. Lastly, a strip seeder was used followed by an additional 7 cm wide band of glyphosate applied over the rows, which disturbed a total of 22% of the perennial ryegrass canopy. Glyphosate applied to the entire perennial ryegrass canopy reduced quality extensively. Furthermore, using the strip seeder and the strip seeder followed by a 7 cm wide band of glyphosate applied over the rows significantly reduced quality, but maintained significantly better quality than glyphosate applied to the entire perennial ryegrass canopy. Similar work by Mittlesteadt et al. (2009) evaluated methods used to convert cool-season turf to sprigged Patriot bermudagrass (*Cynodon dactylon* L. Pers. X *C. transvaalensis* Burtt-Davy). Among the methods evaluated was killing strips in cool-season turfgrass prior to sprigging. Quality was sacrificed up to 55 days after sprigging (DAS). However, at 80 DAS quality was significantly better than observed in nontreated. When transitioning from one species to another, partial control techniques will initially result in a reduction in quality. However, if this reduction in quality can be tolerated for a limited time, the techniques will result in higher quality over time by increasing desirable turf cover.

Application techniques effect on bermudagrass cover. Only the main effect of application technique was significant for bermudagrass cover ($p<0.0001$). At 20 days after the first partial control treatment (DAPT), regression indicates all application techniques had increased bermudagrass cover from 19% in nontreated plots to over 30% in partial control treated plots (Figure 2). At 63 DAPT, the time at which the blanket treatment of foramsulfuron was applied, nontreated turf had 40% bermudagrass cover and all partial control treatments significantly increased bermudagrass cover 12 to 20%. The effect of herbicide and number of partial control treatments was not significant. Differences often occurred between the targeted pattern of treated perennial ryegrass and the actual amount of perennial ryegrass that died in the plots, especially with strip application. Strip application typically killed more perennial ryegrass than intended as the template openings were designed for the desired amount of perennial ryegrass control but foramsulfuron and trifloxysulfuron sodium are both systemic, leaving strips of perennial ryegrass control wider than intended. This increased percent perennial ryegrass control probably contributed to the significantly higher bermudagrass cover in strip plots 63 DAPT (Figure 2) and significantly lower turf quality in strip plots at earlier rating dates (Figure 1). The 12 to 15% increase in bermudagrass cover 63 DAPT by drip and sponge treatments is encouraging as quality of these plots remained between 7 and 8 for the first 50 DAPT (Figure 1). Bermudagrass cover was improved 15 to 20% over nontreated plots 79 DAPT (Figure 2). At 107 and 114 DAT, bermudagrass covered between 92 and 95% of plots that had been treated and 84% of nontreated plots (Figure 2). All application techniques were effective at stimulating bermudagrass and can result in significantly more bermudagrass cover at the end of the growing season (Figure 2). An improvement of 15% bermudagrass cover is substantial considering it took nontreated plots 20 days after the blanket foramsulfuron treatment to add 15% additional cover (Figure 2).

Data from this study are supported by data from similar research conducted previously. Fry et al. 2007 reported that strip seeding bermudagrass (disrupting 11% of perennial ryegrass canopy) increases bermudagrass cover 29% compared to broadcast seeded plots after one growing season. Strip seeding in combination with glyphosate overspray (disrupting 22% of perennial ryegrass canopy) increased bermudagrass cover 44% compared to the broadcast seeded plots after one growing season. Strip seeding has been evaluated for its effectiveness on converting perennial ryegrass to zoysiagrass. Results indicate significant increases in zoysiagrass coverage can be obtained 1 and 2 years after seeding when compared to nontreated (Zuk and Fry 2005). Zoysiagrass grows less aggressively than bermudagrass, thus more time is required to see benefits of the strip seeding method. Mittlesteadt et al. (2009), observed that killing strips prior to sprigging Patriot bermudagrass increases bermudagrass cover 12% at the end of the growing season compared to plots in which Patriot bermudagrass was directly sprigged into the cool-season turfgrass.

CONCLUSIONS

Turfgrass managers in the transition zone searching for improved results during spring transition will find that partially controlling perennial ryegrass using different application techniques can increase bermudagrass cover and improve quality after a blanket application of foramsulfuron is applied (Figure 2). Furthermore, strip is the only application technique that decreases quality to a level that does not justify the benefits of increased bermudagrass cover after a blanket application of foramsulfuron (Figures 1 and 2). The dot patterns exhibited by drip and sponge treatments represent a novel concept in turfgrass management and were shown to improve turf quality over strip application while maintaining similar improvement in bermudagrass cover.

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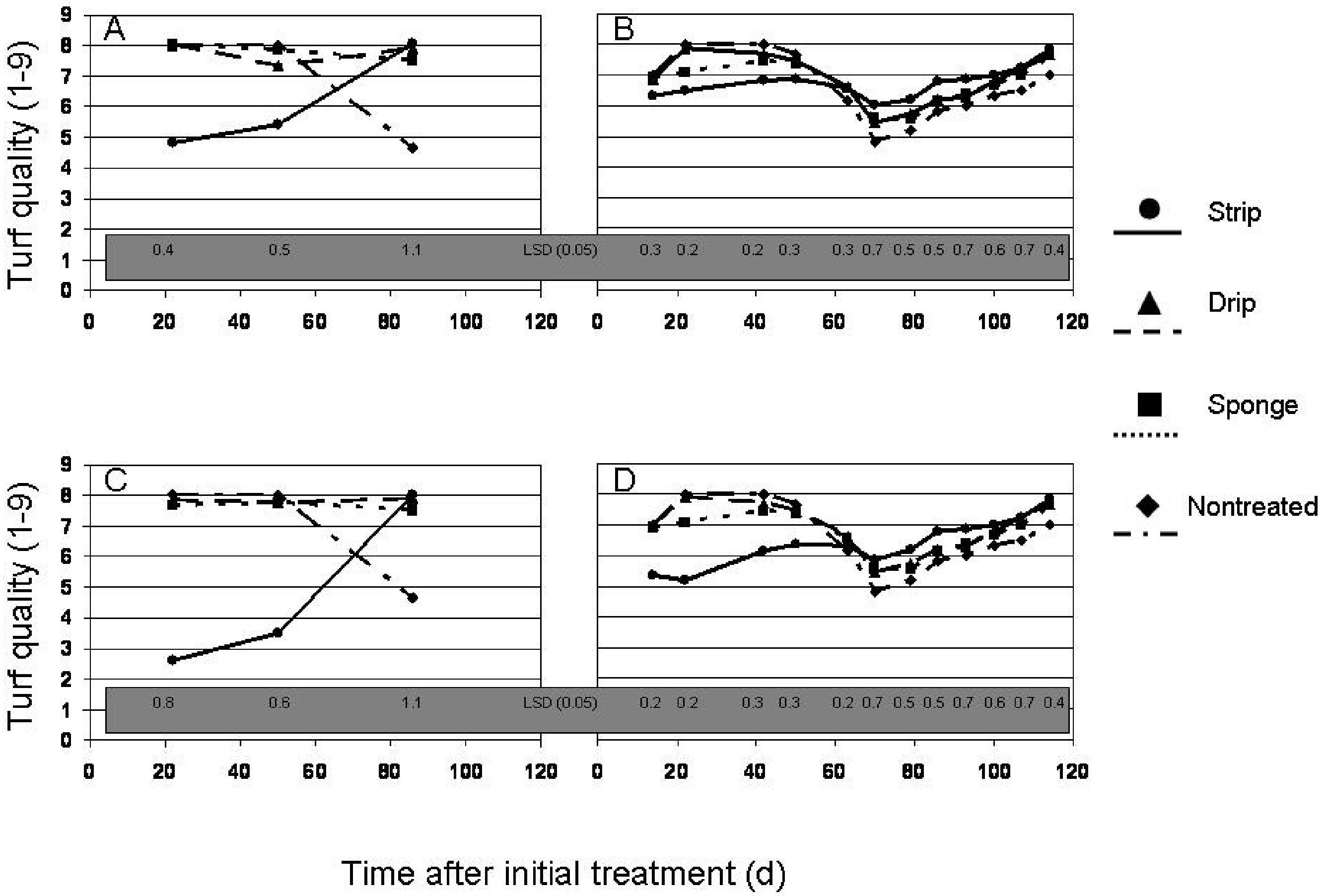
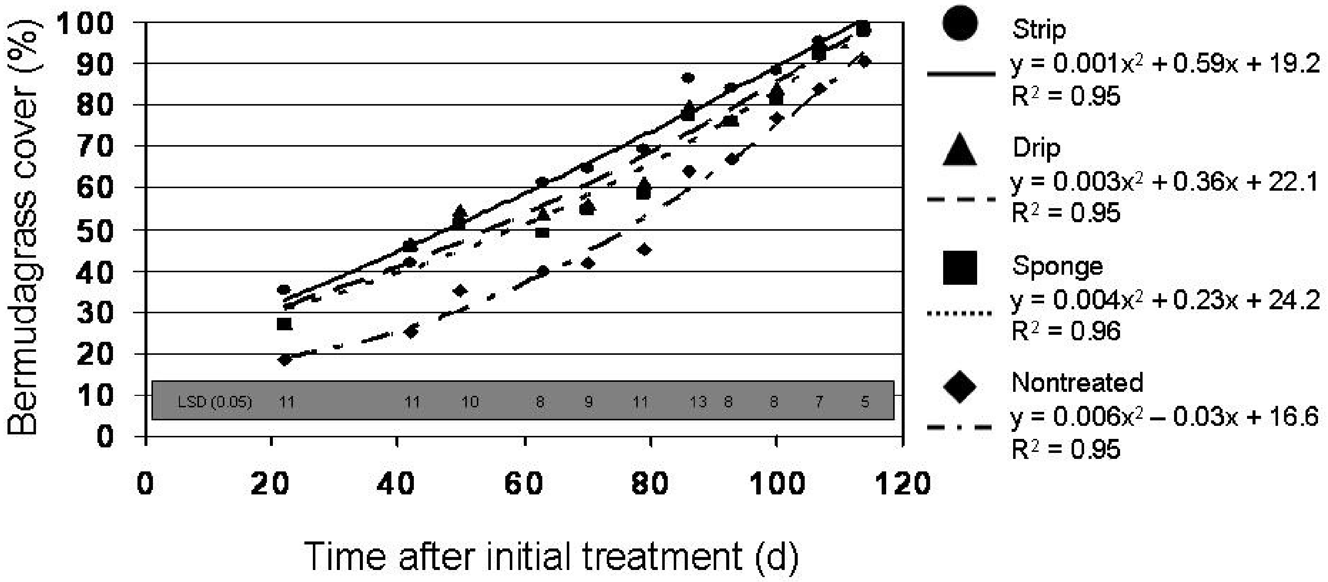
Figure 1. Turfgrass quality influenced by partial control application techniques.



A = Turfgrass quality when viewed at 0° (perpendicular to axis of application) in 2006
B = Turfgrass quality when viewed at 0° (perpendicular to axis of application) in 2007
C = Turfgrass quality when viewed at 90° (parallel to axis of application) in 2006
D = Turfgrass quality when viewed at 90° (parallel to axis of application) in 2007

Figure 2. Bermudagrass cover influenced by partial control application techniques.



Chapter 4.

Improving Perennial Ryegrass Establishment in 'Patriot' Bermudagrass Using Cultural and Chemical Treatments

INTRODUCTION

Bermudagrass (*Cynodon dactylon* L.) and (*Cynodon dactylon x C. transvaalensis* Burtt Davy) are warm season turfgrasses that are commonly used in the transition zone and southern climates on golf courses, athletic fields, and home lawns (Patton et al. 2008). Bermudagrass is used for athletic fields and high use areas because it tolerates wear and recuperates quickly after injury (Richardson et al. 2007; Schmidt and Shoulders 1980). However, bermudagrass enters a dormant period in the winter during which pigment loss in stems and leaves results in a light tan to a whitish-tan appearance (Beard 1973). As a result, bermudagrass is commonly overseeded with a cool-season grass to provide a green surface during the winter months. Perennial ryegrass (*Lolium perenne* L.) is most commonly used for winter overseeding (Richardson et al. 2007; Schmidt and Shoulders 1980). Its dark green color, fine texture, and speed of establishment make it a desirable grass for overseeding (Morris 2004). Furthermore, perennial ryegrass tolerates a low mowing height which is desirable for greens and fairways (Ward et al. 1974).

Fall transition deals with the establishment of perennial ryegrass or other cool-season grasses into bermudagrass as it enters dormancy. Askew et al. (2006) reported that dense, aggressive cultivars were difficult to transition in fall (establish perennial ryegrass) and easy to transition in spring (control perennial ryegrass). Establishing perennial ryegrass in the fall is often more important to athletic field managers because many athletic events are hosted in the fall through early winter, and again next spring. Furthermore, athletic fields are subjected to more wear stress than other types of turf and require aggressive, dense turfgrasses to withstand wear and quickly recover. These factors combine to make fall transition a serious problem for athletic field managers. Establishment of perennial ryegrass in the fall is of paramount importance and dense bermudagrass cultivars negatively impact perennial ryegrass establishment.

'Patriot' bermudagrass produces a dense dark green surface and has cold hardiness. Furthermore, relative to other cultivars of bermudagrass, it displays a vigorous growth habit (Taliaferro et al. 2006). A dense dark green surface, vigorous growth habit, and good cold hardiness make 'Patriot' bermudagrass a popular turfgrass variety for athletic field use in the transition zone. 'Patriot' bermudagrass is being used on all levels of athletics including professional, college, high school, and parks and recreation. 'Patriot' bermudagrass' dense surface and vigorous growth habit presents significant challenges in establishing a winter overseeding of cool-season turfgrass. Seedbed preparation is essential for overseeding establishment and must occur at the right time or stand failures may result at any seeding rate (Mazur and Rice, 1999; Gill et al., 1967; Ward et al., 1974). Previous research indicates vertical mowing and core aeration combined with topdressing performed 4 to 6 weeks prior to overseeding prove to be most effective when establishing winter overseeding (Mazur and Rice, 1999; Schmidt, 1970; Ward et al., 1974). Vertical mowing just prior to overseeding removes thatch and reduces competition from bermudagrass allowing for improved seedling stands (Mazur and Rice, 1999; Duble, 1978; Gill et al., 1967). Furthermore, it has been stated that optimal soil temperatures for perennial ryegrass establishment are between 22 and 26 C (Mazur and Rice, 1999; Batten et al., 1980; Beard and Menn, 1988). Most research that has evaluated fall transition was conducted on golf putting greens. Creeping bentgrass (*Agrostis stolonifera* L.), rough stalk bluegrass (*Poa trivialis* L.), and perennial ryegrass establishment were promoted by vertical mowing, topdressing, and applying trinexapac ethyl (Sifers and Beard 2001). In a separate study, Mazur and Rice (1999) observed perennial ryegrass establishment increased with topdressing and increasing perennial ryegrass seeding rate. Trials were established to determine if cultural and chemical treatments prior to overseeding 'Patriot' bermudagrass increase perennial ryegrass establishment and evaluate turfgrass color in response to cultural and chemical treatments.

MATERIALS AND METHODS

Field experiments were conducted at the Glade Road Research Facility (GRRF) on a 'Patriot' bermudagrass fairway with a native soil rootzone and the Turfgrass Research Center (TRC) on a 'Patriot' bermudagrass fairway with a sand based rootzone in Blacksburg, VA, in 2007 and 2008 respectively. 'Patriot' bermudagrass plots were maintained at 1.5 cm mowing height and fertilized at 48 kg P ha^{-1} prior to overseeding. Overseeding dates were September 20, 2007 and October 2, 2008. Perennial ryegrass was seeded at 489 kg ha^{-1} pure live seed. Plots were watered a maximum of three times daily until adequate perennial ryegrass establishment was achieved and then irrigated periodically to prevent wilt.

A split-plot experimental design was used. Main plots were cultural treatments and were randomly assigned to replicate blocks. Subplots were chemical treatments and were randomly assigned to each main plot. All treatments were replicated three times. Main plots were 3 by 7.3 m with each subplot being 1.8 by 3 m. Cultural treatments included a nontreated check, topdressing with sand at a depth of 0.64 cm following seeding, verticutting in one direction, verticutting in two directions, and core aerification in one direction combined with verticutting in two directions. A tractor mounted, PTO driven verticutter with 5 cm blade spacings and a 2 cm depth of cut was used. Core aerification was performed at a depth of 10.2 cm and 1.9 cm core width [1]. Verticutting was performed after core aerifying to allow the cores to be broken up. Remaining debris was removed with a blower. Chemical treatments included a nontreated check, trinexapac ethyl at 45 g ai ha^{-1}, triclopyr at 1122 g ai ha^{-1}, and triclopyr at 1122 g ai ha^{-1} combined with mesotrione at 279 g ai ha^{-1}. All chemical treatments were applied with a CO_2-pressurized backpack sprayer delivering 281 L ha^{-1} at 276 kPa with XR11004 nozzles. Cultural and chemical treatments were applied the same day as seeding. In an attempt to simulate conditions that turf managers face when overseeding, traffic was applied to every plot simulating 1 game weekly beginning 4 weeks after seeding using a 200 kg, 76 cm wide turf roller[2] modified by installing bolts in the roller to simulate cleat wear (Ervin and Koski 2001). Approximately 2 passes simulated one game of wear.

Visual ratings included percent perennial ryegrass cover and turf color. Percent perennial ryegrass cover was rated on a scale of 0 to 100%, where 0% is no perennial ryegrass cover and 100% is complete perennial ryegrass cover. Turf color was rated on a

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[1] Toro Turf Aerator 686, Smith Turf and Irrigation, Richmond, VA

[2] Brouwer TR 130, Brouwer Turf Equipment, Dalton, OH

1 to 9 scale, where 1 is poor and 9 is excellent and less than 6 indicates unacceptable turf. Percent perennial ryegrass cover was also assessed using the line intersect method (Richardson et al. 2001) with 100 intersections. Turf color was also assessed using a Fieldscout TCM 500 NDVI Turf Color Meter (Spectrum Technologies, Inc.).

Variance was tested for homogeneity by plotting residuals in SAS 9.1 and comparing normal data to log and arcsine square root transformed data. If transformation was needed to stabilize variance for ANOVA, nontransformed data were used for mean separation to make data interpretation easier. A combined analysis of variance was conducted with sums of squares partitioned to reflect trial effects and the split plot treatment structure. Main plots were tested using the mean square of rep by main plot interaction while subplot main effects were tested using the mean square of their interaction with the random variable, trial (McIntosh 1983). Appropriate means were separated using Fisher's Protected LSD test at $p = 0.05$.

RESULTS AND DISCUSSION

Perennial ryegrass cover. Trial by chemical treatment by cultural treatment interactions were significant on perennial ryegrass cover at 28 ($P=0.0028$), 54 ($P=0.048$), and 73 ($P=0.0084$) DAS. This interaction could be due to differences in Patriot bermudagrass density between locations. In 2007 the trial was located on very dense Patriot bermudagrass. In 2008 the trial was located on Patriot bermudagrass that had just been sprigged the previous year and was not as dense. Furthermore, in 2008 application error contributed to the interaction. Topdressing was applied prior to applying chemicals and the sand adsorbed some of the chemicals leading to inhibition of perennial ryegrass germination in some cases. Differences between visual, grid counts, and digital image analysis using a SigmaScan pro macro (Karcher and Richardson 2005; Richardson et al. 2001) cover ratings were analyzed in SAS 9.1 using proc core. No significant differences were observed at any rating dates ($P<0.0001$) and $R^2>0.84$. Further validation of the accuracy of visual ratings are represented in Figure 1. Therefore, only visual data will be discussed.

At 28 DAS in 2007, significant differences in perennial ryegrass cover were only observed between cultural treatments when combined with triclopyr + mesotrione (Figure 2 and Table 1). Applying triclopyr + mesotrione combined with verticutting in 2 directions + core aerifying increased perennial ryegrass cover 20% compared to applying triclopyr + mesotrione alone (Figure 2 and Table 1). Furthermore, applying triclopyr + mesotrione followed by topdressing increased perennial ryegrass cover 17% compared to applying triclopyr + mesotrione alone (Figure 2 and Table 1). Applying triclopyr alone, triclopyr combined with verticutting once, triclopyr combined with verticutting twice, and triclopyr combined with verticutting twice + core aerifying significantly increased perennial ryegrass cover compared to not applying any chemicals (Figure 2 and Table 1). In addition, applying triclopyr + mesotrione combined with topdressing, verticutting twice, and verticutting twice + core aerifying significantly increased perennial ryegrass cover (Figure 2 and Table 1). At 28 DAS in 2008, topdressed plots had significantly less perennial ryegrass cover when combined with any chemical treatment compared to all other cultural treatments because of the application error discussed earlier (Figure 3 and Table 1). No significant differences in perennial ryegrass cover were observed between all other cultural treatments (Figure 3 and Table 1). Furthermore, combining chemicals with cultural treatments did not increase perennial ryegrass cover and in some cases reduced perennial ryegrass cover (Figure 3 and Table 1). This can be explained by the weaker stand of Patriot bermudagrass in 2008. Perennial ryegrass was able to establish without the aid of cultural treatments and chemical treatments.

By 54 DAS in 2007, no significant differences in perennial ryegrass cover were observed between cultural treatments (Figure 2 and Table 2). However, applying triclopyr + mesotrione alone or in combination with all cultural treatments significantly increased perennial ryegrass cover when compared to not applying chemicals (Figure 2 and Table 2). In addition, applying triclopyr alone or in combination with topdressing, verticutting twice, and verticutting twice + core aerifying significantly increased perennial ryegrass cover when compared to not applying chemicals (Figure 1 and Table 2). Furthermore, applying trinexapac ethyl in combination with topdressing, verticutting twice, and verticutting twice + core aerifying significantly increased perennial ryegrass cover compared to not applying chemicals (Figure 2 and Table 2). Significantly less perennial ryegrass cover was observed in plots that were sprayed with triclopyr or triclopyr + mesotrione and combined with topdressing by 54 DAS in 2008 (Figure 3 and Table 2). Application error discussed earlier is likely the cause for this decrease in perennial ryegrass cover. In general, chemical treatments did not significantly increase perennial ryegrass cover (Figure 3 and Table 2). However, applying triclopyr in combination with verticutting twice + core aerifying, significantly increased perennial ryegrass cover compared to verticutting twice + core aerifying without applying any chemical treatment (Figure 3 and Table 2).

At 73 DAS in 2007, verticutting twice + core aerifying combined with triclopyr + mesotrione increased perennial ryegrass cover 23% compared to applying triclopyr + mesotrione alone (Figure 2 and Table 3). Furthermore, applying triclopyr or triclopyr + mesotrione significantly increased perennial ryegrass cover regardless of cultural treatment (Figure 2 and Table 3). In addition, applying trinexapac ethyl in combination with topdressing, verticutting twice, and verticutting twice + core aerifying significantly increased perennial ryegrass cover compared to not applying chemical treatments (Figure 2 and Table 3). In 2008 at 73 DAS, significant differences between cultural treatments on perennial ryegrass cover were observed in topdressing only (Figure 3 and Table 3). Plots that were topdressed and had triclopyr or triclopyr + mesotrione applied to them had significantly less perennial ryegrass cover compared to all other cultural treatments (Figure 3 and Table 3). This is due to application error discussed earlier. Significant increases in perennial ryegrass cover were observed with the use of triclopyr or triclopyr + mesotrione (Figure 3 and Table 3). Applying triclopyr in combination with verticutting twice + core aerifying increased perennial ryegrass cover 9% compared to not applying chemical treatments (Figure 3 and Table 3). Furthermore, applying triclopyr + mesotrione in combination with verticutting twice and verticutting twice + core aerifying increased perennial ryegrass cover 6 and 7 % respectively (Figure 3 and Table 3).

Turfgrass color. Trial by chemical treatment interactions were significant for turfgrass color at 28 and 54 DAS ($P<0.0001$). This interaction could be due to differences in Patriot bermudagrass density at each location. In 2007 the trial was located on dense Patriot bermudagrass which remained green through much of the early part of the study. Thus, chemical treatment effects were noticeable. However, in 2008 Patriot bermudagrass was thin and went dormant within days after treatment applications. Thus, chemical treatment effects were not very noticeable. Differences between visual and color meter turfgrass color ratings were analyzed in SAS 9.1 using proc core. No significant differences were observed at any rating dates ($P<0.0001$) and $R^2>0.68$. Therefore, only visual data will be discussed.

In 2007 at 28 DAS, all chemical treatments significantly reduced turfgrass color when compared to nontreated (Table 4). Furthermore, applying triclopyr or triclopyr + mesotrione reduced turfgrass color 2.3 and 2.5 points, respectively, compared to the nontreated (Table 4). However, trinexapac ethyl reduced turfgrass color significantly less at 0.4 points compared to nontreated (Table 4). In addition, applying triclopyr or triclopyr + mesotrione lowered turfgrass color below acceptable levels ($\geq$ 6) at 5.0 and 4.8 respectively (Table 4). However, trinexapac ethyl maintained turfgrass color above acceptable levels ($\geq$ 6) at 6.9 (Table 4). At 28 DAS in 2008, all chemical treatments significantly reduced turfgrass color when compared to nontreated (Table 4). Furthermore, applying triclopyr or triclopyr + mesotrione reduced turfgrass color 1.1 and 1.2 points respectively compared to the nontreated (Table 4). However, trinexapac ethyl reduced turfgrass color significantly less at 0.5 points compared to nontreated (Table 4). All chemical treatments reduced turfgrass color below acceptable levels ($\geq$ 6) (Table 4). However, turfgrass color was already greatly reduced because the bermudagrass was going dormant.

In 2007 at 54 DAS, all chemical treatments increased turfgrass color compared to nontreated (Table 4). This color enhancement is due to increases in perennial ryegrass cover as a result of chemical treatments. Applying trinexapac ethyl, triclopyr, and triclopyr + mesotrione increased turfgrass color 0.5, 0.6, and 0.8 points, respectively, compared to nontreated (Table 4). Furthermore, applying triclopyr + mesotrione significantly increased turfgrass color compared to applying trinexapac ethyl (Table 4). In 2008 54 DAS, applying triclopyr or triclopyr + mesotrione significantly reduced turfgrass color 0.4 and 0.6 points respectively (Table 4). Less dense bermudagrass at the 2008 trial site allowed for more perennial ryegrass establishment in nontreated plots. Thus, benefits of applying chemicals for increased perennial ryegrass cover and increased turfgrass color were overshadowed.

CONCLUSIONS

Data from 2007 and 2008 trials indicate that at all rating dates, slowing bermudagrass growth via chemical treatments positively impacts perennial ryegrass cover more than cultural treatments (Figures 2 and 3 and Tables 1, 2, and 3). In general applying triclopyr or triclopyr + mesotrione is more effective at increasing perennial ryegrass cover (Figures 2 and 3 and Tables 1, 2, and 3). Furthermore, in most cases the addition of cultural treatments does not increase perennial ryegrass cover (Figures 2 and 3 and Tables 1, 2, and 3). With this being said, applying triclopyr or triclopyr + mesotrione significantly reduces turfgrass color until bermudagrass goes dormant (Table 4). At this point, turfgrass color is increased by applying triclopyr or triclopyr + mesotrione due to an increase in perennial ryegrass cover (Table 4).

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Figure 1. Validation of perennial ryegrass cover assessment comparing visual, line intersect, and digital image analysis on December 1, 2007

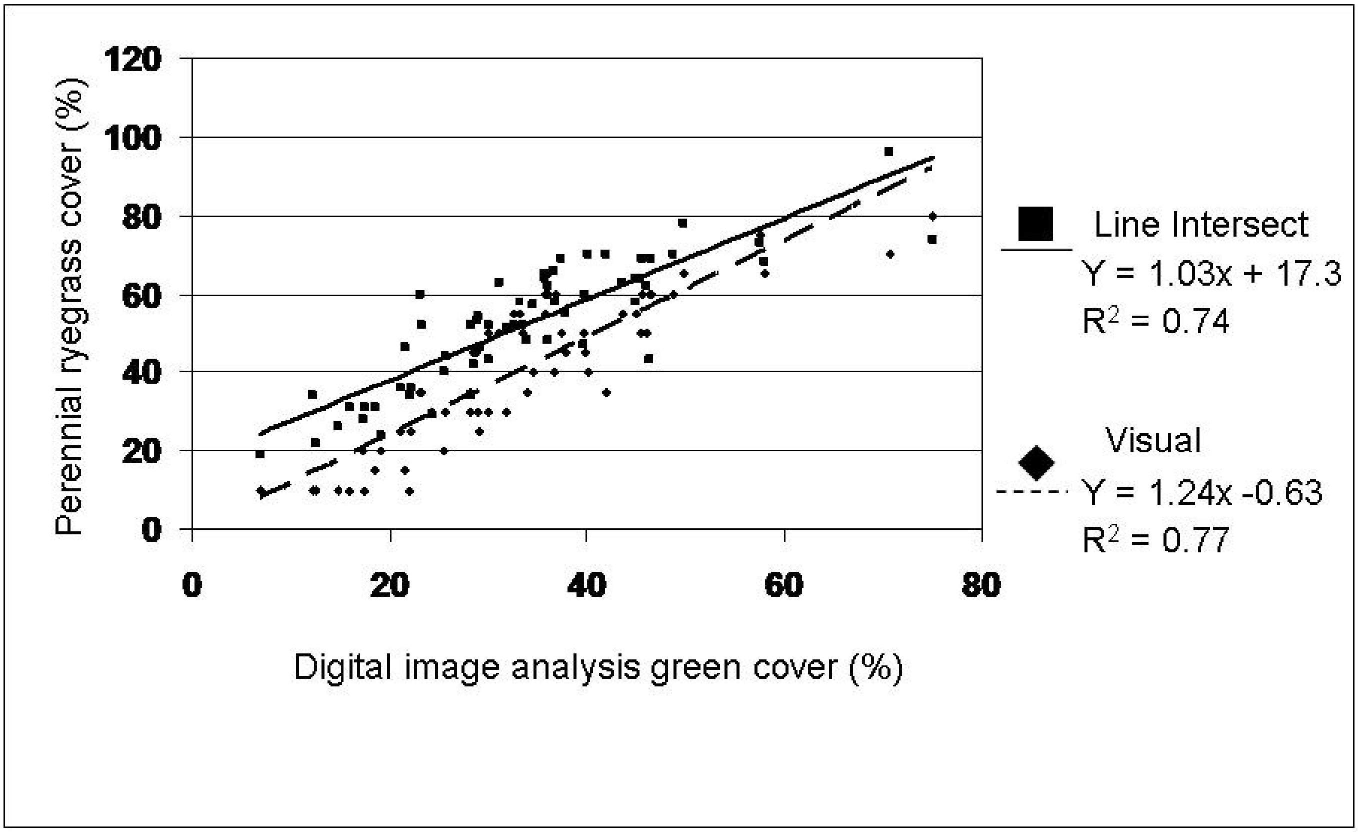
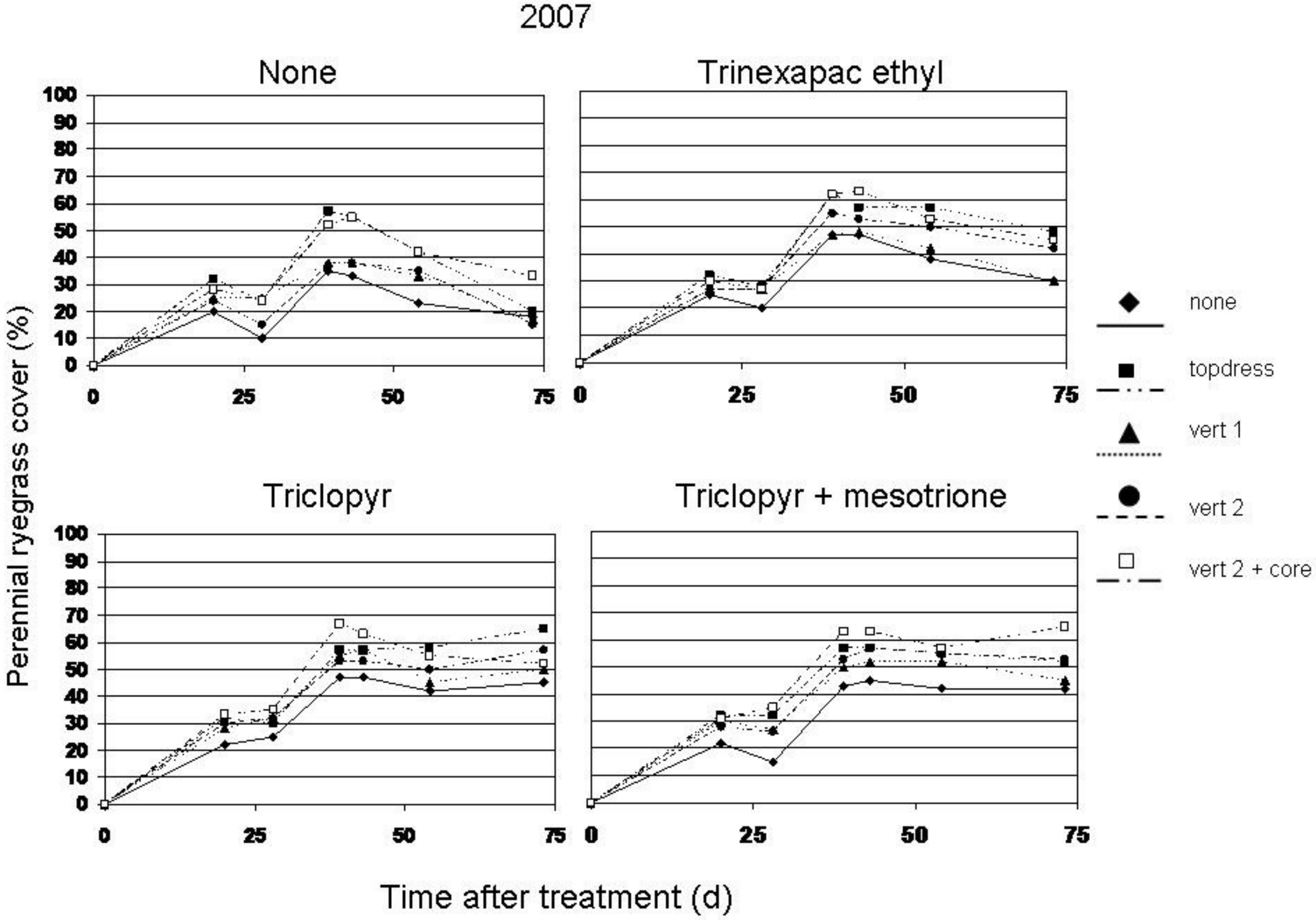
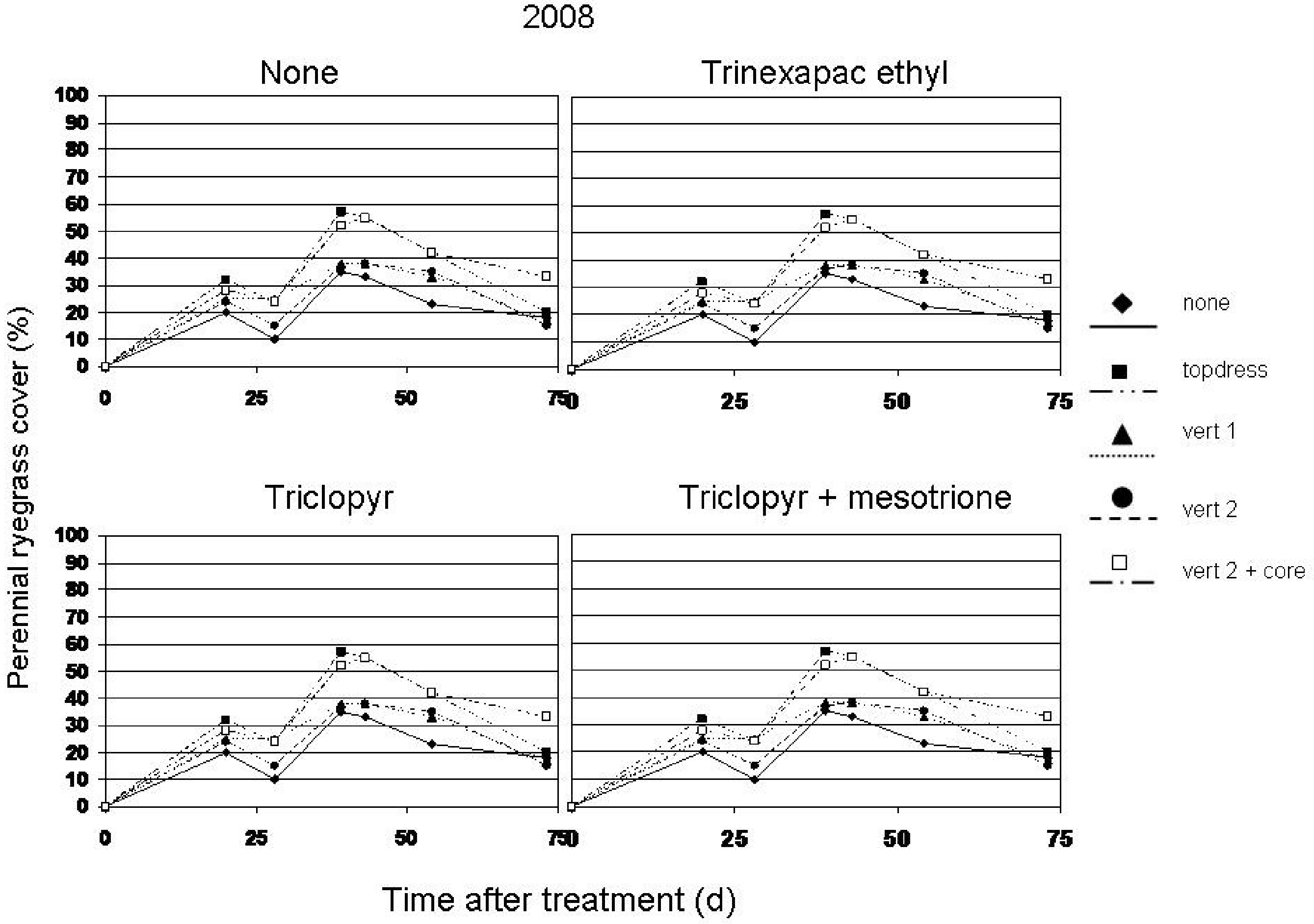


Figure 2. Perennial ryegrass cover as influenced by trial (2007), chemical treatments, and cultural treatments



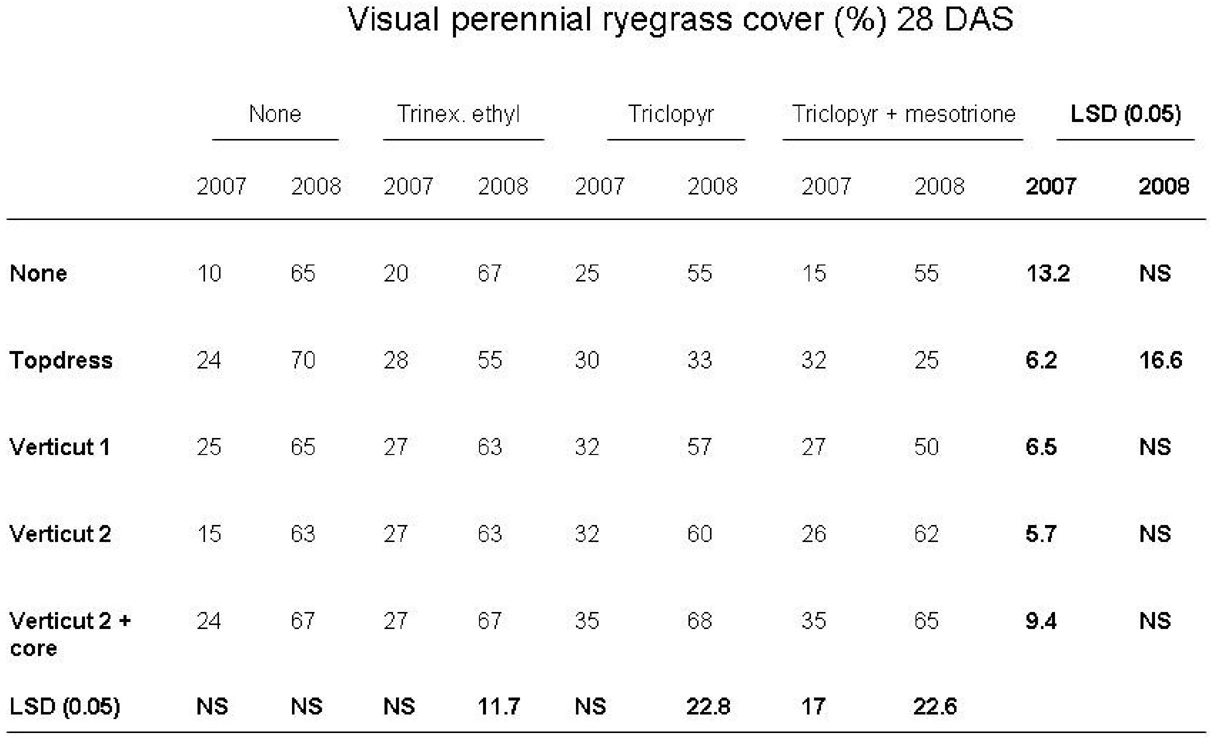
[a] Abbreviations: vert 1, verticut in one direction; vert 2, verticut in 2 directions; vert 2 + core, verticut in 2 directions + core aerify

Figure 3. Perennial ryegrass cover as influenced by trial (2008), chemical treatments, and cultural treatments.



[a] Abbreviations: vert 1, verticut in one direction; vert 2, verticut in 2 directions; vert 2 + core, verticut in 2 directions + core aerify

Table 1. Perennial ryegrass cover as influenced by trial, chemical treatments, and cultural treatments 28 DAS.

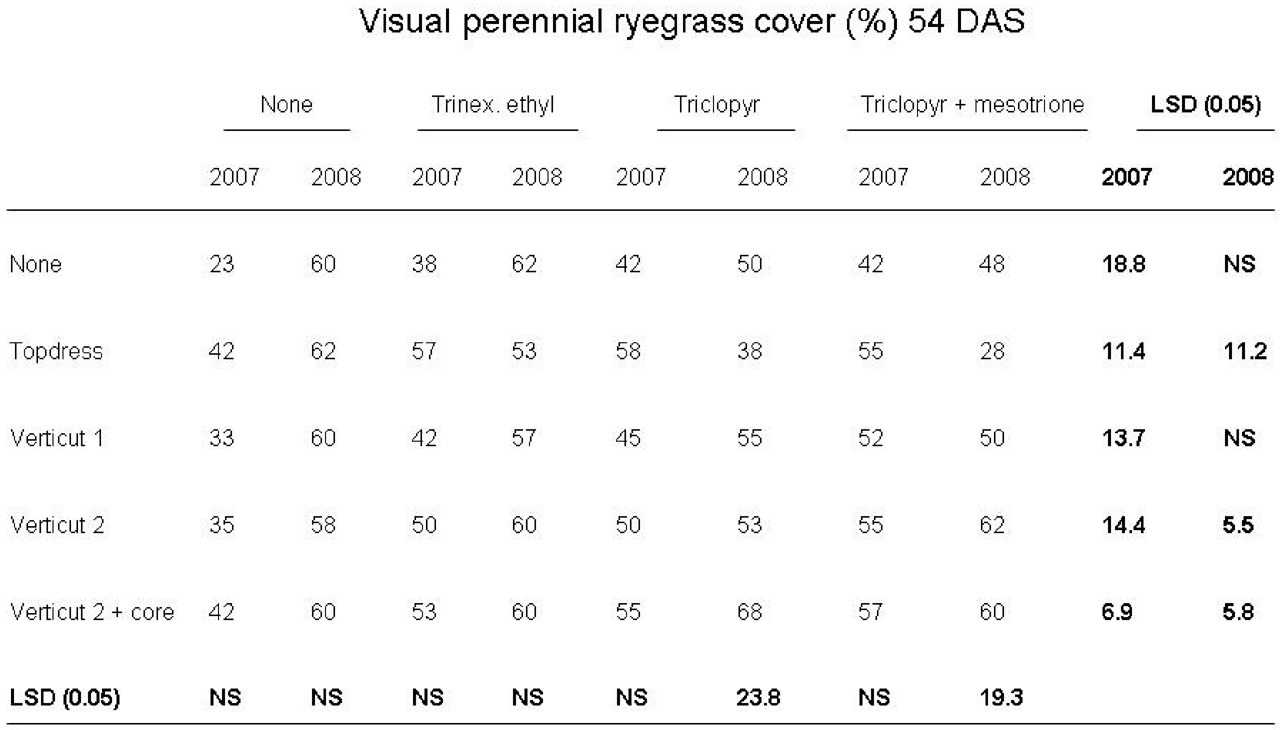


Visual perennial ryegrass cover (%) 28 DAS

	None		Trinex. ethyl		Triclopyr		Triclopyr + mesotrione		**LSD (0.05)**	
	2007	2008	2007	2008	2007	2008	2007	2008	**2007**	**2008**
None	10	65	20	67	25	55	15	55	**13.2**	**NS**
Topdress	24	70	28	55	30	33	32	25	**6.2**	**16.6**
Verticut 1	25	65	27	63	32	57	27	50	**6.5**	**NS**
Verticut 2	15	63	27	63	32	60	26	62	**5.7**	**NS**
Verticut 2 + core	24	67	27	67	35	68	35	65	**9.4**	**NS**
LSD (0.05)	**NS**	**NS**	**NS**	**11.7**	**NS**	**22.8**	**17**	**22.6**		

[a] Abbreviations: DAS, days after seeding; LSD, least significant difference; NS, not significant; verticut 1, verticut in one direction; verticut 2, verticut in 2 directions; verticut 2 + core, verticut in 2 directions and core aerify; Trinex. Ethyl, trinexapac ethyl

Table 2. Perennial ryegrass cover as influenced by trial, chemical treatments, and cultural treatments 54 DAS.

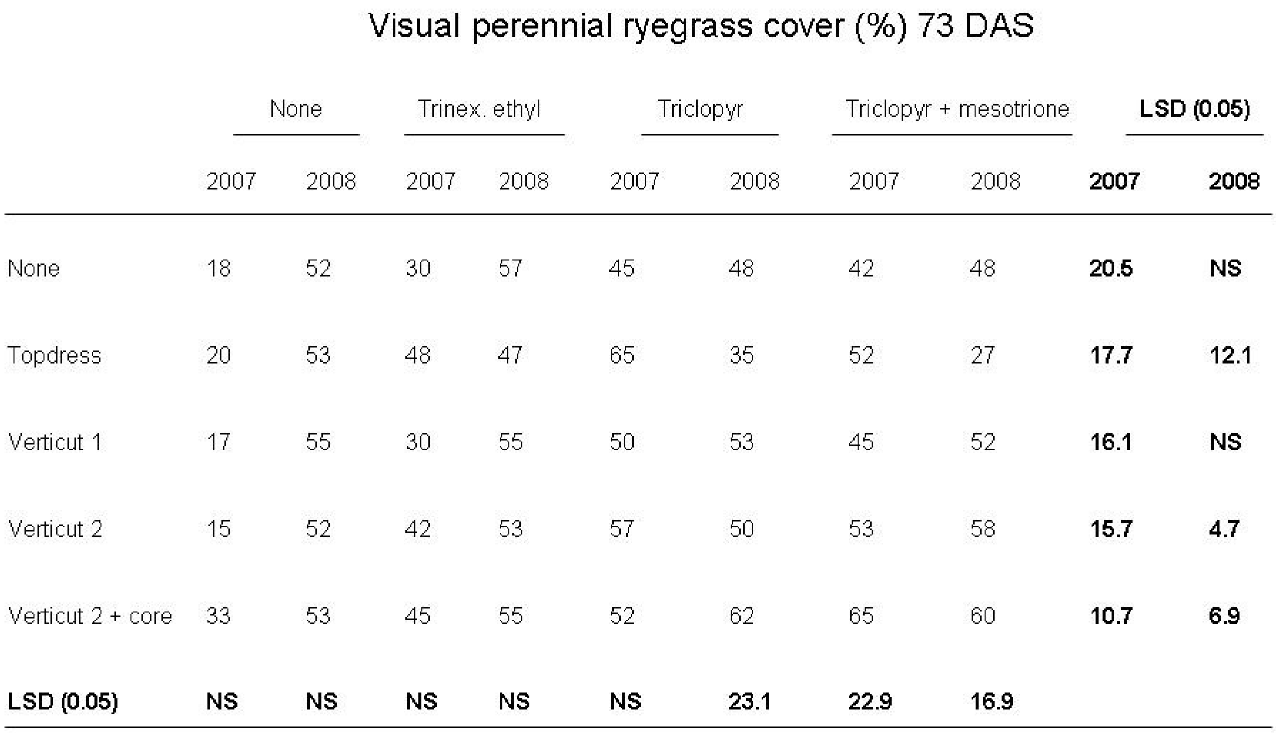


Visual perennial ryegrass cover (%) 54 DAS

	None		Trinex. ethyl		Triclopyr		Triclopyr + mesotrione		**LSD (0.05)**	
	2007	2008	2007	2008	2007	2008	2007	2008	**2007**	**2008**
None	23	60	38	62	42	50	42	48	**18.8**	**NS**
Topdress	42	62	57	53	58	38	55	28	**11.4**	**11.2**
Verticut 1	33	60	42	57	45	55	52	50	**13.7**	**NS**
Verticut 2	35	58	50	60	50	53	55	62	**14.4**	**5.5**
Verticut 2 + core	42	60	53	60	55	68	57	60	**6.9**	**5.8**
LSD (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**23.8**	**NS**	**19.3**		

[a] Abbreviations: DAS, days after seeding; LSD, least significant difference; NS, not significant; verticut 1, verticut in one direction; verticut 2, verticut in 2 directions; verticut 2 + core, verticut in 2 directions and core aerify; Trinex. Ethyl, trinexapac ethyl

Table 3. Perennial ryegrass cover as influenced by trial, chemical treatments, and cultural treatments 73 DAS.



Visual perennial ryegrass cover (%) 73 DAS

	None		Trinex. ethyl		Triclopyr		Triclopyr + mesotrione		**LSD (0.05)**	
	2007	2008	2007	2008	2007	2008	2007	2008	**2007**	**2008**
None	18	52	30	57	45	48	42	48	**20.5**	**NS**
Topdress	20	53	48	47	65	35	52	27	**17.7**	**12.1**
Verticut 1	17	55	30	55	50	53	45	52	**16.1**	**NS**
Verticut 2	15	52	42	53	57	50	53	58	**15.7**	**4.7**
Verticut 2 + core	33	53	45	55	52	62	65	60	**10.7**	**6.9**
LSD (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**23.1**	**22.9**	**16.9**		

[a] Abbreviations: DAS, days after seeding; LSD, least significant difference; NS, not significant; verticut 1, verticut in one direction; verticut 2, verticut in 2 directions; verticut 2 + core, verticut in 2 directions and core aerify; Trinex. Ethyl, trinexapac ethyl

Table 4. Turfgrass color response to chemical treatments in 2007 and 2008 at 28 and 54 DAS, respectively.

	Turfgrass color (1-9) 2007		**Turfgrass color (1-9) 2008**	
Chemical treatment	28 DAS	54 DAS	28 DAS	54 DAS
None	7.3	4.2	6.0	5.3
Trinexapac ethyl	6.9	4.7	5.5	5.1
Triclopyr	5.0	4.8	4.9	4.9
Triclopyr + mesotrione	4.8	5	4.8	4.7
LSD (0.05)	**0.27**	**0.3**	**0.3**	**0.3**

[a] Abbreviations: DAS, days after seeding; LSD, least significant difference