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OVERSEEDED BERMUDAGRASS SPRING TRASITION RESPONSE TO MOWING HEIGHT, NITROGEN RATE, SULFONYLUREA HERBICIDE, AND ALLELOPATHY

Raymond Mccauley
Clemson University, mccauleyturf@yahoo.com

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Raymond Kevin McCauley
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Accepted by:
Dr. Lambert B. McCarty, Committee Chair
Dr. Haibo Liu
Dr. Ted Whitwell
Dr. Joe Toler

ABSTRACT

Hybrid bermudagrass [*Cynodon transvaalensis* Burtt-Davey x *C. dactylon* (L.) Pers.] is the preferred turf for golf courses and athletic fields across the southern United States because of its dark green color, fine texture, good wear and drought tolerance, and excellent recuperative rate. Despite its many attributes, bermudagrass goes dormant and turns an unsightly brown color when soil temperatures fall below 10-13^{o}C (50-55^{o}F). Perennial ryegrass (*Lolium perenne* L.) is often overseeded into bermudagrass in the fall to sustain acceptable turf quality through the spring months. However, perennial ryegrass aggressively competes with the bermudagrass for resources in the spring and potentially releases disruptive allelochemicals into the environment. This competition and inhibition complicate the spring transition, impair the bermudagrass base, and result in unacceptable turf quality. Field studies were conducted to determine the best treatment(s) to optimize the spring transition and ensure continuous acceptable turf quality. Growth chamber studies were conducted to investigate potential ryegrass inhibition/allelopathy on common bermudagrass seedlings.

The field experiment utilized an overseeded soccer field to monitor the spring transition under different mowing heights, fertility rates, and trifloxysulfuron applications. Two mowing heights (1.2 and 2.5 cm), two nitrogen rates [18 kg N ha^{-1} week^{-1} (low) and 36 kg ha^{-1} week^{-1} (high)], and three herbicide rates and application dates [trifloxysulfuron at 0.005 (low) and 0.017 kg ai ha^{-1} (high) April; low and high May; and untreated] were examined. Turf responses measured were turf quality (TQ), percent perennial ryegrass (PRG), shoot dry weight (SDW), root dry weight (RDW), bermudagrass shoot counts (BSC), and percent bermudagrass (PBG). Trifloxysulfuron (TFS) had a significant effect both years on all measured responses except 2006 RDW. In 2006, untreated and 2.5 cm low April TFS treatments sustained acceptable turf quality while all other treatments experienced unacceptable quality for a minimum of 2 weeks. However, both 2.5 cm low April TFS and control treatments possessed unacceptable PRG at study's end, 30 June 2006. In 2007, untreated and 1.2 cm low May TFS treatments at both fertility levels maintained acceptable (>7) quality for the duration of the study. All TFS treatments had 0 PRG and 100 BSC and PBG ratings at study's end, 1 July 2007.

The first growth chamber experiment utilized pots seeded with bermudagrass that received irrigation water contaminated with various concentrations of perennial ryegrass roots or shoots. The potential allelopahic/inhibitory effects of two sources of contaminant (perennial ryegrass roots or shoots) and four amendment rates (0, 5, 10, 20 g L^{-1}) on bermudagrass germination and growth (root length density, root mass density, specific root length, root ash weight, dry shoot weight, bermudagrass shoot number, and bermudagrass tiller number) were examined. No bermudagrass inhibition or yield reductions were observed for any of the ryegrass irrigation solutions.

The second growth chamber experiment utilized pots that contained bermudagrass seeded in soil amended with various rates of perennial ryegrass root or shoot. The potential allelopathic/inhibitory effects of two sources of amendment (perennial ryegrass roots or shoots) and four amendment rates (0, 2, 12, 23% per 25g soil) on bermudagrass

germination and growth (root length density, root mass density, specific root length, root ash weight, dry shoot weight, bermudagrass shoot number, and bermudagrass tiller number) were examined. The highest concentration of ryegrass shoots per mix (23%) reduced bermudagrass shoots, tillers, shoot weight and ash weight.

In conclusion, cultural practices must be coupled with herbicides that aid spring transition to achieve a complete, timely spring transition in Clemson, SC. Under normal spring and summer conditions, best overall transition in Clemson, SC followed 1.2 cm mowing height, 36 kg N ha^{-1} $week^{-1}$ and 0.005 kg ai ha^{-1} mid-May trifloxysulfuron treatments.

Perennial ryegrass shoots amended into the soil inhibited bermudagrass seedling emergence and subsequent growth. Reductions in germination, size, and weight of bermudagrass seed and seedlings are evidence of allelopathic/inhibitory effects by perennial ryegrass (Inderjit and Keating, 1999; Rice, 1974). Therefore, allelochemicals are potentially leaking from severed and decaying perennial ryegrass shoots and inhibiting/altering bermudagrass growth and development.

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CHAPTER 1

INTRODUCTION

Overseeding

Hybrid bermudagrass [*Cynodon transvaalensis* Burtt-Davey X *C. dactylon* (L.) Pers.] is the standard for sports fields and golf courses in the southern United States due to its desirable color, density, texture, and wear tolerance. However, bermudagrass growth ceases when air temperatures drop below 15.5^{o}C (60^{o}F), goes dormant when soil temperatures fall below 10-13^{o}C (50-55^{o}F), and turns a brown color (McCarty, 2005). Bermudagrass remains dormant until daytime temperatures are consistently in the 12.2 to 13.3^{o}C (54 to 56^{o}F) range and will not begin active growth until night temperatures reach the 17.7 to 18.8^{o}C (64 to 66^{o}C) range.

To maintain turf color and uniformity, buffer against excessive traffic, and reduce winter weed pressure, bermudagrass is commonly overseeded with a cool season turfgrass. Perennial ryegrass (*Lolium perenne* L.) has traditionally been used due to its desirable dark green color, rapid establishment, good wear-, and low mowing tolerance (Binghmam et al., 1969; Hawes, 1982). Fairways and sports fields are traditionally overseeded with perennial ryegrass at 280 to 505 kg ha^{-1} (250 to 450 lbs ac^{-1}) when soil temperatures at 10 cm (4 in.) are approximately 20^{o}C (lower 70's^{o}F); night and mid-day air temperatures are 10 and 20^{o}C (50 and70^{o}F) respectively; and/or 30 days before the first projected frost. Despite the multiple environmental cues, overseeding dates are often dictated by sporting and special events (Landry, 1993; Duble, 1996; McCarty, 2005).

Improvements through turf breeding in perennial ryegrass' shoot density, heat-, drought-, disease-, and low mowing height tolerance have resulted in better playing surfaces (Mazur and Wagner, 1987;). However, these improved features and erratic weather patterns enable ryegrass to persist longer into the spring and summer months, hampering spring transition, which is the conversion back to the bermudagrass base (Kopec et al., 2001; Horgan and Yelverton, 1998; Mazur, 1988; Mazur and Wagner, 1987).

Spring Transition

Ideally, a "smooth" or "seamless" transition would occur from converting one turf species to another without losing acceptable turf quality, such as with overseeded ryegrass back to the permanent bermudagrass base (McCarty, 2005). Although a smooth, harmonious, spring transition is desired, fierce ryegrass competition for light, water, and nutrients delays bermudagrass emergence, weakens rhizomes, and induces spring root decline (Horgan and Yelverton, 1998; 2001; Duble, 1982; Ward et al., 1974). Alone or combinations of bermudagrass winterkill, thinning by prolonged ryegrass competition, and/or exposure of dormant bermudagrass canopy by sudden overseeding death, often results in poor spring transitions (Hawes, 1982).

During the spring, perennial ryegrass is growing optimally, and its more erect growth habit effectively restricts light penetration to the extremely shade sensitive bermudagrass base (Gelernter and Stowell, 2005b). Light is the most limiting resource to bermudagrass, and it requires nearly four times the solar radiation as cool season turf

(Beard, 2002; Yelverton, 2005). Zuk and Fry (2006) noted a 1.4 cm (0.55 in) perennial ryegrass canopy reduced the amount of solar radiation that reached the soil's surface by 72%. Bermudagrass needs 8 hours of full sunlight and 90 to 100 days of ideal growing conditions free of overseeded pressure to ensure stolon and rhizome regeneration and stand preservation (Bunnell, 2003; Keese et al., 2003). Unfortunately, turf managers have to overseed too early in the fall and transition too late into the summer, slowing bermudagrass recovery (Yelverton, 2004; Meyers and Horn, 1970; Palmertree, 1975). Without ample time to recover, constantly overseeded bermudagrass stands often eventually deteriorate. Due to adverse weather conditions and improved performance of cool season varieties, turf managers often must employ cultural and/or chemical treatments for cool season turf removal (Yelverton, 2005).

Cultural Treatments

Prior to fall overseeding, turf managers typically perform cultural and chemical practices for seedbed preparation. These practices ensure good seed-to-soil contact and successful overseeding establishment by reducing warm season turf competition and thatch layer (Askew et al., 2006; McCarty, 2005). Green et al. (2004) noted spring transition of an overseeded 'Tifgreen' bermudagrass green was not influenced by fall-applied scalping level, chemical, and seed rate treatments. Meanwhile, fall vertical mowing, topdressing, and mowing did not alter spring green-up of 'Ormond' bermudagrass managed under home lawn conditions (Gill et al., 2004). However, Johnson (1986) cautioned against aggressive vertical mowing during the fall because it excessively removes stolons and rhizomes, impeding spring transition.

While fall cultural practices are predominantly performed to ensure overseeded turf establishment and success, spring cultural practices are designed to thin the overseeded turf to increase soil temperatures and bermudagrass light interception. Duble (1982) reported spring vertical mowing in two directions weekly and core aeration improved the conditions for bermudagrass emergence. Bruneau et al. (1985) found that close mowing at 1.2 cm (0.5 in) enhanced bermudagrass green-up at the expense of the overseeded turf [15.6^{o}C (60^{o}F)]. Ledeboer (1973) recommended delaying vertical mowing to thin out perennial ryegrass from green's height turf until soil temperatures warm up sufficiently for bermudagrass growth. Sifers and Beard (2001) reported successful spring transitions of 'Champion' bermudagrass using cultural treatments (single core cultivation, consistent height of cut, weekly vertical mowing, topdressing, doubled N rates, and adequate irrigation) when soil temperatures at the 10 cm (4 in) depth exceeded 17^{o}C (63^{o}F).

Water and fertilizer undesirably extend the competitiveness of the overseeded grasses (Duble, 1982; Meyers et. al., 1970). However, greening bermudagrass root system is depleted and highly stressed during the spring and demands good soil moisture for success (Hawes, 1982). Mazur and Wagner (1987) noted the cultural treatments core aerification, vertical mowing, and topdressing did not hasten overseeded bermudagrass coverage, and all reduced turf quality at some point during spring transition. Both bermudagrass coverage and turf quality were reduced by verticutting (Mazur and

Wagner, 1987). Horgan and Yelverton (2001) reported cultural treatments: biweekly vertical mowing, scalping, core cultivation, and vertical mowing plus scalping treatments, or early/ late applications of NH_4NO_3, did not consistently enhance transition in overseeded 'Tifway' bermudagrass at fairway and sports field conditions. Instead, they concluded that relative humidity and temperature, dictated ryegrass removal (Horgan and Yelverton, 2001; Ledeboer, 1973). Both spring and fall cultural treatments have provided limited success for hastening spring transition.

Chemical Transition Aids

Since the combination of climate and cultural practices do not always effectively transition perennial ryegrass, chemical alternatives are often needed, especially in cooler growing regions (Willis et al., 2007). Spring transition aids are often needed to provide the 90 to 100 days of unrestricted, ideal bermudagrass growth, and a consistent, effective transition without reductions in usability or quality (Mazur, 1988; Horgan and Yelverton, 1998; Askew et al., 2005; Chen, 2005; Yelverton, 2005; Willis et al., 2007).

Plant growth regulators have been studied extensively for their potential aid in spring transitions (McCarty, 2005). When applied to overseeded hybrid bermudagrass, ethephon, mefluidide, and maleic hydrazide treatments increased bermudagrass coverage, but only ethephon provided acceptable turf quality during spring transition (Alexander and Wright, 1964; Mazur, 1988). Ethophon at 5.6 or 11.2 kg ai ha^{-1} (3.4 or 6.8 lbs ai ac^{-1}) did not enhance percent bermudagrass when applied either before, during, or after soil moisture stress was imposed on overseeded turf (Kopec et al., 2001). Spring trinexapac-ethyl applications delayed perennial ryegrass disappearance and disrupted spring transition (Wharton, 1999).

Transition aid herbicides appear to be the most effective, consistent approach to providing a “seamless” spring transition, and bermudagrass stands improve significantly when used consecutive years (Mazur, 1988; Horgan and Yelverton, 1998; Gelernter and Stowell, 2005b). Prior to the introduction of sulfonylurea herbicides in turf, pronamide was the standard for hastening spring transitions. Pronamide is very slow to work at cool temperatures, but late spring appears to be the ideal application time because of higher temperatures and increased light intensities (Burt and Gerhold, 1970; Coats, 1975; Horgan and Yelverton, 2001). However, due to its inconsistency, sluggish kill rate (~6 weeks), and soil mobility, pronamide’s use as a transition aid has greatly diminished. Attention has hence shifted to sulfonylureas (SUs) (Yelverton, 2005; Gelemter and Stowell, 2005b).

Sulfonylureas herbicides are currently the most studied and used transition aid herbicides on the market (Askew et al., 2005). Due to their high post-emergence selectivity of specific weed species (especially monocots) at low active ingredient rates, SU herbicides have gained increased acceptance in turfgrass since their debut in the 1980’s (Keese et al., 2003). All SU herbicides inhibit the chloroplast enzyme acetolactate synthase (ALS), which is vital in the production of three essential amino acids (valine, leucine, and isoleucine) unique to plants (Keese et al., 2003). Once the enzyme is blocked, the production of these essential amino acids ceases, the toxic precursors of amino acids accumulate, and the plant eventually starves (Keese et al., 2003; Willis et al., 2007). Trifloxysulfuron is both root and shoot absorbed several hours after application, but subsequent growth inhibition, chlorosis, and necrosis may not appear for 2 to 3 weeks (Keese et al., 2003; Willis et al., 2007). SU work quicker with warm temperatures; however, some possess undesirable lateral soil mobility, although not as drastic as pronamide (Yelverton, 2005; Willis et al., 2007).

The rate of overseeding removal and secondary weeds controlled are the main difference between transition aid herbicides. Rate of overseeding removal from slowest to fastest: pronamide<metsulfuron<foramsulfuron=rimsulfuron=trifloxysulfuron. Yelverton (2004) recommends trifloxysulfuron at 0.017 kg ai ha^{-1} (0.3 oz ac^{-1}) to ensure consistent, complete ryegrass control.

The duration of the spring transition can be manipulated by adjusting transition aid herbicide rates and timings. Rates ½ to ⅔ of the highest labeled rate slow transition; however, neither the cool season turf nor other labeled weeds may be completely controlled (Gelernter and Stowell 2005b). Ryegrass removal is directly proportional to the rate of the most commonly used SUs-flazasulfuron, foramsulfuron, rimsulfuron, or trifloxysulfuron. Higher rates of transition aid herbicides are more effective during the early spring; meanwhile, all products and rates are effective in June with higher temperatures (Umeda and Towers, 2004).

Successful spring transitions have been best when transition aid herbicides and cultural practices were merged (Yelverton, 2004; Askew et al., 2004; Gelernter and Stowell, 2005a; 2005b). To limit the loss of turf quality when using transition aid herbicides, Yelverton (2004) recommended applying spring transition aids to a strong

(>80%) bermudagrass base. Askew et al. (2004) suggested applying transition aid herbicides when both ryegrass and bermudagrass are actively growing (late May to late June) and verticut and aggressively fertilize before and during transition. Regardless of the product, application dates later into the spring and early summer months provide better turf quality with more seamless transition versus earlier application timings; however, applications made after June 15 yield minimal to no benefits (Gelernter and Stowell, 2005b). Gelernter and Stowell (2005b) observed the best transition for coastal California when bermudagrass cover was >50%, average air temperature >18.3^{o}C (65^{o}F), and soil temp at 15.24 cm (6 in) depth were above 21.1^{o}C (70^{o}F). Prior to herbicide application, a bermudagrass grow-in fertilizer regime should be adopted to minimize loss of turf quality. Gelernter and Stowell (2005b) advocated fertilizing biweekly with 24.4 kg N ha^{-1} (21.8lb N a^{-1}) of quick release fertilizers, maintaining adequate soil moisture, and lowering the height of cut four to six weeks before herbicide application. Turf yellowing can be expected and prolonged if the spring is unseasonably cool <18.3^{o}C (65^{o}F) for extended periods; however, less yellowing and bare spots may be expected when applications are applied later in the year when average air temperatures are >22.7^{o}C (73^{o}F) for 5 plus consecutive days (Gelernter and Stowell, 2005b).

Allelopathy / Inhibition

The intense competition between overseeded perennial ryegrass and the bermudagrass base in spring is undeniable. This competition with excessive overseeding preparation, overseeding rates, mat/thatch accumulation, and unseasonably cool late-spring/summer weather hinders spring transition (Kopec et al., 2001). In addition to the intense competition between grasses, ryegrass allelopathy has been proposed as a possible explanation for waning bermudagrass stands (Kopec et al., 2001).

Allelopathy, the detrimental interaction between plants and the environment and each other through the release of chemicals into the environment, has been difficult to separate from plant competition (Inderjit et al., 1995). While competition entails plants vying for limited resources, light water, nutrients, etc. within the environment, allelopathy involves the addition of chemicals into the environment from plants (Zimdahl, 1999; Foy and Inderjit, 2001). Willis (1985) defined the requirements to establish negative allelopathy pattern of inhibition of one species on another: aggressor must produce a toxin, the toxin must be enter the environment, it must enter or exposed to the host, the host must be sensitive, and it can not be explained by other means. To some degree, all plants contain toxic allelochemicals, and some plants introduce these chemicals into the environment through various mechanisms. Delivery of allelochemicals into the environment includes leaching of living plant tissue, root exudation, residue decomposition, volatilization, microbial activity, agricultural practices, and other processes.

Despite the delivery route, most allelochemicals are believed to act through the soil (Muller, 1966; 1969; Rice, 1974; Duke and Weston, 1993; Olofsdotter and Mallik, 2001). Multiple chemical classes including phenolic compounds, flavonoids, terpenoids, alkaloids, steroids, carbohydrates, and amino acids, may possess allelopathic effects either alone or synergistically. The most common and widely distributed phenolic compounds are the derivatives of cinamic acid and benzoic acids, coumarins, tannins, polyphenolic complexes, and certain flavoniods include lignin, anthocyanin and tannins (Ribereau-Gayon 1968; Walker 1975; Einhellig 2004; Zuk and Fry, 2006). Although no common mode of action between allelochemicals is apparent, examples include influencing cell division, pollen germination, nutrient uptake, photosynthesis, and specific enzyme function. The allelopathic potential of phenolic compounds appears to be non-species specific and act as broad pre-emergence growth inhibitors.

Amount and type of phenolic compounds released by plants and their allelopathic activity may be highly dependent upon seasonal changes, soil physical and chemical conditions, plant genetics, soil nutrition, and biotic factors such as plant density, plant stress, and soil microbial activities. Allelopathic responses are influenced by concentration, biotic, abiotic, spatial and temporal, and management factors (Rice & Pancholy, 1974; Glass, 1976; McClure et al., 1978; Whitehead et al., 1981; 1982; Blum, 1996; 1998; Olofsdotter and Mallik, 2001; Wu et al., 2002). Phytotoxicity of allelochemicals depends on their movement, fate, and persistence in the soil. As allelochemicals move through the soil, they are altered by microorganisms, bound to organic matter, and distorted by polymerization (Inderjit, 2001). These alterations in the rhizophere, especially by microbes, - may be responsible for allelochemicals activation. (Inderjit, 2001).

Extracts from allelopathic plants applied as biosynthetic herbicides are viewed as safer alternatives to synthetic herbicides as they are more biodegradable (Rice, 1984; 1995; Dayan et al., 1999; Duke et al., 2000). Currently, allelopathic cover crops effectively suppress weed populations and are a good supplement for no-till cropping systems (Blum et al., 2002). Allelopathy has the potential to provide new chemistries for traditional chemical weed controls and revolutionize organic farming.

In the past, numerous allelopathy trials have been conducted in forest and agricultural settings; however, little research has been conducted in turfgrass.
Cool- and warm- season turfgrasses vary significantly in their concentrations of phenolic compounds (Wu et al., 2002). Of the warm season turfgrasses tested, bahiagrass (*Paspalum notatum* Fluegge), buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.], perennial dropseed (*Sporobolus heterolepsis*), and centipedegrass [*Eremochloa ophiuroides* (Munro) Hack] may possess allelopathic potential (Martin and Smith, 1994; Wu et al., 2002; Gannon et al., 2006). Increasing rates of centipedegrass leaf debris reduced shoot and root dry weight of radish, supporting allelopathic interactions. However, centipedegrass soil leachates did not inhibit/reduce annual bluegrass (*P. annua* L.), goosegrass [*Eleusine indica* (L.) Gaertn.], henbit (*Lamium amplexicaule* L.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.] or perennial ryegrass germination versus control (Gannon et al., 2006).

Of the cool season turfgrasses evaluated, the fescues and perennial ryegrass have shown the most allelopathic promise. Bertin et al. (2003) demonstrated the cultivar dependent allelopathic properties of red fescue (*Festuca rubra* L.), and allelopathic screenings of tall fescue (*Festuca arundinacea* Schreb.) have yielded conflicting results (Chung and Miller, 1995; Pederson, 1986; Peters and Zam, 1981; Smith and Martin, 1994; Lickfeldt et al., 2001). Weston (1990) found that living and dead fescue sod effectively suppressed weeds over a three month period. Curley cress (*Lepidium sativum*) and crabgrass (*Digitaria* spp.) were suppressed when exposed fine fescue debris or seedlings. Although fine fescue seedlings exuded large quantities of bioactive root exudates into the agar medium, older plants had a more profound effect on test species (Bertin et al., 2003). Intrigue, a turf type chewing fescue cultivar, exudes meta-tyrosine from its roots, which is also present in the root exudates of all cultivars of AZ fescue, creeping red fescue, chewing fescues, and myrtle spurge (*Euphorbia myrsinite*). The amino acid, m-tyrosine, is highly toxic at low concentrations; however, its mode of action is unclear (Carson, 2008). When exposed to m-tyrosine, growth of plants possessing the compound was not influenced; however, plants without m-tyrosine, large crabgrass (*Digitaria sanguinalis* L.), dandelion (*Taraxacum officinale* Weber), mustard (*Brassica* spp.) and other small-seeded weeds, were negatively affected (Carson, 2008). Brede (1987) demonstrated an allelopathic effect of *Poa annua* L. on *Agrostis palustris* L. when grown from seed within 1.2 cm from each other. Brede (1987) suggested that a weakly water soluble compound from annual bluegrass was inhibiting creeping bentgrass seedling growth.

The allelopathic/inhibitory effects of perennial ryegrass are well documented. Nineteen phenolic compounds extracted from 'Citation' perennial ryegrass, negatively impacted lettuce germination (*Lactuca sativa* L.) (Rao and Buta, 1983). Perennial ryegrass has inhibitory/ allelopathic effects on 'Zenith' Zoysiagrass (*Zoysia japonica* Steud.), duckweed (*Lemna minor* L.), alfalfa (*Medicago sativa* L.), nodding thistle (*Caruus nutans* L.), white clover (*Trifolium repens* L.), medics (*Medicago* spp.), and lettuce (Gussin and Lynch, 1981; Buta et al., 1987; Takahashi et al., 1988, 1991, 1993; Nicholson et al., 1990; Quigley et al., 1990; Prestidge et al., 1992; Chung and Miller, 1995; Mattner and Parbery, 2001; Zuk and Fry, 2006). Koski and Newberry (2004) proposed either intense ryegrass competition or allelopathic potential impeded Kentucky bluegrass (*Poa pratensis* L.) establishment into perennial ryegrass stands at fairway height. When crabgrass was grown on agar tainted with ryegrass extracts, crabgrass germination was inhibited, and seedling chlorosis and premature death were observed (King, 1996) However, differences in allelochemical content of the 12 cultivars employed did not produce practical field differences in crabgrass suppression (King, 1996).

Literature Cited

Alexander, P.M. and G.M. Wright. 1964. Transition aided by maleic hydrazide. Golf Course Rptr. 32(9):36-40.

Askew, S. D., J. B. Willis, D. B. Ricker, E. H. Ervin, and A. LaBranche. 2006. Effects of bermudagrass cultivars and herbicides on transition. Golf Course Manage. 74(6):75-78.

Askew, Shawn D., D. McCall, W. L. Barker, and J. B. Beam. 2005. Chemical transitions on overseeded golf fairways and athletic fields. VA Turfgrass J. January/February:22-23.

Askew, S.D., J.B. Beam, and W.L. Barker. 2002. Spring transition from overseeded perennial ryegrass to bermudagrass monoculture. VPI Turf and Landscape Field Day Research Summary. July 31, 2002.

Beard, J.B. 2002. Turf Management for Golf Courses. Ann Arbor Press. Chelsea, MI.

Bertin, C., X. Yang and L.A.Weston. 2003. The role of root exudates and allelochemicals in the rhizosphere. Plant and Soil 256:67-83.

Bingham, S.W., R.E. Schmidt, and C.K. Curry. 1969. Annual bluegrass control in overseeded bermudagrass putting green turf. Agron. J. 61(6):908-911.

Blum, U. 1996. Allelopathic interactions involving phenolic acids. J. Nematol. 28:259-267.

Blum, U. 1998. Effects of microbial utilization of phenolic acids and their phenolic acid breakdown products on allelopathic interactions. J. Chem. Ecol. 24:685–708.

Brede, A. D. 1987. Can poa annua suppress bent?. p. 46-49. In *Proceedings of the 41st Annual Northwest TurfgrassConference*. Salishan Lodge, Oregon, September 21-24, 1987. Northwest Turfgrass Association

Bruneau, A.H., J.M. Dipaola, W.M. Lewis, W.B. Gilbert, and L.T. Lucas. 1985. Overseeding bermudagrass turf. N.C. Agric. Ext. Sev. AG-352.

Bunnell, B.T. 2003. Physiological response of hybrid bermudagrass (*Cynodon dactylon* (L.) Pers X *C. transvaalensis* Burtt-Davy) to reduced light environments. Ph.D. Dissertaton. Clemson University. Clemson, SC.

Burt, E.O. and N.R. Gerhold. 1970. Poa annua control in bermudagrass turf with Kerb. Proc. S. Weed. Sci. Soc. 23:122-126.

Buta, J.G., D.W. Spaulding, and A.N. Reed. 1987. Differential growth responses of fractionated turfgrass seeds and leachates. HortScience 22:1317-1319.

Carson, T. 2008. Herbicidal turf. Golf Course Manage. 76(2):42.

Chen, Xi. 2005. Selective elimination of perennial ryegrass by activation of a pro-herbicide through engineering *E. coli argE* gene. Molecular Breeding 15:339-347.

Chung, Ill-Min and D.A. Miller. 1995. Allelopathic influence of nine forage grass extracts on germination and seedling growth of alfalfa. Agron. J. 87:767-772.

Coats, G.E. 1975. Phytotoxicity of pronamide to overseeding species. Proc. S. Weed. Sci. Soc. 28:80.

Danneberger, T.K. 1993. Turfgrass Ecology and Management. G.I.E. Inc. Cleveland, OH.

Duble, R.L. 1982. Minimize transition problems in overseeded greens. Southern Turfgrass. 17(1):9-11.

Duble, R.L. 1996. Turfgrasses, Their Management and Use in the Southern Zone. Texas A&M University Press. College Station, TX.

Einhellig,F.A. 2004. Mode of allelochemical action of phenolic compounds. In: F.A. Macías, J.C.G. Galindo, J.M.G. Molinillo and H.G. Cutler, Editors, *Allelopathy: chemistry and mode of action of allelochemicals*, CRC Press, Boca Ratón, FL: 217–238.

Foy, C.L. and Inderjit. 2001. Understanding the role of allelopathy in weed interference and declining plant diversity. Weed Tech. 15(4):873-878.

Gannon, T.W., F.H. Yelverton, and J.S. McElroy. 2006. Allelopathic potential of centipedegrass (*Eremochloa ophiuroides*). Weed Sci. 54:521-525.

Gelernter, W. and L. Stowell. 2005a. Improved overseeding programs 1. the role of weather. Golf Course Manage. 73(3):108-113.

Gelernter, W. and L.J. Stowell. 2005b. Improved overseeding programs: 2. managing the spring transition. Golf Course Manage. 73(3):114-118.

Gill, W.J., W.R. Thompson, and C.Y. Ward. 1967. Species and methods for overseeding bermudagrass greens. Golf Superintendent 35(5):10,13,15,17.

Glass, A.D.M. 1976. Regulation of potassium absorption in barley roots. Plant Physiology 58(1):33-37.

Green, R.L., G.J. Klein, F. Merino, and V. Gibeault. 2004. Influence of fall-applied treatments on spring transition of an overseeded bermudagrass green. HortScience. 39(3):611-614.

Green, R.L. 1999. Improvement of the spring transition of overseeded bermudagrass putting greens. Calif. Fairways. 8(1):12.

Gussin, E.J. and J.M. Lynch. 1981. Microbial fermentation of grass residues to organic acids as a factor in the establishment of new grass swards. New Phytol. 89:449-457.

Hawes, D.T. 1982. Some ideas for easing the southern transition blues. USGA Green Section Record. 20(6):1-3.

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

Horgan, B. and F. Yelverton. 1998. Removing overseeded ryegrass from bermudagrass. Grounds Maintenance. 33(1):18,22-25.

Inderjit and K.M.M. Dakshini. 1995. On laboratory bioassays in allelopathy. Bot. Rev. 61:28-44.

Johnson, B.J. 1986. Response to vertical mowing and ethofumesate treatments for annual bluegrass control in bermudagrass turf. Agron. J. 78:495-498.

Johnson, B.J. 1987. Tolerance of overseeded perennial ryegrass to selected tricalcium arsenate treatments. HortScience. 22(1):868-888.

Keese, R., D. Spak, and C. Sain. 2003. New tools for the golf course superintendent a practical user's guide to the sulfonylurea herbicides. Green Section Record. 43(4): 16-18.

King, J. 1996. Allelopathy vs. *Acremonium* endophytes vs. competition effect on crabgrass suppression by 12 perennial ryegrasses. *Turfgrass Environ Res. Summ.* 52-54.

Kopec, D.M., J. Gilbert, K. Marcum, M. Pessarakli, and D. Jensen. 2001. Effect of overseeding rate on spring transition: the evidence shows that more is not better. USGA Green Section Record. 39(4):10-12.

Kopec, D.M., D.P. Jensen, and J.J. Gilbert. 2001. Ethephon Potential for Spring Transition of Perennial Ryegrass Back to Common Bermudagrass. Unin. of AZ. Col. of Ag. 2001 Turf and Orn. Res. Rpt.

Kopec, D.M., J. Gilbert, M. Pessarakli, and K. Umeda. 2004. Use of foramsulfuron (tads) as a transition agent to remove *Poa trivialis* from an overseeded tifgreen bermudagrass putting green. Unin. of AZ. Col. of Ag. 2005 Turf and Orn. Res. Rpt.

Landry, G. 1993. Success with overseeding warm-season grasses. SportsTURF. 9(9):12-14.

Ledeboer, F.B. 1973. Transition-some rethinking. USGA Green Section Record 11(3):11-12.

Lickfeldt, D.W., T.B. Voigt, B.E. Branham, and T.W. Fermanian. 2001. Evaluation of allelopathy in cool season turfgrass species. International Turfgrass Society. 9:1013-1018.

Mattner, S.W. and D.G. Parbery. 2001. Rust-enhanced allelopathy of perennial ryegrass against white clover. Agron. J. 93:54-59.

Mazur, A.R. and D.F. Wagner. 1987. Influence of aeration, topdressing, and vertical mowing on overseeded bermudagrass putting green turf. HortScience 22(6):1276-1278.

Mazur, A.R. 1988. Influence of plant growth regulators on transition of bermudagrass putting green overseeded with perennial ryegrass. J. Amer. Soc. Hort. Sci. 113(3):367-373.

McCarty, L.B. 2005. Best Golf Course Management Practices. Prentice-Hall Inc. Upper Saddle River, NJ.

McClure, P.R., H.D. Gross, and W.A. Jackson. 1978. Phosphate absorption by bean varieties: the influence of ferulic acid. Canadian J. of Bot. 56:764-767.

Meyers, H.G. and G.C. Horn. 1970. Transition from overseeded to permanent warm season grasses. The Golf Superintendent. 38(1):62-65.

Muller, C.H. 1966. The role of chemical inhibition (alelopathy) in vegetation composition. Bulletin of the Torry Botanical Club. 3(5):332-351.

Muller, C.H. 1969. Allelopathy as a factor in ecological process. Vegetatio. 18:348-357.

Nicholson, K.S., A. Rahman, and D.A. Wardle. 1990. Interactions between establishing nodding thistle and pasture seedlings, p. 225-228. In: Proc 43rd Weed and Pest Control Conf., Hamilton, New Zealand.

Olofsdotter, M. and A.U. Mallik. 2001. Allelopathy symposium. Ag. J. 93:1-2.

Ostmeyer, T. 2004. Golf's extreme makeover: for many, overseeding is a necessary evil, but is it really only skin deep? Golf Course Manage. 72(7):50-52,56,58,60.

Palmertree, H.D. 1975. Management of overseeded greens during spring transition period. The Golf Superintendent. 43(3):27-29.

Pederson, G.A. 1986. White clover seed germination in agar containing tall fescue leaf extracts. Crop Sci. 26(6):1248-1249.

Peters, E. J., and A. H. B. Zam. 1981. Allelopathic effects of tall fescue genotypes. Agron. J. 73(1):56-58.

Prestidge, R.A. , E.R. Thom, S.L. Marshall, M.J. Taylor, B. Willoughby, and D.D. Wildermoth. 1992. Influence of *Acremonum lolii* infection in perennial ryegrass on germination, emergence, survival and growth of white clover. N.Z. J. Agr. Res. 35:225-234.

Quigley, P.E., F.J. Snell, P.J. Cunningham, and W. Frost. 1990. The effects of endophyte infected ryegrass on the establishment, persistence and production of mixed pastures in Australia. Proc. 1st International Symposium on Acremonium/Grass Interactions: 49-51.

Ribereau-Gayon, P. 1968. Plant Phenolics. Oliver & Boyd, Edinburgh,UK.

Rice, E.L. 1974. Allelopathy. Academic. New York, NY.

Rice, E.L. and S.K. Pancholy, 1974, Inhibition of nitrification by climax ecosystems. III. inhibitors other than tannins. American J. of Botany. 61:1095-1103.

Sifers, S.I. and J.B. Beard. Turf quality and morphological comparisons of winter overseeding methodologies for a high-density dwarf *Cynodon* turf. International Turf Soc. Res. J. 9:934-940.

Smith, A.E., and L.D. Martin. 1994. Allelopathic characteristics of three cool-season grass species in the forage ecosystem. Agron. J. 86(2):243-246.

Takahashi, Y., T. Otani, S. Uozumi, Y. Yoden, and R. Igarashi. 1988. Studies on the allelopathic interactions among some grassland species. I. Effects of root exudates from some grass and legume species on the growth of their own species and other species. J. Jap. Soc. Grassl. Sci. 33:334-338.

Takahashi, Y., T. Otani, S. Uozumi, Y. Yoden, and R. Igarashi. 1991. Studies on the allelopathic interactions among some grassland species. II. assessment of the allelopathic interactions between perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) using a root exudate recirculating system. J. Jap. Soc. Grassl. Sci. 37:274–282.

Takahashi, Y., T. Otani, and K. Hagino. 1993. Studies on interactions among some grassland species. V. collection and isolation of allelopathic hydrophobic compounds from the root exudates of *Lolium perenne* L. J. Jap. Soc. Grassl. Sci. 39:236–245.

Umeda, K., and G. Towers. 2004. Comparison of sulfonylurea herbicides for spring transition. *Turfgrass Landscape* Urban IPM Res. Summ.:1-9.

Walker, J.R.L. 1975. The Biology of Plant Phenolics. Edward Arnold. London,UK.

Ward, C.Y., E.L. McWhirter, and W.R. Thompson, Jr. 1974. Evaluation of cool season turf species and planting techniques for overseeding bermudagrass golf greens. p. 480-495. In: E.C. Roberts (ed.). Proc Second Intl. Turfgrass Res. Conf., Amer. Soc. Of Agron., Madison, Wis.

Wharton, S.M. 1999. Overseeded bermudagrass fairway performance and post dormancy transition as influenced by winter overseeding practices and trinexapac-ethyl. M.S. Thesis. VA Poly I&S University.

Whitehead, D.C., H. Dibb, and R.D. Hartley 1981. Extractant pH and the release of phenolic compounds from soils, plant roots and leaf litter. Soil Bio. and Biochem. 13:343-348.

Whitehead, D.C., H. Dibb, and R.D. Hartley. 1982. Phenolic compounds in soil as influenced by the growth of different plant species. J. of Applied Ecology. 19(2): 579-588.

Willis, R.J. 1985. The historical bases for the concept of allelopathy. J. of the History of Biology. 18:71-102.

Willis, J.B., S.D Askew, and B.W. Compton. 2007. Cold influences overseeded perennial ryegrass control: cold temperatures have a direct impact on the effectiveness of some sulfonylurea herbicides used for overseeded perennial ryegrass control in the transition zone. Golf Course Manage. 75(5):118-120.

Wu, L.L., M.A. Harivandi, and X. Guo. 2002. Distribution of phenolic acids and allelopathic potential in cool-season and warm-season turfgrass species. Calif. Turfgrass Cult. 52(1 & 2):5-9.

Yelverton, F. 2005. Spring transition: going, going, gone: removal of overseeded perennial ryegrass from bermudagrass is a must. USGA Green Section Record. 43(2):22-23.

Yelverton, F. 2004. In transition: new sulfonylurea herbicides offer options for transitioning overseeded turf into spring. Grounds Maintenance. 39(2):33-36.

Zimdahl, R.L. 1999. Fundamentals of Weed Science. Academic Press. San Diego, CA.

Zuk, A.J. and J.D. Fry. 2006. Inhibition of ‘zenith’ zoysiagrass seedling emergence and growth by perennial ryegrass leaves and roots. HortScience. 41(3):818-821.

CHAPTER 2

MOWING HEIGHT, NITROGEN, AND HERBICIDE INFLUENCE ON SPRING TRANSITION

Introduction

For a variety of reasons, warm-season turf managers often overseed with a cool-season species, such as perennial ryegrass (*Lolium perenne* L.) (McCarty, 2005; Yelverton, 2005; Ostmeyer, 2004). Overseeding effectively hides dormant, brown colored bermudagrass, improves winter playability, and subsequently, generates revenue from increased winter and spring play. Play on overseeded turf can account for up to 85% of annual golf play at resorts and daily fee courses (Ostmeyer, 2004; Kopec et al., 2001). Due to advances in perennial ryegrass breeding, newer cultivars possess better heat tolerance and improved shoot densities, enabling them to potentially become short-lived perennials in southern climates (Yelverton, 2005). Overseeding, however, overshadows the bermudagrass base, keeping soil temperatures cooler, often delaying spring green-up while prolonged overseeding cover can weaken bermudagrass stands (McCarty, 2005).

If the climate is not conducive to a natural spring transition, cultural treatments alone will not effectively or consistently aid in providing a desirable spring transition (Willis et al., 2007; Askew et al., 2005; Horgan and Yelverton, 1998; Mazur and Wagner, 1987). In recent years, the sulfonylurea class of herbicides has grown in popularity as spring transition aids versus the slower, more inconsistent pronamide (Askew et al., 2001). However, experience indicates a “smooth”, “seamless”,or gradual spring transition is not satisfactorily obtained with herbicides alone. Effectively merging cultural and chemical controls to achieve a desired transition with acceptable turf quality appears necessary. The objective of this research was to evaluate combinations of mowing height, fertilizer rate, and trifloxysulfuron (a sulfonylurea herbicide; USA trade name: Monument 75 DG) timing and rate for the best "seamless" spring transition from the overseeded ryegrass back to permanent bermudagrass base.

Materials & Methods

A 12 week study was conducted from mid-April to July 2006 and repeated in 2007 on the Clemson University athletic department's soccer practice fields in Clemson, SC. The experiment was conducted on an established stand of 'Tifway 419' hybrid bermudagrass [*Cynodon transvaalensis* Burt-Davey x *C. dactylon* (L.) Pers.]. The soil profile was a Toccoa sandy loam (67% sand, 15% silt, and 18% clay) with 3.4% organic matter (LOI), and a pH 6.1 (P:148 kg ha^{-1}; K: 211 kg ha^{-1}). Prior to experiment initiation, routine maintenance for sports fields were followed including mowing 3 times weekly at 1.9 cm (0.75 in) with clippings returned, irrigated as needed to prevent wilt, and fertilized yearly with a total of 391 kg N; 244 kg P; 244 kg K ha^{-1} (348 lbs N, 218 lbs P, and 218 lbs K ac^{-1}).

Prior to overseeding, the field was mowed at 1.2 cm (0.5 in), vertically mowed (model ref. Veemo MkII VMO/2 Sisis Inc., Sandy Springs, SC) in one direction at a depth of 0.3 cm (0.125 in) with a blade spacing of 3.6 cm (1.4 in). Debris was removed, and the field was mowed again at 1.2 cm with clippings returned. The field was overseeded in two directions with Barenbrug Turf Star Brand perennial ryegrass (*Lolium perenne* L.) blend (32.82% Pinnacle II perennial ryegras; 32.45% Premier II perennial ryegrass; and 32.45% Barlennium perennial ryegrass) at 341.51 kg ha^{-1} (7.0 lbs 1,000 ft^{-2}) pure live seed with a rotary spreader (Lely USA Inc.) on 3 October 2005 and 29 September 2006. Seed was incorporated into the soil surface with a steel drag matt/brush.

Treatments

A complete listing of treatments is presented in Table 1. Two mowing height treatments (1.2 and 2.5 cm) were maintained from 11 April to 1 July 2006 and 2007. Prior to implementing these mowing heights, all plots were mowed at 1.9 cm (0.75 in) until 9 April 2006. Plots assigned the 1.2 cm (0.5 in) mowing height were maintained at 1.6 cm (0.625 in) from 9 April until 11 April to prevent scalping, when the mowing height was lowered to 1.2 cm (0.5 in) on 11 April for the duration of the experiment. Plots maintained at 1.2 cm (0.5 in) were mowed four times weekly with a commercial walk behind reel mower (model #220A, John Deere & Company, Moline, IL) while all 2.5 cm (1.0 in) plots were mowed three times per week with a triplex reel mower (Toro Reelmaster® 3100-D w/Sidewinder, The Toro Company, Bloomington, IL). Clippings were returned. All mowing heights were based on bench settings.

From 13 April to 30 June, plots were fertilized on a weekly basis with agricultural grade ammonium nitrate (NH_4NO_3). Two nitrogen rates, 18 and 36 kg ha^{-1} week^{-1} (0.375 & 0.75 lbs N 1,000 ft^{-2}), were applied during the study. All low nitrogen treatments were applied using a calibrated rotary spreader (model # SR-2000, The Andersons, Maumee, Ohio) while high nitrogen treatment rates were hand fertilized in two directions with a shaker jar. Low N treatments received 225 kg N ha^{-1} (4.5 lbs N 1,000ft^{-2}) over the course of 12 weeks while high nitrogen treatments received 450 kg N ha^{-1} (9 lbs N 1,000ft^{-2}). To minimize turf injury, fertilizer was applied to dry turf, and all plots were immediately irrigated with 0.2 cm (0.076 in) of water.

Trifloxysulfuron was applied either in April or May at either a low (0.005 kg ai ha^{-1}, 0.1 oz a^{-1}) or high rate (0.017 kg ai ha^{-1}, 0.3 oz a^{-1}) using the 75 wettable formulation. Induce, a nonionic surfactant, was added to all mixes at 0.25 % v v^{-1}. Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated at 187 L ha^{-1} and a 2 m boom with Teejet 8003 flat fan nozzles.

Table 2-1. Cultural (whole plot factors) and trifloxysulfuron (TFS) (subplot factors) treatments of 2006 and 2007.

	Subplot factors		Whole plot factors	
Treatment	TFS†		Cultural treatments	
	Timing‡	Rate	Mowing height	Fertility rate
		Kg ai ha^{-1}	cm	kg N ha^{-1} $week^{-1}$
Low-April	April	0.005	1.2	18.3
High-April	April	0.017		
Low-May	May	0.005		
High-May	May	0.017		
Control	-	-		
Low-April	April	0.005		36.6
High-April	April	0.017		
Low-May	May	0.005		
High-May	May	0.017		
Control	-	-		
Low-April	April	0.005	2.5	18.3
High-April	April	0.017		
Low-May	May	0.005		
High-May	May	0.017		
Control	-	-		
Low-April	April	0.005		36.6
High-April	April	0.017		
Low-May	May	0.005		
High-May	May	0.017		
Control	-	-		

† A nonionic surfactant was added to all mixes at a rate of 0.25 % v v^{-1}.

‡ Mid-April applications were applied on April 14, 2006 and April 13, 2007. Mid-May applications were applied on May 16, 2006 and May 15, 2007.

Measurements

Turfgrass quality (TQ) was visually rated on a weekly basis using a scale from one to nine (1=dead/dormant turf; 9=exceptional turf color and density; 7= minimally acceptable turf). Perennial ryegrass density was visually rated weekly using 0-100% scale. Plots with a rating of 0 had no ryegrass, and plots with a rating of 100 had complete ryegrass coverage. Clippings were harvested monthly from a1.12 m^2 strip of each plot with a walk behind reel mower, dried at 71^oC (160^oF) for 72 hr, and weighed (g).

Bermudagrass root samples were obtained form each plot once a year from 11 June to 30 June using a standard golf course cup cutter (10.6 cm diameter x 15.24 cm deep) of both years. Root samples were separated from below the thatch layer, washed, collected using a sieve, dried at 71^oC (160^oF) for 72 hr, and weighed (g).

Bermudagrass shoot counts were measured twice during the study. Bermudagrass shoot counts were measured 5 days after the second treatment (DAST) and 43 DAST using a metal 7.62 x 7.62 cm grid with nine 2.54 x 2.54 cm squares. If a shoot was under the intersection of one of the 16 total, it was recorded as a positive "hit."

Statistical Design and Analysis

The field study was a split plot design with completely randomized whole plots and subplots and four replications. Trifloxysulfuron rate and timing were the sub-plot factors while nitrogen rate and mowing height were the whole plot factor. Two mowing heights (1.2 and 2.5 cm), two nitrogen rates (18 and 36 kg N ha^{-1} $week^{-1}$), and three trifloxysulfuron rates and application dates (high/low April, high/low May, and untreated) were examined in this study, and treatments were replicated four times as listed in Table 1.

Statistics were analyzed using analysis of variance the GLM procedure (PROCGLM) of SAS (SAS Institute, 2007) for all calculations. Treatment effect means were separated using Fisher's protected Least Significant Difference (LSD) test with an alpha of 0.05. All three-way factor interactions except percent ryegrass on 21 June 2007 were not significant at a 5% level of significance.

Results and Discussion

Due to significant treatment by year interactions, results for each year were examined separately.

Year 1 (2006)

Turfgrass Quality

Turf quality of 2.5 cm (1.0 in) height and trifloxysulfuron (TFS) treatments is in Table 2. Seven rating dates (22, 29 April, 29 May, and 7, 11, 18, 24 June) had significant two way interactions between mowing and herbicide treatments while fertility level and TFS interactions had five significant rating dates during 2006. However, only the untreated and 2.5 cm low April TFS treatments sustained acceptable turf quality while all other treatments experienced unacceptable quality for a minimum of 2 weeks. All April TFS treatments achieved acceptable turf quality by 29 May, and all May TFS treatments obtained acceptable turf quality on 24 June. Gelernter and Stowell (2005b) noted that warm weather >21.1^{o}C (>70^{o}F) following transition aid herbicides applications will result in short (2 to 3 week) periods of unacceptable turf quality while cooler weather may extend turf yellowing/browning to 8 weeks. Bare spots/voids within TFS treated plots may have been the result of TFS being applied to a <50% greened-up bermudagrass base or before optimal average air temperatures: 22.7^{o}C (73^{o}F) for five plus days (Gelernter and Stowell, 2005b)

Table 2-2. Effect of trifloxysulfuron (TFS) on turf quality in 2006.

	Rating date†					
TFS‡	22-Apr	6-May	21-May	7-Jun	18-Jun	30-Jun
			1 to 9			
Control	8.6	8.7	8.8	8.1	8.1	8.1
High-April	7.1	6.8	7.1	7.4	8.1	8.6
Low-April	7.3	7.4	7.3	7.9	8.4	8.6
High-May	-	-	8.4	6.6	6.9	8.4
Low-May	-	-	8.4	6.7	7.4	8.4
LSD (0.05)	0.22	0.21	0.35	0.35	0.34	0.36

† TQ was visually rated weekly using a scale of 1 to 9 with a rating of 9=exceptional color and density, 1=dead turf, and 7=minimally acceptable.
‡ Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated to 187 L ha^{-1} at either low or high rates (0.005 or 0.017 kg ai ha^{-1}, respectively) in mid-April and mid-May.

Percent Ryegrass Coverage

The combined effects of all treatments on the percentage of perennial ryegrass at studies end in 2006 are shown in Table 3. Despite maintaining acceptable turf quality, control treatments, 1.2 cm low April TFS treatments; and 2.5 cm low April TFS treatments possessed significant quantities (>17%) of perennial ryegrass at studies end. Despite abruptly losing significant quantities of perennial ryegrass after application, high and low April TFS treatments at 1.2 cm and low April TFS treatments at 2.5 cm experienced a reoccurrence in percent perennial ryegrass. This regrowth may be attributed to cold spell and rainfall events from 8 to 20 May. Horgan and Yelverton (2001) experienced a reappearance of perennial ryegrass in scalp and scalp/vertical mowing treated plots following a cool snap and rainfall event during early June. This cool snap with elevated fertility potentially encouraged the overseeded perennial ryegrass at the expense of the bermudagrass base (Hawes, 1982; McCarty, 2005; Howard and

Ellwood, 2006). Willis et al. (2007) credited SUs' failure to control perennial ryegrass to cold temperatures one week after application. However, Gelernter and Stowell (2005b) noted that application timing of trifloxysulfuron had little effect on its performance as a spring transition aid. Willis et al. (2007) recommended TFS applications even if cold temperatures were present during application and still observed acceptable results nine weeks after cool weather TFS applications despite an initial two week lag. Amino acid production slows with cooler temperatures causing slower control with SUs (Willis et al., 2007).

Table 2-3. Effect of mowing height, N rate, and trifloxysulfuron (TFS) on percent perennial ryegrass during final rating date (30 June 2006).

Mowing height	N rate	TFS†	Ryegrass‡
cm	kg ha^{-1} week^{-1}		%
1.2	18.3	Low-April	27.5
		High-April	10.0
		Low-May	20.0
		High-May	0.0
		Control	52.5
	36.6	Low-April	15.0
		High-April	0.0
		Low-May	0.0
		High-May	0.0
		Control	37.5
2.5	18.3	Low-April	22.5
		High-April	10.0
		Low-May	17.5
		High-May	12.5
		Control	57.5
	36.6	Low-April	12.5
		High-April	0.0
		Low-May	2.5
		High-May	0.0
		Control	42.5
LSD (0.05)			11.06

† Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated to 187 L ha^{-1} at either low or high rates in mid-April and mid-May (0.005 or 0.017 kg ai ha^{-1}, respectively). Mid-April applications were applied on April 14, 2006. Mid-May applications were applied on May 16, 2006.

‡ Ryegrass was visually rated weekly using a scale of 0 to 100%.

Clipping Yields

Significant two way interactions between height and TFS were observed in 2006 during both May and June harvests (Table 4). During the May harvest, untreated and

May treatments at 1.2 cm yielded the most clippings, signifying a high percentage of perennial ryegrass was still present. The 1.2 cm height and low April TFS rate yielded significantly more clippings than 1.2 cm height and high April TFS, indicating little ryegrass remained in high April TFS treatments. Yelverton (2004) also observed more effective perennial ryegrass control with 0.017 kg ai ha^{-1} (0.3 oz ac^{-1}) TFS applications. With the June harvest, high and low April TFS and 1.2 cm height treatments contained 175% more biomass than both May TFS treatments and 1.2 cm height. These yields suggest 1.2 cm mowing height and April TFS treatments contained denser bermudagrass stands, and both May TFS treatments at 1.2 cm height possessed little or no perennial ryegrass plus reduced bermudagrass density in June. However, these yields contradict percent perennial ryegrass observations. Although low April TFS treatments at 1.2 cm contained 10 to 16% more ryegrass present versus other TFS treatments, clipping yields were not inflated by ryegrass present.

Table 2-4. Combined effect of mowing height and trifloxysulfuron (TFS) treaments on clipping yields in 2006.

		Harvest date†	
Mowing	TFS‡	May 21	June 28
Cm		$g \cdot m^{-2}$	
1.2	Control	6.3	9.6
	High-April	0.9	8.6
	Low-April	3.1	9.3
	High-May	5.5	2.7
	Low-May	5.7	3.9
2.5	Control	0.4	0.9
	High-April	0.1	0.3
	Low-April	0.2	0.1
	High-May	0.4	0.4
	Low-May	0.4	0.3
LSD (0.05)		0.77	1.28

† Clippings were harvested 5 and 43 days (May and June, respectively) after the May TFS application (14 May) by mowing a 1.1 m^2 strip of each treatment, dried at 71°C for 72 hr, and weighed (g).
‡ Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated to 187 L ha^{-1} at either low or high rates (0.005 or 0.017 kg ai ha^{-1}, respectively) in mid-April and mid-May.

Bermudagrass Shoot Counts

Significant combined effects of nitrogen rate and TFS were observed with bermudagrass shoot counts in June 2006 (Table 6). Bermudagrass shoot counts supported percent ryegrass/ bermudagrass observations and measurements. On 25 June April and May TFS applications at high fertility and all TFS applications at low fertility had highest bermudagrass shoot counts (95 to 100%).

All TFS treated plots possessed significantly more bermudagrass shoot counts than either high- or low-fertility control treatments (73 and 60%, respectively). High fertility control treatments had significantly more bermudagrass shoot counts versus low fertility control treatments (73 vs. 60%, respectively). Although elevated fertility alone did not provide 100% bermudagrass counts/coverage, it did improve bermudagrass coverage for all treatments.

Year 2 (2007)

Turfgrass Quality

Turf quality was significantly impacted by mowing height and TFS treatments in 2007 (Table 7). Untreated and 1.2 cm height and low May TFS treatments at both fertility levels maintained acceptable (>7) quality for the duration of the study (Figure 2). All other treatments experienced unacceptable turf quality for a minimum of two weeks. One to two weeks after application, all April TFS treatments experienced unacceptable turfgrass quality for ≥2 weeks regardless of fertility and mowing height. The significant loss of April TFS treatment's turfgrass quality coincided with their sharp reduction in percent perennial ryegrass coverage. The abrupt transition occurred before the bermudagrass base could fill the vacated ryegrass voids, resulting in thin, non-uniform bermudagrass stands, which may have been avoided with a ≥80% greened-up bermudagrass base and daily air temperatures ≥23^{o}C for more than five consecutive days (McCarty, 2005; Gelernter and Stowell, 2005b; Yelverton, 2004). Since high May TFS treatments at 1.2 cm abruptly lost their perennial ryegrass cover, they experienced unacceptable turf quality for three weeks. Both 2.5 cm May TFS treatments also experienced sharp reductions in turf quality following application, resulting in unacceptable turfgrass quality for two weeks. Perennial ryegrass at 2.5 cm shaded both

May TFS treatments and impaired bermudagrass percentages prior to application, resulting in unacceptable spring transitions (Bruneau et al., 1985; Beard, 2002; Gelernter and Stowell, 2005b; Yelverton, 2005). However, all treatments achieved acceptable turf quality by 1 July 2007.

Table 2-5. Combined effect of 1.2 cm mowing height and trifloxysulfuron (TFS) on turf quality (TQ) in 2007.

	Rating date†						
TFS ‡	19-Apr	30-Apr	16-May	28-May	6-Jun	21-Jun	3-Jul
	1 to 9						
Control	9.0	8.8	8.9	8.9	8.9	8.7	8.6
High-April	8.6	5.8	6.2	8.3	9.0	9.0	9.0
Low-April	8.7	6.2	6.7	8.8	9.0	9.0	9.0
High-May	-	-	8.7	6.9	6.5	8.8	9.0
Low-May	-	-	8.8	7.6	7.1	9.0	9.0
LSD (0.05)	0.16	0.20	0.26	0.67	0.31	0.24	0.19

† Turf quality was visually rated weekly using a scale of 1 to 9 with a rating of 9=exceptional color and density, 1=dead turf, and 7=minimally acceptable
‡ Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated to 187 L ha^{-1} at either low or high rates (0.005 or 0.017 kg ai ha^{-1}, respectively) in mid-April and mid-May.

Percent Ryegrass Coverage

Percentages of perennial ryegrass present per treatment at studies end for 2007 are in Table 8. Perennial ryegrass percentages were not different between high and low TFS rates. At studies end, all TFS treatments contained 0% ryegrass; while the control at 1.2 and 2.5 cm heights treatments with either high or low fertility rate had 18 and 31% more ryegrass, respectively. However, 1.2 cm control treatments had 11% less ryegrass present versus 2.5 cm controls regardless of fertility level (18 and 29%, respectively). Close mowing with 15.6^{o}C night temperatures adversely affected overseeded turf, reduced competition, and warmed the soil surface to enhance bermudagrass recovery (Bruneau et al., 1985). The high fertility rate decreased the percent perennial ryegrass in 1.2 cm control treatments by 9% versus the matching low fertility controls (25 and 36%, respectively). All controls possessed unacceptable amounts of perennial ryegrass at studies end (1 July 2007). Horgan and Yelverton (2001) concluded that cultural treatments, biweekly vertical mowing, scalping, core cultivation, and vertical mowing/ scalping or two application timings of NH_4NO_3, alone do not consistently hasten perennial ryegrasses' ultimate disappearance from overseeded bermudagrass. However, Horgan and Yelverton (2001) noted a hastened transition 7 and 13 wks after the initial application of the spring transition-aid herbicide pronamide. Perennial ryegrass percentages drastically dropped one to two weeks following TFS treatments.

Table 2-6. Effect of mowing height, N rate, and trifloxysulfuron (TFS) on percent perennial ryegrass during final rating date (1 July 2007).

Mowing height	N rate	TFS†	Ryegrass‡
cm	kg ha^{-1} week^{-1}		%
1.2	18.3	Low-April	0.0
		High-April	0.0
		Low-May	0.0
		High-May	0.0
		Control	20.0
	36.6	Low-April	0.0
		High-April	0.0
		Low-May	0.0
		High-May	0.0
		Control	16.0
2.5	18.3	Low-April	0.0
		High-April	0.0
		Low-May	0.0
		High-May	0.0
		Control	31.0
	36.6	Low-April	0.0
		High-April	0.0
		Low-May	0.0
		High-May	0.0
		Control	26.0
LSD (0.05)			4.38

† Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated to 187 L ha^{-1} at either low or high rates in mid-April and mid-May (0.005 or 0.017 kg ai ha^{-1}, respectively). Mid-April applications were applied on April 13, 2007. Mid-May applications were applied on May 15, 2007.

‡ Ryegrass was visually rated weekly using a scale of 0 to 100%.

Clipping Yield

Trifloxysulfuron was the only treatment that significantly impacted clipping yield during all three rating dates (Table 9). During the April harvest, non TFS treated plots yielded the most clippings, indicating intacted overseeding stands. April TFS treatments yielded 600% less clippings versus untreated and May TFS treatments. Poor yields from April TFS treatments indicated little perennial ryegrass was present and the bermudagrass base was not actively growing.

In May, untreated plots produced 70 to 419% more clippings than May and April TFS treatments, respectively, indicating a significant perennial ryegrass stand. Meanwhile, May treatments yielded 200% more clippings than April treatments, suggesting May treatments had significant quantities of perennial ryegrass present. April TFS treatments yielded the least clippings, indicating bermudagrass monostands.

During the June harvest, April TFS treatments yielded the most clippings, suggesting an aggressively growing bermudagrass stand was present. Perennial ryegrass may have been present in the low May TFS treatments, inflating the clipping yield while the high May TFS treatment possessed little to no perennial ryegrass thus lower clipping yields.

Table 2-7. Effect of trifloxysulfuron (TFS) on clipping yields in 2007.

		Harvest date‡	
TFS †	April 30	May 20	June 27
		$g \cdot m^{-2}$	
Control	6.3	16.1	13.4
High-April	0.9	2.4	16.5
Low-April	1.0	3.8	18.0
High-May	-	9.2	10.1
Low-May	-	9.4	13.9
LSD (0.05)	2.40	2.64	4.09

† Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated to 187 L ha^{-1} at either low or high rates (0.005 or 0.017 kg ai ha^{-1}, respectively) in mid-April and mid-May.
‡ Clippings were harvested monthly by mowing a 1.1 m^2 strip of each treatment, dried at 71^{o}C for 72 hr, and weighed (g).

Dry Root Weight

The single interaction of TFS on 2007 dry root weights is in Table 10. Only TFS produced significant difference between dry root weights in 2007. Both April treatments had 20 to 50% less dry root mass versus untreated treatments; however, low April TFS treatments had similar root yields to low May TFS treatments. Although neither percent perennial ryegrass nor bermudagrass shoot counts revealed any ryegrass in May TFS treated plots, dead/decaying ryegrass roots may have inflated control and May TFS treatments. Meanwhile, April TFS treatments' root yields were lower and similar to that of non-overseeded bermudagrass (not listed). Less root mass possibly equates to a healthier bermudagrass stand without perennial ryegrass pressure.

Table 2-8. Effect of trifloxysulfuron (TFS) on dry root weights (cg) in 2007.

TFS †	Dry root weight‡
Control	118.6
High-April	83.4
Low-April	96.8
High-May	118.7
Low-May	107.4
LSD (0.05)	13.85

† Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated to 187 L ha^{-1} at either low or high rates (0.005 or 0.017 kg ai ha^{-1}, respectively) in mid-April and mid-May.
‡ Roots were sampled with a standard golf course cup cutter (10.6 cm diameter x 15.24 cm deep) from 11 June to 30 June, separated from below the thatch layer, washed, collected using a sieve, dried at 71^{o}C for 72 hr, and weighed (g).

Percent Bermudagrass Coverage

Percent bermudagrass response to mowing height and TFS is shown in Table 11, and percent bermudagrass response to fertility rate and TFS is in Table 12. Combined interactions of mowing height with TFS and fertility with TFS were observed on 21 June and 1 July, and TFS alone was significant at all other rating dates. On 1 July, untreated 1.2 and 2.5 cm controls had 21 to 35% less bermudagrass coverage, respectively, versus TFS treatments (100%). Regardless of TFS treatment, on 21 June, all 1.2 cm mowing height and 36 kg N ha^{-1} $week^{-1}$ (0.75 lbs N 1,000 ft^{-2} $week^{-1}$) treatments possessed 0 to 9% more bermudagrass than their matching 2.5 cm treatment. The lower mowing heights weakened the perennial ryegrass and reduced its adverse shading effects on the bermudagrass base (McCarty, 2005). High fertility control treatments possessed >9% more bermudagrass versus low fertility control treatments on 21 June and >6 % more bermudagrass on 2 July. The added fertility enabled the bermudagrass base to effectively compete with the ryegrass while progressively exhausting the overseedings' carbohydrate reserves (Howard and Ellwood, 2006). To achieve a smoother spring transition, Gelernter and Stowell (2005b) recommended complimenting transition aid herbicides with a grow-in fertilizer regime starting six weeks before spring transition aid application. Early or late applied NH_4NO_3 enhanced bermudagrasss shoot density in both years (Horgan and Yelverton, 2001). Because April TFS treatments reduced ryegrass competition for resources (light, water, and nutrients) at an earlier date, they achieved full bermudagrass coverage and uniformity before May TFS treatments (Horgan and Yelverton, 2001). April TFS treatments had 20 to 25% and 18 to20 % more bermudagrass coverage versus May TFS treatments on 22 May 22 and 13 June, respectfully.

Table 2-9. Combined effect of mowing height and trifloxysulfuron (TFS) on percent bermudagrass in 2007.

Mowing height	TFS†	Percent bermudagrass‡ 27-Apr	22-May	13-Jun	1-Jul
Cm		——— % ———			
1.2	Control	41.5	47	68.5	83
	High-April	63	67.5	100	100
	Low-April	67.5	71	100	100
	High-May	41.5	48	85	100
	Low-May	41.5	50	86.5	100
2.5	Control	32.5	37	67.5	74
	High-April	48	63.5	100	100
	Low-April	43.5	61	96.5	100
	High-May	30	39.5	75.5	99
	Low-May	32.5	38.5	82.5	99.5
LSD (0.05)		3.75	4.63	7.75	2.34

† Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated to 187 L ha^{-1} at either low or high rates (0.005 or 0.017 kg ai ha^{-1}, respectively) in mid-April and mid-May. Mid-April applications were applied on April 13, 2007. Mid-May applications were applied on May 15, 2007.
‡ Bermudagrass percentages were visually rated weekly using a scale of 0 to 100%.

Bermudagrass Shoot Counts

Bermudagrass shoot counts response to mowing height and TFS is presented in Table 13. Bermudagrass shoot counts supported percent ryegrass/bermudagrass observations and measurements. On April 22, both rates of TFS at 1.2 cm heights had 50% more bermudagrass shoots versus both controls and both May TFS treatments at 1.2 and 2.5 cm (69 vs. ~20%, respectively).

On 6 June, all 1.2 and 2.5 cm April TFS treatments and 1.2 cm height May TFS treatments possessed 25 to 52% more bermudagrass shoots (100%) than all other treatments (100 vs. 48-75%, respectively). May 2.5 cm TFS treatments had more shoots versus both 1.2 and 2.5 cm controls (75 and 63%, respectively). Untreated 1.2 cm (96%) and 2.5 cm (79%) height had less bermudagrass shoots than April and May TFS treatments (100%) at studies end.

Table 2-10. Combined effect of mowing height and trifloxysulfuron (TFS) applications on bermudagrass shoot counts in 2007.

		Bermudagrass shoot counts†			
Mowing height	TFS‡	23-Apr	22-May	6-Jun	1-Jul
Cm		%			
1.2	Control	26.0	45.4	62.7	95.2
	High-April	68.3	96.7	100.0	100.0
	Low-April	69.2	95.8	100.0	100.0
	High-May	-	59.8	95.2	100.0
	Low-May	-	66.0	94.8	100.0
2.5	Control	11.9	39.6	50.0	80.4
	High-April	68.5	95.8	100.0	100.0
	Low-April	56.9	96.3	100.0	100.0
	High-May	-	40.0	75.8	100.0
	Low-May	-	45.2	73.8	99.6
LSD (0.05)		5.16	5.52	2.84	2.28

† Bermudagrass shoot counts were measured using a metal 7.62 x 7.62 cm grid with nine 2.54 x 2.54 cm squares. Bermudagrass shoots at each intersection were recorded as a positive 'hit'. The total number of 'hits' was divided by the total number of intersections (48) and multiplied by 100 to achieve percent bermudagrass shoots.

‡ Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated to 187 L ha^{-1} at either low or high rates (0.005 or 0.017 kg ai ha^{-1}, respectively) in mid-April and mid-May.

Conclusion

Untreated plots maintained acceptable turf quality during both studies; however, they possessed 47% (2006) and 23% (2007) ryegrass coverage, less bermudagrass density, and fewer bermudagrass shoot counts than TFS treated plots. The 1.2 cm mowing height in 2006 and 2007 and the increased fertility level, 36 kg N ha^{-1} $week^{-1}$ (0.75 lb N 1,000 ft^{-2}) in 2007 reduced perennial ryegrass pressure while promoting the bermudagrass base (Askew et al, 2005; Gelernter and Stowell, 2005b). Nevertheless, both cultural practices failed to provide a completely "seamless" transition. Prolonged perennial ryegrass cover often compromises the bermudagrass base and eventually causes it to deteriorate (Yelverton, 2004; McCarty, 2005). It has been suggested that bermudagrass requires ~90 to 100 days of ideal growing conditions free from overseeding pressure to fully recover and maintain a strong base (McCarty, 2005; Yelverton, 2005; Horgan and Yelverton, 1998). Therefore, transition aid herbicides are often needed to ensure the bermudagrass stand has sufficient time to fully regenerate (Willis et al., 2007; Askew et al., 2005; Gelernter and Stowell, 2005b; Horgan and Yelverton, 1998).

Although no treatment(s) was consistent over both years, the low May trifloxysulfuron (0.005 kg ai ha^{-1}) rate at 1.2 cm mowing height and 36 kg N ha^{-1} $week^{-1}$ (0.75 lb N 1,000ft^{-2}) fertility treatments maintained acceptable turf quality throughout 2007. Despite maintaining acceptable turf quality throughout 2006, the low April TFS treatment at 2.5 cm height still possessed 50% perennial ryegrass. Other April treatments experienced unacceptable turf quality both years as the perennial ryegrass transitioned abruptly before the bermudagrass became actively growing. Subsequently, the bermudagrass base could not rapidly fill in the vacated perennial ryegrass voids. Bermudagrass percentages were 10 to 25% higher going into the May applications versus April applications, enabling May treatments to experience minimal losses of turf quality (Askew et al., 2005; Gelernter and Stowell, 2005b; Horgan and Yelverton, 1998). A poor 2006 spring transition may be attributed to unseasonably cool, wet spring, which favored the overseeding (Gelernter and Stowell, 2005a; Horgan and Yelverton, 1998; Hawes, 1982). Meanwhile, the hot and dry spring and summer of 2007 were more conducive for an effective spring transition, which may explain why a distinct successful treatment emerged (Horgan and Yelverton, 1998). Gelernter and Stowell (2005b) suggested adopting a grow-in fertilizer regime and reducing the height of cut before applying spring transition aid herbicides to minimize the loss of turf quality.

In Clemson, SC, cultural practices must be coupled with spring transition aid herbicides to achieve a complete, timely spring transition. Under normal spring and summer conditions, 1.2 cm mowing height, 36 kg ha^{-1} $week^{-1}$ (0.75 lb N wk^{-1}) and 0.005 kg ai ha^{-1} (0.1 oz a^{-1}) mid-May trifloxysulfuron application provides acceptable turf quality and spring transition.

Literature Cited

Askew, S.D., D. McCall, W. L. Barker, and J. B. Beam. 2005. Chemical transitions on overseeded golf fairways and athletic fields. VA Turfgrass J. January/February:22-23.

Beard, J.B. 2002. Turf Management for Golf Courses. Ann Arbor Press. Chelsea, MI.

Bruneau, A.H., J.M. Dipaola, W.M. Lewis, W.B. Gilbert, and L.T. Lucas. 1985. Overseeding bermudagrass turf. N.C. Agric. Ext. Sev. AG-352.

Gelernter, W. and L. Stowell. 2005a. Improved overseeding programs 1. the role of weather. Golf Course Manage. 73(3):108-113.

Gelernter, W. and L.J. Stowell. 2005b. Improved overseeding programs: 2. managing the spring transition. Golf Course Manage. 73(3):114-118.

Hawes, D.T. 1982. Some ideas for easing the southern transition blues. USGA Green Section Record. 20(6):1-3.

Horgan, B. and F. Yelverton. 1998. Removing overseeded ryegrass from bermudagrass. Grounds Maintenance. 33(1):18,22-25.

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

Howard, H. F. and P. Ellwood. 2006. Proactive transition: part II: making it happen. Golf Course Manage. 74(3):111-114.

Kopec, D.M., J. Gilbert, K. Marcum, M. Pessarakli, and D. Jensen. 2001. Effect of overseeding rate on spring transition: the evidence shows that more is not better. USGA Green Section Record. 39(4):10-12.

Mazur, A.R. and D.F. Wagner. 1987. Influence of aeration, topdressing, and vertical mowing on overseeded bermudagrass putting green turf. HortScience. 22(6):1276-1278.

McCarty, L.B. 2005. Best Golf Course Management Practices. Prentice-Hall Inc. Upper Saddle River, NJ.

Ostmeyer, T. 2004. Golf's extreme makeover: for many, overseeding is a necessary evil, but is it really only skin deep? Golf Course Manage. 72(7):50-52,56,58,60.

SAS Instituet Inc. 1999. SAS Version 9.1. SAS Inst., Cary, NC.

Willis, J.B., S.D Askew, and B.W. Compton. 2007. Cold influences overseeded perennial ryegrass control: cold temperatures have a direct impact on the effectiveness of some sulfonylurea herbicides used for overseeded perennial ryegrass control in the transition zone. Golf Course Manage. 75(5):118-120.

Yelverton, F. 2004. In transition: new sulfonylurea herbicides offer options for transitioning overseeded turf into spring. Grounds Maintenance. 39(2):33-36.

Yelverton, F. 2005. Spring transition: going, going, gone: removal of overseeded perennial ryegrass from bermudagrass is a must. USGA Green Section Record. 43(2):22-23

CHAPTER 3

ALLELOPATHIC EFFECTS OF PERENNIAL RYEGRASS ON BERMUDAGRASS SEEDLINGS

Introduction

When overseeding a permanent grass such as bermudagrass with perennial ryegrass during the spring and early summer months, the perennial ryegrass is growing optimally and its upright growth shades the base grass. Although the inter-stand competition between both species is obvious, ryegrass allelopathy has been proposed to further complicate spring transition. Allelopathy, the suppression of growth of one plant species by another through the release of chemicals into the environment, has been documented for many plants. Allelopathic effects on indicator species and certain turfgrasses; however, ryegrass allelopathy on bermudagrass has been suggested but not documented.

Perennial ryegrass has inhibitory/allelopathic effects on 'Zenith' zoysiagrass (*Zoysia japonica* Steud.), duckweed (*Lemna minor* L.), alfalfa (*Medicago sativa* L.), nodding thistle (*Caruus nutans* L.), white clover (*Trifolium repens* L.), medics (*Medicago* spp.), and lettuce (*Lactuca sativa* L.) (Gussin and Lynch, 1981; Buta et al., 1987; Takahashi et al., 1988; 1991; 1993; Nicholson et al., 1990; Quigley et al., 1990; Prestidge et al., 1992; Chung and Miller, 1995; Mattner and Parbery, 2001; Zuk and Fry, 2006). Koski and Newberry (2004) proposed either intense ryegrass competition or allelochemicals impeded Kentucky bluegrass (*Poa pratensis* L.) establishment into perennial ryegrass stands at fairway height. Rao and Buta (1983) extracted nineteen phenolic compounds from ‘Citation’ perennial ryegrass, which negatively impacted lettuce germination. Crabgrass seedling inhibition, chlorosis, and premature death were observed when grown on ryegrass extract tainted agar (King, 1997).

Experiments that monitor indicator species germination and growth in the presence of leachates, extracts, or debris of potential allelopathic agents are acceptable ways of establishing and understanding allelopathic potential and subunits (Inderjit and Keating, 1999; Iderjit and Weston, 2000). The objective of this research at Clemson University was to determine if perennial ryegrass tainted soil media and irrigation water would inhibit common bermudagrass establishment and growth in a controlled environment.

Materials and Methods

Perennial Ryegrass Solution Experiments

The objective of this study was to evaluate bermudagrass germination and growth when irrigated with deionized water tainted with perennial ryegrass debris. A blend of ‘Icon’ (44.55%); ‘Vixen’ (34.51%); and ‘Overdrive’ (19.54%) perennial ryegrass was seeded on 10 January 2008 at 341 kg ha^{-1} (300 lbs ac^{-1}) (PLS) in 52 x 26 x 6.5 cm deep flats containing an 85:15 (v/v %) sand to peat root mix. Perennial ryegrass flats were maintained for 2 months at a height of 5 cm. Flats were watered daily with 1.3 cm of tap water, and fertilized weekly starting two weeks after germination with a soluble fertilizer 16 N-2.6 P-6.6 K to provide 24.4 kg N ha^{-1} $week^{-1}$ (0.5 lbs N 1,000ft^{-2} $week^{-1}$). After two months, perennial ryegrass shoots and roots were harvested, and cut into 1 cm segments. Leaves or roots were placed in deionized water in 2.0 L plastic containers for 48 hrs to provide tissue at 5, 10, or 20 $g \cdot L^{-1}$. After 48 hrs, the solution was screened and vacuumed filtered of debris and stored in a cooler at 5^{o}C until bermudagrass irrigation.

On 17 March 2008, 10 x 10 x 9 cm pots were filled with germination mix (Fafard Germination Mix Super Fine: 60% Canadian sphagnum peat; 25% perlite; 15% vermiculite), and saturated with 300 ml of solution. Twenty ‘Arizona Common’ bermudagrass (*Cynodon* spp.) seeds were placed on the potting soil in each pot, and pots were placed within a growth chamber set at 30/25^{o}C (day/night) with a 16 h photoperiod (331 $umol \cdot m^{-2}s^{-1}$) for 35 d and irrigated daily with 30 ml of designated irrigation solution. Pots were removed on April 2008 and placed in cooler at 5^{o}C until seedlings were harvested. Samples of irrigation solution were analyzed for macro- and micro-nutrients, pH, and conductivity, and soil from the surface 2.5cm of each pot was collected and tested for salinity level and macro- and micro-nutrients.

Identical parameters for assessing bermudagrass germination and growth with ryegrass amended soil were employed for ryegrass tainted irrigation solutions.

Statistical Design and Analysis

Both root and shoot tainted irrigation solutions experimental designs were a 2 (root or leaf amendment) x 3 (5, 10, or 20 $g \cdot L^{-1}$) factorial plus a control in a completely randomized design with four replications, and studies were repeated simultaneously. Since results between root and shoot experiments were variable, they are presented separately. Data was analyzed in two steps using the Statistical Analysis Systems (SAS, 2006) general linear model (GLM) procedure. Pairwise comparisons versus the control were performed for each treatment combination using the t tests. The analysis of variance (ANOVA) used to test for effects of soil amendments and levels in the 2 x 3 factorial. Means were separated using Fisher's protected LSD tests and linear, quadratic, and cubic models (Zuk and Fry, 2006).

Soil Amended Studies

The objective of this study was to evaluate bermudagrass germination and growth in soil amended with perennial ryegrass root and shoot debris. A blend of 'Icon' (44.55%); 'Vixen' (34.51%); and 'Overdrive' (19.54%) perennial ryegrass [*Lolium perenne* (L.)] was seeded at 454 kg ha^{-1} (400 lbs ac^{-1}) pure live seed (PLS) in 52 x 26 x

6.5 cm deep flats containing an 85:15 (v/v %) sand to peat root mix on 2 September 2007. Perennial ryegrass was maintained at 5 cm with hand-held clipper, and flats were watered daily with 1.3 cm tap water. Three weeks after germination, flats were fertilized with water soluble fertilizer 16N-2.64P-6.6K to provide 350 mg N week^{-1} (0.25 lbs N 1,000 ft^{-2} week^{-1}). Perennial ryegrass shoots and roots were harvested after 2 months, cut into 1 cm segments, and either roots or shoots incorporated at 0%, 2%, 12%, and 23% of soil weight into the surface 2.5 cm germination mix (Fafard Germination Mix Super Fine: 60% Canadian sphagnum peat; 25% perlite; 15% vermiculite). Twenty-five grams of potting soil were mixed with perennial ryegrass root or shoot segments to produce the 2.5 cm deep amended soil layer. The amended soil layer was placed atop 37 g (3.5 cm deep) of potting soil in 10 x 10 x 6 cm deep containers.

On 30 November 2007, thirty PLS 'Arizona Common' bermudagrass (*Cynodon* spp.) seeds were placed on the soil surface in each pot and moved into a growth chamber set at 30/25^{o}C (day/night) with a 16 h photoperiod (417 umol$\cdot$m^{-2} s^{-1}) for 24 days. Treatments were watered twice daily with deionized water (5 mm d^{-1}). After 24 d, pots were removed and set at 5^{o}C until harvest. Bermudagrass plants were harvested, and seedling number, tiller number, shoot dry weight, root length density (RLD), root mass density (RMD), specific root length (SRL) and root ash weight were recorded. Bermudagrass shoot dry weight was obtained by drying the plant tissue in a convection oven at 71^{o}C for 72 h then weighed. Roots were washed of germination mix, scanned (Epson Expression 1680, Seiko Epson Corp., Japan) and analyzed with WinRhizo (Regent Instruments Inc., Quebec, Qc, Canada) root measuring software. After scanning, roots were dried in convection oven at 71°C for 72 h, weighed, placed in a muffle furnace at 900°C for 2 h, cooled, and weighed again. Ash weight was obtained by subtracting muffle furnace weight from convection oven weight.

Statistical Design and Analysis

Both experimental designs were a 2 (root or leaf amendment) x 3 (2%, 12%, or 23% by weight) factorial plus a control in a completely randomized design with four replications, and studies were repeated simultaneously. Since results between root and shoot experiments were variable, they are presented separately. Data was analyzed in two steps using the Statistical Analysis Systems (SAS, 1999) general linear model (GLM) procedure. Pairwise comparisons versus the control were performed for each treatment combination using the t-tests. The analysis of variance (ANOVA) used to test for effects of soil amendments and levels in the 2 x 3 factorial. Means were separated using Fisher's protected LSD tests and linear, quadratic, and cubic models (Zuk and Fry, 2006).

Allelopathy Ryegrass Root Tainted Irrigation Water

Results and Discussion

Since interactions between treatments and studies were not significant, both results between both studies were combined. Bermudagrass responses are reported as individual treatment means evaluating the effect of ryegrass tainted irrigation solution on shoot and tiller number, shoot and ash weight, RLD, RMD, and SRL. Responses of bermudagrass shoot and tiller number, shoot and ash weight, RLD, RMD, and SRL to varying concentrations of perennial ryegrass root tainted irrigation solution are presented in Table 13.

Shoot Number

Shoot numbers were not significantly different between root solution concentrations, and root solutions did not impact bermudagrass germination.

Tiller Number

A positive linear relationship was observed with bermudagrass tiller numbers when irrigated with ryegrass root tainted water. More tillers were present with increasing rates of ryegrass roots, and the highest concentration of roots (20 $g \cdot L^{-1}$) possessed 39 to 80% more tillers versus all other treatments (32 vs. 17 to 23, respectively).

Shoot Weight

When irrigated with root tainted solutions, a positive linear relationship was observed with bermudagrass shoot weights. Bermudagrass shoot weights progressively increased with increasing rates of ryegrass roots, and the highest concentration of ryegrass roots (20 $g \cdot L^{-1}$) yielded the highest bermudagrass shoot weights (0.8 g) versus the other three treatments, suggesting no allelopathic effect.

Ash Weight

A linear relationship with bermudagrass ash weight was observed when irrigated with root soaked solutions. Bermudagrass ash weight increased linearly with increasing rates of ryegrass roots, and the highest concentration of roots (20 $g \cdot L^{-1}$) possessed 100% more root mass than all other treatments.

Root Mass Density (RMD) Root Length Density (RLD) & Specific Root Length (SRL)

Root mass density increased linearly with increasing concentrations of ryegrass roots in solution, and the highest concentration of ryegrass roots (20 $g \cdot L^{-1}$) had the greatest RMD. However, no relationships with SRL and RLD were observed, and all treatments possessed similar yields when irrigated with root tainted solutions.

Table 3-1. Bermudagrass germination and growth response to increasing concentrations of perennial ryegrass root tainted irrigation water.

Perennial ryegrass†	Shoot no.	Tiller no.	Shoot weight	Ash weight	Root length density (RLD)	Root mass density (RMD)	Specific root length (SRL)
$g \cdot L^{-1}$	0-20	No.	Grams	grams	$cm \cdot m^{-3}$	$g \cdot cm^{-3}$	$cm \cdot g^{-1}$
0	10.4	17.6	0.3	0.2	2.7	3.0×10^{-4}‡	9846
5	11.9	22.9	0.4	0.2	2.9	3.0×10^{-4}	9443
10	10.5	22.8	0.5	0.2	2.4	3.0×10^{-4}	8796
20	12.9	32.3	0.8	0.3	2.9	4.0×10^{-4}	7755
Source of variation							
Linear	NS	*	*	*	NS	*	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS
Cubic	NS	NS	NS	NS	NS	NS	NS

† Fresh perennial ryegrass roots were soaked in deionized water at 0, 5, 10, or 20 ($g \cdot L^{-1}$) for 48 hours.

‡ Exponential expression for root mass density (RMD).

* Significant at 0.05 probability level.

Allelopathy Ryegrass Shoot Tainted Irrigation Water

Results and Discussion

Since interactions between treatments and studies were not significant, both results between both studies were combined. Bermudagrass responses are reported as individual treatment means evaluating the effect of ryegrass tainted irrigation solution on shoot and tiller number, shoot and ash weight, RLD, RMD, and SRL. Responses of bermudagrass shoot and tiller number, shoot and ash weight, RLD, RMD, and SRL to varying concentrations of perennial ryegrass shoot tainted irrigation solution are presented in Table 14.

Shoot Number

When irrigated with ryegrass shoot amended solutions, a linear relationship was observed with bermudagrass shoot number; however, the highest concentration of ryegrass shoots (20 g L^{-1}) possessed more bermudagrass shoots than both control and 10 g L^{-1} (2.464 and 1.089 more shoots, respectively). These results contradict those of Zuk and Fry (2006) who observed zoysiagrass seeds' inhibition when exposed to ryegrass tainted irrigation.

Tiller Number

A linear relationship was also observed with bermudagrass tiller numbers when irrigated with shoot amended water. Tiller numbers increased with increasing concentrations of shoots immersed in solution, but 10 and 20 g L^{-1} solutions possessed similar tiller numbers (36).   These results vary from that of Zuk and Fry (2006), and suggest no allelopathic interaction occurred.

Shoot Weight

A possible rate response was observed with shoot tainted irrigation solutions. Both 10 and 20 $g \cdot L^{-1}$ solutions yielded similar shoot weights, and both yielded more than untreated pots (1.0 vs. 0.4, respectively), suggesting no allelopathic/inhibitory interaction.

Ash Weight

The 10 $g \cdot L^{-1}$ shoot solution had 50% higher root weights versus the control and 20 $g \cdot L^{-1}$ shoot solution. This is possible evidence of rate response curve where ash weights crested with the 10 $g \cdot L^{-1}$ treatment.

Root Mass Density (RMD) Root Length Density (RLD) Specific Root Length (SRL)

A rate/concentration response was observed with RMD, and the 10 $g \cdot L^{-1}$ solution had 100 and 50% more RMD versus the untreated and 20 $g \cdot L^{-1}$ concentrations, respectively, indicating no allelopathic/inhibitory effects on bermudagrass RMD.

Although neither a linear nor quadratic relationship was observed with shoot tainted irrigation solutions, Fisher's protected LSD showed that the control had 44 % more SRL versus the 10 $g \cdot L^{-1}$ solutions. The highest ryegrass tainted solution (20 $g \cdot L^{-1}$) had similar SRLs as the control and 10 $g \cdot L^{-1}$. This is the only evidence of an inhibitory /allelopathic effect of ryegrass root or shoot tainted irrigation solutions on bermudagrass growth. A rate response may have been present where 10 g·L^{-1} lowered bermudagrass' SRL, but the highest concentration (20 g·L^{-1}) and untreated were unaltered. Zuk and Fry (2006) also observed varying rate responses with zoysiagrass irrigated with ryegrass tainted solution

Table 3-2. Bermudagrass germination and growth response to increasing concentrations of perennial ryegrass shoot tainted irrigation water.

Perennial ryegrass†	Shoot no.	Tiller no.	Shoot weight	Ash weight	Root length density (RLD)	Root mass density (RMD)	Specific root length (SRL)
g·L^{-1}	0-20	No.	Grams	grams	cm·m^{-3}	g·cm^{-3}	cm·g^{-1}
0	11.1	20.8	0.4	0.2	2.7	3.0×10^{-4}‡	9222
10	12.6	38.7	1.1	0.3	3.1	6.0×10^{-4}	6383
20	13.7	35.7	0.9	0.2	2.7	4.0×10^{-4}	7085
Source of variation							
Linear	*	*	*	NS	NS	NS	NS
Quadratic	NS	NS	*	*	NS	*	NS

† Fresh perennial ryegrass shoots were soaked in deionized water at 0, 5, 10, or 20 grams per liter (g·L^{-1}) for 48 hours.

‡ Exponential expression for root mass density (RMD).

* Significant at 0.05 probability level.

Conclusion

With the exception of RMD, bermudagrass inhibition and yield reductions were not observed with ryegrass tainted irrigation solutions. While Zuk and Fry (2006) observed 50% less germination and 65% less root mass of zoysiagrass irrigated with ryegrass root and shoot tainted water at all concentrations, no reductions were observed with any irrigation solutions on bermudagrass seedlings. Likewise, perennial ryegrass leachates recycling did not inhibit or alter the growth of test target species (Lickfeldt et al. 2001). When using Petri dish bioassays, Lickfeldt et al. (2001) noted root growth was negatively affected more than shoot growth, which may explain why only bermudagrass RMD was negatively affected by shoot tainted solution. Gannon et al. (2006) observed no impact from soil leachates of intact centipedegrass roots and shoots. Lickfeldt et al. (2001) concluded that cool season turfgrasses failed to produce/introduce significant amounts of allelochemicals into the environment and that varying weed populations in turf can be attributed to competition.

Since ryegrass root and shoot soaked irrigation solution possessed low salinity, Zuk and Fry (2006) suggested zoysiagrass seedling inhibition and impairment by tainted irrigation solution was an allelopathic effect. In our study, no problems with calcium, phosphorous or soil salinity were observed, and all soil samples were within the acceptable ranges for soil-less media: EC of 0.8 to 5.0 dS/m and TDS of 512 to 3200 ppm. All soil nitrate (NO_3) levels were in the insufficient range except the highest ryegrass shoot tainted irrigations solution (20 $g \cdot L^{-1}$), which had 66 ppm of nitrate present The highest ryegrass root tainted irrigation solution had 26 ppm nitrate present, which was significantly more than other treatment, but still insufficient. These elevated nitrate levels are surprising because all root and shoot solutions possessed 0 ppm nitrate; but they may explain why these treatments had elevated germination and growth yields. Elevated magnesium and phosphorus levels were present in pots receiving irrigation water with shoots at 20 $g \cdot L^{-1}$. Lickfeldt et al. (2001) observed greater shoot yields from leaf extract irrigation versus the deionized control, which they credited to potential elevation of primary nutrients from leaves in solution.

Depending on location, overseeded perennial ryegrass is present from 4 to 12 months enabling the potential build-up of allelochemicals. Twenty-three days may not have been sufficient time for allelochemicals to build-up in the root-zone and negatively affect bermudagrass growth (Likcfeldt et al. 2001). Ryegrass harvesting date also may have impacted ryegrass' effect or lack there of on bermudagrass seedlings. Bertin et al. (2003) observed that fine fescue seedlings exuded large quantities of bioactive root exudates into the agar medium, but older fescue plants had a more profound effect on test species. Ryegrass' extract effect on duckweed (*Lemna minor* L.) fronds was dependent upon concentration and sampling date (King, 1996). Prior to experiment initiation, perennial ryegrass tissues were harvested from healthy, unstressed plants. Negative bermudagrass growth effects may have been observed with ryegrass tissue from stressed ryegrass (Fry and Huang, 2004; Mattner and Parberry, 2001). M-tyrosine, an amino acid analogue that selectively inhibits turf weed growth when exuded from fine leaf fescue roots, increased 2 to 3-fold when fine fescues were subjected to moisture stress (Bertin et al., 2003).

Gannon et al. (2006) observed no impact from soil leachates of intact centipedegrass roots and shoots; however, Zuk and Fry (2006) theorized that this could be because intact roots and shoots do not produce as much allelochemicals as fractured roots. However, fractured ryegrass roots and shoot failed to inhibit germination or negatively impact bermudagrass growth. Lickfeldt et al. (2001) proposed that raw plant material is not the source of allelochemicals. Instead, decomposition of plant leaves/materials by micro-organisms within the thatch layer may replenish the supply allelochemicals into the environment (Lickfeldt et al., 2001). With the sole exception of perennial ryegrass shoot solution on bermudagrass RMD, no inhibitory/allelopathic effects were observed with ryegrass tainted solutions on bermudagrass growth after eliminating ryegrass competition.

Allelopathy Ryegrass Root Amended Soil

Results and Discussion

Since there was no interaction between treatments and studies, both results between both studies were combined. Bermudagrass responses are reported as individual treatment means evaluating the effect of ryegrass tainted irrigation solution on shoot and tiller number, shoot and ash weight, RLD, RMD, and SRL. Responses of bermudagrass shoot and tiller number, shoot and ash weight, RLD, RMD, and SRL to varying rates of perennial ryegrass roots and shoots amended soil are presented in Table 15.

Shoot Number

No statistical differences (linear, quadratic, deviation) were observed between ryegrass root amended treatments on bermudagrass shoot numbers, and Fisher's protected LSD yielded no statistical differences between ryegrass root mixes. Lettuce germination, shoot weight, and root weight were not reduced when centipedegrass debris was incorporated into the soil medium (Gannon et al., 2004).

Tiller Number

As with shoot numbers, ryegrass root amended soil failed to impact bermudagrass growth, and no statistical differences were observed between treatments. All ryegrass root concentrations yielded similar tiller numbers (~25 tillers).

Shoot Weight

A quadratic relationship was observed with bermudagrass shoot weights to ryegrass root amended soil. The highest rate of roots (23%) and the untreated yielded similar shoot masses (0.3 g), but both 2 and 12% rates possessed the least shoot mass (0.2 g). Zuk and Fry (2006) also observed varying rate responses of zoysiagrass to both root and shoot solutions and amended soils. Although significant reductions were observed with ryegrass leaves at the 12%, the highest leaf mix rate (23%) yielded similar results as the control (Zuk and Fry, 2006).

Ash Weight

A curvilinear relationship was present with bermudagrass ash weight, when grown in ryegrass root amended soil. Untreated, 2, and 12% root mixtures yielded similar ash weights, but the 23% rate yielded 100% more root mass than all other treatments. This increase in root ash weight with increasing root mixture does not appear to support an inhibitory/allelopathic effect.

Root Length Density (RLD)

A curvilinear relationship was present with root amended soil. Untreated plots had the highest RLD; however, RLD decreased 46% in 2% root mixture. Root length density then gradually increased with mixture rate; however, all mixtures had lower RLDs versus the untreated.

Specific Root Length (SRL)

A negative linear relationship was observed with bermudagrass SRL and increasing ryegrass root amendment rates. Specific root lengths diminished with increasing root concentrations, and the highest amendment rate had 61% lower SRL versus the untreated (24,141 vs. 14,998 $cm \cdot g^{-1}$, respectfully), supporting a possible allelopathic/inhibitory response with increasing ryegrass root concentrations. Lower SRL indicates a short, stubby root system, while a high SRL indicates a thin, highly branched root system similar to that observed with turf grown under low light conditions (Jiang et al., 2004).

Root Mass Density (RMD)

There was a positive linear relationship with increasing ryegrass root amendment rates. Root mass density increased linearly with increasing ryegrass amendment rates resulting in no evidence of inhibition or allelopathy on RMD.

Table 3-3. Bermudagrass germination and growth yields in response to increasing concentrations of perennial ryegrass root amended soil.

Perennial Ryegrass†	Shoot no.	Tiller no.	Shoot weight	Ash weight	Root length density (RLD)	Root mass density (RMD)	Specific root length (SRL)
$g \cdot g^{-1}$	0-30	No.	Grams	Grams	$cm \cdot m^{-3}$	$g \cdot cm^{-3}$	$cm \cdot g^{-1}$
0	22.3	25.8	0.3	0.1	1.3	2.1×10^{-4}‡	24141
2	22.3	26.6	0.2	0.1	0.9	1.9×10^{-4}	23810
12	22	24	0.2	0.1	1	2.4×10^{-4}	20281
23	24.9	26.3	0.3	0.2	1	3.1×10^{-4}	14998
Source of variation							
Linear	NS	NS	*	*	NS	*	*
Quadratic	NS	NS	*	*	NS	NS	NS
Cubic	NS	NS	NS	*	*	NS	NS

† Fresh perennial ryegrass shoots were incorporated into the soil at 0; 0.2; 0.12; or 0.23 grams per gram of soil-less media.

‡ Exponential expression for root mass density (RMD).

* Significant at 0.05 probability level.

Allelopathy Ryegrass Shoot Amended Soil

Results and Discussion

Since there was no interaction between treatments and studies, both results between both studies were combined. Bermudagrass responses are reported as individual treatment means evaluating the effect of ryegrass tainted irrigation solution on shoot and tiller number, shoot and ash weight, RLD, RMD, and SRL. Responses of bermudagrass shoot and tiller number, shoot and ash weight, RLD, RMD, and SRL to varying rates of perennial ryegrass shoots amended soil are presented in Table 16.

Shoot Number

A negative linear relationship was observed between bermudagrass shoots when grown in ryegrass shoot amended soil. Bermudagrass shoots decreased with increasing ryegrass shoot concentrations. Untreated and 2% treatments (24 and 22 shoots, respectively) had the most bermudagrass shoots while the 23% treatment had the least (16.3 shoots).

Tiller Number

While ryegrass root amended soil failed to impact bermudagrass tillering, a quadratic relationship was observed with ryegrass shoot amended soil treatments. Bemudagrass tiller numbers increased as the rate of soil amendment increased from 0 to 12%. Although the 12% treatment possessed the most tillers, the highest shoot mixture (23%) had least tillers versus the other treatments (27 vs. 23 tillers, respectively).

Stimulatory responses at lower rates and increasing linear inhibitory effects at higher rates of debris have been observed with centipedegrass on radish, hairy vetch (*Vicia villosa* Roth) and crimson clover (*Trifolium incarnarum* L.) on morningglory (*Ipomea* spp) (White et al., 1989; Inderjit and Keating, 1999).

Shoot Weight

Despite increasing shoot amendment rates significantly reducing both tiller and shoot numbers, no significant differences were observed between ryegrass shoot amended soil treatments on bermudagrass shoot weights. Although the highest concentration (23%) had the lowest shoot weight (0.21 g), this was only an observed trend.

Ash Weight

A negative linear relationship was observed with bermudagrass ash weight and increasing ryegrass shoot amendments. Bermudagrass ash weights gradually decreased as ryegrass shoot concentrations increased, and the highest shoot concentration, 23%, had the least root mass, which supports a possible allelopathic effect.

Root Length Density (RLD)

A linear relationship with RLD was present with increasing ryegrass shoot amendments. Root length density diminished with increasing shoot amendment rates, and the highest shoot mixture had 44% less RLD versus the untreated. This decrease of

RLD demonstrates a possible allelopathic/inhibitory effect with increasing shoot amendment rates.

Specific Root Length (SRL)

No statistical relationships were observed with ryegrass shoot amended soils on bermudagrass SRL, despite the negative response observed with progressively increasing root amendment rates.

Root Mass Density (RMD)

When exposed to increasingly higher concentrations of ryegrass shoot amended soil, a negative linear relationship was present with RMD. Root Mass Density decreased with increasing rates of shoot amendments, and the highest concentration had 125% less RMD than the untreated, supporting allelopathy/inhibition with increasing rates of ryegrass shoot amendments.

Table 3-4. Bermudagrass germination and growth yields in response to increasing concentrations of perennial ryegrass shoot amended soil.

Perennial ryegrass†	Shoot no.	Tiller no.	Shoot weight	Ash weight	Root length density (RLD)	Root mass density (RMD)	Specific root length (SRL)
$g \cdot g^{-1}$	0-30	No.	Grams	grams	$cm \cdot m^{-3}$	$g \cdot cm^{-3}$	$cm \cdot g^{-1}$
0	24.5	26.1	0.23	0.11	4.38	1.8×10^{-4}‡	25159
2	22.1	26.8	0.22	0.08	4.29	1.5×10^{-4}	130657
12	19.1	28.9	0.26	0.08	3.94	1.4×10^{-4}	162307
23	16.3	23.5	0.21	0.05	3.05	0.8×10^{-4}	150844
Source of variation							
Linear	*	NS	NS	*	*	*	NS
Quadratic	NS	*	NS	NS	NS	NS	NS
Cubic	NS	NS	NS	NS	NS	NS	NS

† Fresh perennial ryegrass shoots were incorporated into the soil at 0; 0.2; 0.12; or 0.23 grams per gram of soil-less media.

‡ Exponential expression for root mass density (RMD).

* Significant at 0.05 probability level.

Conclusions

The highest concentration of ryegrass shoots per mix (23 $g \cdot mix^{-1}$) had the fewest bermudagrass shoots, tillers, shoot weight and ash weight. Incorporated ryegrass shoots appear to be the most promising for producing allelopathic/inhibitory results in this study, which is similar to the ryegrass inhibition/allelopathic effects Zuk and Fry (2006) recorded with zoysiagrass. Although Zuk and Fry (2006) observed allelopathic/inhibitory effects regardless of ryegrass tissue source amended into the soil, they observed the greatest reduction of zoysiagrass seedling shoot and root parameters with perennial ryegrass shoot amended soil. Likewise, in our study, perennial ryegrass shoots were the only amendment to consistently inhibit/stunt bermudagrass germination and growth. With the exception of bermudagrass SRL, perennial ryegrass roots failed to inhibit bermudagrass germination and growth. Rice (1974) noted that allelochemicals are more potent and concentrated in shoot tissue, but they most likely act through the soil, which is consistent with our results.

Although ryegrass' allelopathic response on bermudagrass appeared to increase linearly with increasing shoot amendment rates, some varying rate responses were observed. Lower ryegrass shoot amendment rates (2 and 12%) improved bermudagrass tiller number, but the highest rate (23%) reduced tiller numbers. Stimulatory responses at lower rates and increasing linear inhibitory effects at higher rates of debris have been observed with centipedegrass on hairy vetch (*Vicia villosa* Roth) and crimson clover (*Trifolium incarnarum* L.) on morningglory (*Ipomea* spp.) (White et al., 1989; Inderjit and Keating, 1999). Increasing rates of centipedegrass leaf debris decreased radish shoot and root dry weights; however, radish germination was not affected (Gannon et al., 2006).

Zuk and Fry (2006) speculated that allelochemicals and/or heightened salinity by inorganic salts from amended perennial ryegrass leaves hampered zoysiagrass seedling's emergence and growth. The high salinity of soil amended with leaves ($5.1\ dS \cdot m^{-1}$) possibly hampered germination of susceptible, sensitive zoysiagrass seedlings (Zuk and Fry, 2006). Although all of our ryegrass amended soils had acceptable soluble salt levels, pH, and magnesium, ryegrass shoot amended soils had insufficient levels of calcium, potassium, nitrates, and marginal phosphorus levels.

Gannon et al. (2006) credited soil nitrate depression from elevated C:N ratios of centipedegrass debris for the reduction of target species radicle and shoot weights. Similar scenarios may be present with sensitive bermudagrass exiting dormancy or emerging from seed. Because of spring root dieback, bermudagrass' root system is weak and very susceptible in the spring (McCarty, 2005). This vulnerable state of bermudagrass root systems in the spring may be comparable to that of young bermudagrass seedlings.

Perennial ryegrass leaves amended into the soil inhibited bermudagrass seedling emergence and subsequent growth. These reductions in germination, size, and weight of bermudagrass seed and seedlings are evidence allelopathic/inhibitory effects by perennial ryegrass (Inderjit and Keating, 1999; Rice, 1974). Therefore, allelochemicals are potentially leaking from severed and decaying perennial ryegrass leaves and inhibiting/altering bermudagrass growth and development.

Literature Cited

Bertin, C., X. Yang and L.A. Weston. 2003. The role of root exudates and allelochemicals in the rhizosphere. Plant and Soil. 256:67-83.

Buta, J.G., D.W. Spaulding, and A.N. Reed. 1987. Differential growth responses of fractionated turfgrass seeds and leachates. HortScience. 22:1317-1319.

Chung, Ill-Min and D.A. Miller. 1995. Allelopathic influence of nine forage grass extracts on germination and seedling growth of alfalfa. Agron. J. 87:767-772.

Fry, J. and B. Huang. 2004. Applied Turfgrass Science and Physiology. Wiley. Hoboken, N.J.

Gannon, T.W., F.H. Yelverton, and J.S. McElroy. 2006. Allelopathic potential of centipedegrass (*Eremochloa ophiuroides*). Weed Sci. 54:521-525.

Guenzi W.D., T.M. McCalla, and F.A.Nordstadt 1967. Presence and persistence of phytotoxic substances in wheat, oat, corn and sorghum residues. Agron. J. 59: 163–165.

Gussin, E.J., and J.M. Lynch. 1981. Microbial fermentation of grass residues to organic acids as a factor in the establishment of new grass swards. New Phytol. 89:449–457.

Inderjit and K.I. Keating. 1999. Allelopathy: principles, procedures, processes, and promises for biological control. Adv. Agron. 67:141-231.

Inderjit and L.A. Weston. 2003 Root exudation: an overview. *In* Root Ecology. Eds. de Kroon and E. J. W. Visser. Springer-Verlag, Heidelberg, Germany.

Jiang Y., R.R. Duncan, and R.N. Carrow. 2004. Assessment of low light tolerance of seashore paspalum and bermudagrass. Crop Sci. 44:587-594.

King, J. 1996. Allelopathy vs. *Acremonium* endophytes vs. competition effect on crabgrass suppression by 12 perennial ryegrasses. Turfgrass Environ Res. Summ.: 52-54.

Koski, T. and J. Newberry. 2004. Conversion of ryegrass fairways to bluegrass: impossible dream? USGA Green Sec. Rec. 42(1):6-7.

Lickfeldt, D.W., T.B. Voigt, B.E. Branham, and T.W. Fermanian. 2001. Evaluation of allelopathy in cool season turfgrass species. International Turfgrass Society. 9:1013-1018.

Martin, L.D. and A.E. Smith. 1994. Allelopathic potential of some warm-season grasses. Crop Protection. 13:388-392.

Mattner, S.W. and D.G. Parbery. 2001. Rust-enhanced allelopathy of perennial ryegrass against white clover. Agron. J. 93:54-59.

McCarty, L.B. 2005 Best Golf Course Management Practices. Prentice Hall., Upper Saddle River, NJ.

Nicholson, K.S., A. Rahman, and D.A. Wardle. 1990. Interactions between establishing nodding thistle and pasture seedlings, p. 225-228. In: Proc. 43rd Weed and Pest Control Conf., Hamilton, New Zealand.

Prestidge, R.A. , E.R. Thom, S.L. Marshall, M.J. Taylor, B. Willoughby, and D.D. Wildermoth. 1992. Influence of *Acremonum lolii* infection in perennial ryegrass on germination, emergence, survival and growth of white clover. N.Z. J. Agr. Res. 35:225-234.

Quigley, P.E., F.J. Snell, P.J. Cunningham, and W. Frost. 1990. The effects of endophyte infected ryegrass on the establishment, persistence and production of mixed pastures in Australia. Proc. 1st International Symposium on Acremonium/Grass Interactions: 49-51.

Rao, M.M. and J.G. Buta. 1983. Growth inhibitors from grasses: hplc of phenolics. Proc. Plant Growth Regul. Soc. Am.: 43-48.

Rice, E.L. 1974. Allelopathy. Academic. New York, NY.

Smith, A.E. 1990. Potential allelopathic influence of certain pasture weeds. Crop Protection. 9:410-414.

SAS Instituet Inc. 1999. SAS Version 9.1. SAS Inst., Cary, NC.

Smith, A.E. and L.D. Martin. 1994. Allelopathic characteristics of three cool-season grass species in the forage ecosystem. Agron. J. 86:243-246.

Takahashi, Y., T. Otani, S. Uozumi, Y. Yoden, and R. Igarashi. 1988. Studies on the allelopathic interactions among some grassland species. I. effects of root exudates from some grass and legume species on the growth of their own species and other species. J. Jap. Soc. Grassl. Sci. 33:334–338.

Takahashi, Y., T. Otani, S. Uozumi, Y. Yoden, and R. Igarashi. 1991. Studies on the allelopathic interactions among some grassland species. II. assessment of the allelopathic interactions between perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) using a root exudate recirculating system. J. Jap. Soc. Grassl. Sci. 37:274–282.

Takahashi, Y., T. Otani, and K. Hagino. 1993. Studies on interactions among some grassland species. V. collection and isolation of allelopathic hydrophobic compounds from the root exudates of *Lolium perenne* L. J. Jap. Soc. Grassl. Sci. 39:236–245.

Tukey, H.G. 1969. Implications of allelopathy in agricultural plant scince. Bot. Rev. 35:1-16.

White, R.H., A.D. Worsham, and U. Blum. 1989. Allelopathic potential of legume debris and aqueous extracts. Weed Sci. 37:674-679.

Zuk, A.J., and J.D. Fry. 2006. Inhibition of 'zenith' zoysiagrass seedling emergence and growth by perennial ryegrass leaves and roots. HortScience*.* 41(3):818-821.

APPENDICES

Appendix A

Atmospheric Conditions during Trifloxysulfuron Applications

During trifloxysulfuron (TFS) applications on 14 April 2006, air and soil temperatures at 10 cm (4 in) depth were 27 and 20^{o}C (82 and 68^{o}F), respectively, while the average wind speed was 4.0 km hr^{-1} (2.48 mi hr^{-1}). The late TFS applications of 0.0069 kg ha^{-1} and 0.02 kg ha^{-1} were applied on 16 May 2006. The air and soil temperatures at 10.0 cm (4.0 in) depth were 19 and 17^{o}C (66 and 62^{o}F), respectively, and the average wind speed was 2.7 km hr $^{-1}$ (1.7 mi hr $^{-1}$). In 2007, the early TFS treatments were applied on 13 April. The air and soil temperatures at 10.0 cm (4.0 in) depth were 21 and 20^{o}C (70 and 68^{o}F), respectively, and the average wind speed was 5.7 km hr $^{-1}$ (5.7 mi hr $^{-1}$). During TFS applications on 15 May 2007, air and soil temperatures at 10 cm (4 in) depth were 23 and 21^{o}C (74 and 70^{o}F), respectively, while the average wind speed was 3.2 km hr^{-1} (2.0 mi hr^{-1}). Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated at 187 L ha $^{-1}$ and a 2 m boom with Teejet 8003 flat fan nozzles.

Table A-1. Atmospheric conditions during trifloxysulfuron (TFS) applications during 2006 and 2007.

TFS Application date†	Air temp.	Soil temp.	Wind speed
2006	^{o}C	^{o}C	km hr^{-1}
14-Apr	27.7	20.1	4.1
16-May	18.8	16.6	2.7

TFS Application date	Air temp.	Soil temp.	Wind speed
2007	^{o}C	^{o}C	km hr^{-1}
13-Apr	21.1	20.1	5.7
15-May	23.3	21.2	3.2

† Trifloxysulfuron applications were made with a CO_2 backpack sprayer calibrated to 187 L ha^{-1} at either low or high rates (0.005 or 0.017 kg ai ha^{-1}, respectively) in mid-April and mid-May.

Appendix B

Illustrations

Illustration B-1. Overview of trfloxysulfuron (TFS), mowing height, and fertility rate treatments on an overseeded Clemson University soccer practice field in Clemson, SC.

Illustration B-2. Mid-April high (0.017 kg ai ha^{-1}) trifloxysulfuron (TFS), high fertility (36 kg N ha^{-1} $week^{-1}$), and 1.2 cm (0.5-in.) height treatment two weeks after application in 2006

Illustration B-3. Mid-May low ((0.005 kg ai ha^{-1}) trifloxysulfuron (TFS), high fertility (36 kg N ha^{-1} $week^{-1}$), and 1.2 cm (0.5-in.) height treatment two weeks after application in 2007.

Illustration B-4. Three 7.62 x 7.62 cm grids with 16 intersections employed twice per study to measure bermudagrass shoot counts. Bermudagrass shoots beneath each intersection was scored as a "hit."

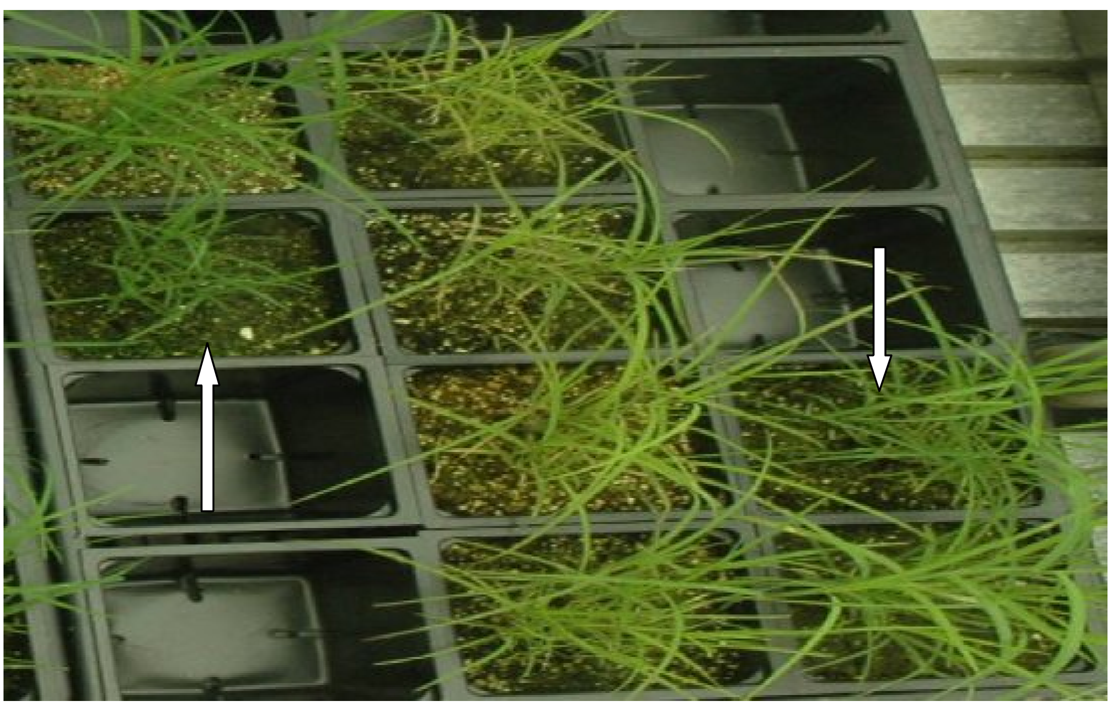

Illustration B-5. Arizona Common bermudagrass response to varying concentrations of ryegrass shoot amended soil twenty days after seeding. Highest ryegrass shoot concentrations ($23 g \cdot mix^{-1}$) noted by arrows