Impact of Sulfonylurea Herbicides on Seeded Bermudagrass Establishment and Cold Temperature Influence on Perennial Ryegrass Response to Foramsulfuron

by

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ABSTRACT

Advancements in cold tolerance of seeded bermudagrass and introduction of sulfonylurea herbicides have given turf managers new tools. Seedling bermudagrass response to sulfonylurea herbicides applied before or soon after seeding has not been characterized. Field observations have indicated that variability exists among sulfonylurea herbicides used for perennial ryegrass control. Objectives of the conducted research were to evaluate sulfonylurea herbicides for safety and utility while establishing seeded bermudagrass, and to elucidate variability in perennial ryegrass control with foramsulfuron. Field experiments were conducted in Blacksburg, VA to assess turfgrass and smooth crabgrass response to flazasulfuron, foramsulfuron, metsulfuron, rimsulfuron, sulfosulfuron, and trifloxysulfuron-sodium, applied 1 and 3 weeks after and before seeding. Herbicides applied 3 weeks after seeding (WAS) were generally more injurious than when applied 1 WAS. Foramsulfuron, metsulfuron, and sulfosulfuron are safe to apply 1 and 3 WAS, causing no reduction in turf cover. Herbicides applied before or after seeding injured bermudagrass in the following order from most to least injurious: flazasulfuron = trifloxysulfuron > rimsulfuron > metsulfuron = sulfosulfuron > foramsulfuron. Flazasulfuron and trifloxysulfuron-sodium are not safe to use within 3 weeks of seeding, while foramsulfuron and metsulfuron can be used anytime before or after seeding bermudagrass. Flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium were evaluated for perennial ryegrass control as affected by environment. Among environmental variables collected soil temperature averaged 7 DAT correlated best with perennial ryegrass response of the three tested products. Soil temperatures below 18 C perennial ryegrass reduced control 9 WAT from 78 to 31% for foramsulfuron while flazasulfuron and trifloxysulfuron-sodium efficacy were not significantly affected. Temperature dependence on perennial ryegrass control can be ranked from most to least as follows; foramsulfuron > trifloxysulfuron-sodium > flazasulfuron. Studies were conducted to determine absorption and translocation of ^{14}C flazasulfuron when applied to perennial ryegrass roots or foliage. Roots treated with ^{14}C flazasulfuron absorbed 41% of recovered ^{14}C while 25% of ^{14}C moved from treated roots to foliage. It appears root absorption is an important component of flazasulfuron efficacy since most of the absorbed ^{14}C remained in treated leaves and root absorbed ^{14}C moved rapidly to foliage.

I dedicate this work to my entire family, for unfailing support, patience, and sacrifice.

And Neugene too.

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Chapter 1. Introduction

Cold-tolerant, seeded bermudagrass [*Cynodon dactylon* (L.) Pers.] cultivars have been developed to have texture, color, and quality equal to vegetative cultivars that have been standard for use in sports turf grown in the transition zone (Anderson et al. 2002; Martin et al. 2001; Morris 2002; Richardson et al. 2004; Taliaferro et al. 2004). Vegetative cultivars must be established from sod or sprigs and generally are more expensive to establish than seeded cultivars (Beard 2005). When repairing damaged turf, use of seeded cultivars to renovate would be easier and more cost effective than use of sprigs or sod. However, seeded turfgrass is slow to establish, increasing opportunity for competition from weeds, which reduces turf color, quality, and uniformity (McCalla et al. 2004; Patton et al. 2004). Summer annual weed competition during seeded bermudagrass establishment could cause total failure of turfgrass establishment. Controlling weeds during establishment is essential (Christians 1998; Dunn and Diesburg 2004; Patton et al. 2004). With increased acceptance of seeded bermudagrass cultivars, solutions for weed control during establishment are needed and many herbicides have been evaluated for this purpose.

Several herbicides have been researched for safety on established bermudagrass (Johnson 1987; McCarty et al. 1991; Keese et al. 2005). However, only recently has emphasis been placed on herbicide safety when applied to seedling bermudagrass turf. Carfentrazone (Anonymous 2005a) and quinclorac (Anonymous 2004) are the only herbicides registered for use during bermudagrass seedling emergence and establishment. Field trials have confirmed that labeled rates are safe during seeded bermudagrass establishment (Askew et al. 2004; Patton et al. 2004; Willis et al. 2005). Siduron is safe for seeded cool-season turfgrass, but can control bermudagrass seedlings and suppress mature bermudagrass (Youngner et al. 1974). Research conducted in Arkansas found that some commonly used postemergence herbicides that are safe to use on established bermudagrass can injure seedling bermudagrass (Richardson et al. 2005). For example, metribuzin at 0.42 kg ai/ha tank-mixed with MSMA at 2.24 kg ai/ha caused severe injury to seeded bermudagrass when applied two and four weeks after emergence. Unacceptable injury from flazasulfuron, foramsulfuron, and trifloxysulfuron at 0.021, 0.029, and 0.029 kg ai/ha, respectively, tank-mixed with MSMA at 2.24 kg ai/ha peaked 3 DAT. Herbicide injury in these trials was short lived and did not significantly reduce end of season turfgrass cover (Richardson et al. 2005). Patton et al. (2004) found that dithiopyr at 0.56 kg ai/ha did not injure seeded bermudagrass when applied one week after emergence or later, with emergence defined as a uniform stand of seedlings at 1.3 cm height. McCalla et al. (2004) conducted field and greenhouse studies with herbicides applied 1, 2, and 4 weeks after emergence, with emergence defined as 75% of expected emergence. They concluded that seedling bermudagrass was more susceptible to injury than established bermudagrass. MSMA, clopyralid, and quinclorac did not injure seedling bermudagrass, while diclofop, metsulfuron, 2,4-D, and dicamba injured seedling bermudagrass. Injury in their trials was short lived and turfgrass establishment was not significantly influenced. Research conducted in North Carolina, Tennessee, and Virginia found differential response among cultivars and only atrazine caused unacceptable injury (McElroy et al. 2005). Askew et al. (2004) conducted preliminary greenhouse trials in Virginia which tested several herbicides applied 3 weeks after emergence. In these trials, foramsulfuron, rimsulfuron, trifloxysulfuron, metsulfuron, and sulfosulfuron did not significantly injure seedling bermudagrass. Field research in Virginia found that trifloxysulfuron at 0.03 kg ai/ha alone or in tank-mixtures with carfentrazone at 0.03 kg ai/ha or quinclorac at 0.84 kg ai/ha significantly injured seeded bermudagrass when applied at 1, 2, and 4 weeks after 80% of seedlings had emerged and had one to three true leaves. Carfentrazone and quinclorac applied alone or in combination was safe for use in emerged seeded bermudagrass (Willis et al. 2005). The research discussed above has concluded that several products were safe when applied to seeded bermudagrass when applied well after emergence. However, in most of this work, herbicides were usually applied after uniform stolon development. Weed competition early in establishment could easily reduce turf establishment by uniform stolon development.

Spring dead spot, damaging winter wear, and other factors can injure bermudagrass during winter months. This damage may not be observed until the overseeded perennial ryegrass is controlled in spring. Likewise, weed infestations often crowd out established bermudagrass, leaving an area without turf after weeds are controlled. Producers may desire to repair these areas by reestablishing turf, possibly with seeded bermudagrass. If herbicides are used before seeding, the newly-seeded bermudagrass could be injured. Residual effects of sulfonylurea herbicides on seeded bermudagrass are not well understood. Sulfonylurea herbicides can be absorbed by plant roots leading to the possibility of injury and/or death. Recent emphasis has been placed on safety and weed control during establishment of seeded bermudagrass varieties (McCalla et al. 2004, McElroy et al. 2005, Patton et al. 2004, Richardson et al. 2004, Willis et al. 2005). However, research has not addressed effects of commonly-used sulfonylurea herbicides applied before seeding bermudagrass.

Turf managers in the transition zone can maintain both cool- or warm-season grasses. Seasonal variation in the transition zone is extreme enough that neither warm- nor cool-season grasses alone can provide a suitable playing surface year round. Winter overseeding a cool-season grass into a warm-season is a common practice for golf course fairways and athletic fields. Perennial ryegrass (*Lolium perenne* L.) is commonly used as an annual in the transition zone for winter overseeding bermudagrass. Winter overseeding provides color, uniform playing surface, and wear resistance, which dormant bermudagrass lacks (Beard 2005; Mazur 1981). Overseeding is more common on higher budget golf courses, winter resort courses, and athletic fields that receive much play and focus in winter months (Beard 2002; Dunn and Diesburg 2004). In spring and summer perennial ryegrass competes with bermudagrass reducing cover and playability of bermudagrass turf, and therefore perennial ryegrass should be removed to preserve bermudagrass (Mittlesteadt and Askew 2008). Perennial ryegrass which persists is a troublesome weed on bermudagrass golf courses that overseed for winter color (Yelverton 2005). Clumps of perennial ryegrass disrupt summer play, reduces bermudagrass cover and uniformity, and decreases health and recuperation of bermudagrass playing surfaces (McCarty et al. 1997; Schmitz 1999; Yelverton et al. 2004).

Ideally, the turf canopy transitions from perennial ryegrass to bermudagrass slowly, not sacrificing color and quality of the playing surface. Environmental factors influence spring transition timing, but turf managers may also control this transition from perennial ryegrass to bermudagrass when growing conditions become favorable for bermudagrass. Southern turf managers often depend on summer stress for transition.

Although perennial ryegrass will die naturally during summers in the deep South, summer heat and stress does not typically control perennial ryegrass in Virginia. Several methods have been proven for perennial ryegrass and other cool-season grass species control in winter overseeded bermudagrass. Horgan and Yelverton (2001) found that using cultural treatments that favored bermudagrass and not perennial ryegrass, including core cultivation, vertical mowing, or fertilization, promoted growth of bermudagrass and reduced perennial ryegrass cover, but did not completely control perennial ryegrass. Herbicides are more reliable for perennial ryegrass control. For many years the industry standard for perennial ryegrass control in overseeded bermudagrass has been pronamide (Anonymous 1999). Johnson (1976) found that plots treated with pronamide had lower color and quality than nontreated plots during transition. However, later in the season, nontreated plots contained perennial ryegrass and had lower color and quality and less bermudagrass coverage than plots treated with pronamide. Several herbicides have recently been registered for control of perennial ryegrass in overseeded bermudagrass (Keese et al. 2005). Most turf managers use a combination of herbicides and cultural promotion of bermudagrass growth for a successful transition.

Foramsulfuron was registered in 2003 for use in warm-season turfgrass under the trade name Revolver^{TM} (Anonymous 2005b; Wiese et al. 2004). Foramsulfuron is used in warm-season grasses for control of cool season grasses, goosegrass [*Eleusine indica* (L.) Gaertn.], and dallisgrass (*Paspalum* spp.) (Anonymous 2005). Foramsulfuron is a preferred transition herbicide for winter overseeded bermudagrass in Virginia because of bermudagrass safety and effective control of perennial ryegrass. Weather patterns in the transition zone are often irregular during spring transition. Some turf managers have observed foramsulfuron failing to control perennial ryegrass during cool weather (Dr. David Spak, personal communication). Weise et al. (2004) found that *Poa annua* L. and *Poa trivialis* L. can be controlled with lower rates in warmer temperatures. Foramsulfuron's product label warns that rate and temperature will influence speed of perennial ryegrass control (Anonymous 2005b). Research conducted in 2004 observed foramsulfuron applications in Danville, VA completely controlling perennial ryegrass, while foramsulfuron applications in Blacksburg, VA did not effectively control perennial ryegrass (unpublished data). This control failure was attributed to cooler weather in Blacksburg compared to Danville. Further research at Virginia Tech found that foramsulfuron controlled annual bluegrass without injuring established perennial ryegrass when applied in winter months (unpublished data). Research in Mississippi observed slower perennial ryegrass control with sulfonylurea herbicide applications at 17 C, while applications at ≥ 20 C resulted in perennial ryegrass control (Hutto 2008). Other research conducted in Virginia found that covering foramsulfuron-treated plots with turf blankets increased perennial ryegrass control compared to noncovered plots treated with the same foramsulfuron rate. Covering plots with a turf blanket caused a subsequent increase in soil temperature, which leads to increased perennial ryegrass control (Willis et al. 2007). Cool temperatures are recognized to have influence on perennial ryegrass response to sulfonylurea herbicides, especially with foramsulfuron, but this concept has not been tested under controlled conditions observing specific environmental parameters.

Environmental conditions can greatly influence herbicide activity. Temperature, relative humidity, and soil moisture levels are documented to influence effectiveness of several herbicides (Ackley et al. 1999; Blair 1985; Collings et al. 2003; Hammerton

1967; Lundkvist 1997; Nalewaja and Adamczewski 1988; Nalewaja and Woznica 1985). Aciflurofen injured showy crotalaria (*Crotalaria spectabilis* Roth) more at 27 and 35° C than at 18° C, and also injured showy crotalaria more at 100 % relative humidity than 40% (Wills and McWhorter 1981). Wild radish (*Raphanus raphanistrum* L.) control improved at higher temperatures with flumetsulam and metosulam (Madafiglio et al. 2000). However, fresh-weight reduction of kochia [*Kochia scoparia* (L.) Schrad.] and green foxtail [*Setaria viridis* (L.) Beauv.] by chlorsulfuron was lower at 30° C than at 10 and 20° C (Nalewaja and Woznica 1985). Olson et al. (2000) observed that temperature after application was more influential on weed efficacy than temperature before application with sulfosulfuron. Published research does not elucidate the effects of multiple environmental parameters on weed control.

Several sulfonylurea herbicides have been registered for selective perennial ryegrass control in overseeded bermudagrass (*Cynodon dactylon* L.) turf (Keese 2005). Flazasulfuron or SL-160 is currently registered for use in grape (*Vitis* L.), citrus, sugarcane (*Saccharum* sp. L.), and non-crop areas (Yoshii 2003), but no registered formulation of flazasulfuron is currently marketed in the United States. Bermudagrass and zoysiagrass (*Zoysia japonica* L.) tolerance has been observed by several researchers in the United States (Askew et al. 2006a; Beam et al. 2004; Brecke et al. 2008; Hutto et al. 2008a). Flazasulfuron is registered and will soon be marketed for use in turfgrass in the US for selective control of cool-season grass, *Cyperus* sp., *Kyllinga* sp., and several broadleaves (Askew et al. 2006b). Some published research has found that flazasulfuron is efficacious for perennial ryegrass, (Hutto et al. 2008b) tall fescue (*Festuca arundinacea* Schreh..) (Yelverton et al. 2003), Virginia buttonweed (*Diodia virginiana*

L.) (Hutto et al. 2008a), nutsedge (*Cyperus* sp. L.), and *Kyllinga* sp. L. (Askew et al. 2006b; Brecke et al. 2008) control in bermudagrass turf. Research in Virginia concluded that reduced rates of flazasulfuron can be effectively used for selective removal of perennial ryegrass from creeping bentgrass (*Agrostis stolonifera* L.) (Goddard et al. 2007). Research conducted in Blacksburg, VA concluded that perennial ryegrass control with flazasulfuron was more consistent than control with foramsulfuron and trifloxysulfuron-sodium at soil temperatures below 17 C (Willis et al. 2007). Hutto et al. (2008) also found that temperatures above 20 C lead to more rapid perennial ryegrass control with flazasulfuron.

Selective placement studies have been conducted with several sulfonylurea herbicides. Foliar and soil plus foliar applications of foramsulfuron were more effective than soil only applications for annual bluegrass and goosegrass (*Eleusine indica* L.) control (Walker 2006). The research determined that root absorption of foramsulfuron was less than foliar absorption (Walker 2006). No attempts have been made to quantify the amount of foramsulfuron absorbed by both roots and foliage of plants. Trifloxysulfuron-sodium was found to control green kyllinga (*Kyllinga brevifolia* Rottb.) better with soil-only applications than foliar-only applications, however no attempts were made to asses the quantity of trifloxysulfuron-sodium absorbed by either plant foliage or roots (McElroy et al. 2004).

Many studies have evaluated foliar absorption of herbicides, while few have attempted to quantify root absorption of herbicides. Bispyribac-sodium had substantial foliar and root absorption in several cool-season turf and grassy weed species (Lycan and Hart 2006). Annual and rough-stalk bluegrass roots absorbed bispyribac-sodium and translocated 77 and 80% of ^{14}C to foliage, respectively. The authors concluded that differential absorption among the species contributed to the selectivity of bispyribac-sodium (Lycan and Hart 2006). Root absorption of trifloxysulfuron-sodium by torpedograss (*Panicum repens* L.) was observed to be more efficient than foliar absorption and thus contributing as much or possibly more to control than foliar absorption. Torpedograss roots retained 56% of absorbed trifloxysulfuron-sodium while the remainder was translocated to other plant parts. Trifloxysulfuron-sodium applied to foliage was absorbed only 29% and very little was translocated (Williams et al. 2003). Little is known about flazasulfuron's absorption in susceptible species. Although flazasulfuron is used for postemergent perennial ryegrass control, foliar absorption is likely not the only source of entry into plants as observed with trifloxysulfuron-sodium absorption in torpedograss (Williams et al. 2003). No published research has evaluated the importance of flazasulfuron absorption nor the importance of root verses foliar absorption of flazasulfuron in perennial ryegrass. Root absorption is likely a contributing factor for flazasulfuron weed efficacy. Field research in Virginia observed severe injury to bermudagrass from applications of flazasulfuron made 1 and 3 weeks before seeding, indicating root uptake may be important component of flazasulfuron absorption (Willis et al. 2008).

Research Objectives

1. Evaluate flazasulfuron, foramsulfuron, metsulfuron, rimsulfuron, sulfosulfuron, and trifloxysulfuron-sodium applied soon after seeding bermudagrass for seedling turfgrass safety and weed control.
2. Evaluate flazasulfuron, foramsulfuron, metsulfuron, rimsulfuron, sulfosulfuron, and trifloxysulfuron-sodium applied before seeding bermudagrass for seedling injury and effects on seeded bermudagrass establishment.
3. Measure perennial ryegrass control from applications of flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium as affected by specific environmental parameters.
4. Evaluate flazasulfuron’s absorption and translocation when applied to foliage and roots of perennial ryegrass.

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Chapter 2.

Sulfonylurea Herbicides Applied During Early Establishment of Seeded Bermudagrass

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Sulfonylurea Herbicides Applied During Early Establishment of Seeded Bermudagrass

John B. Willis, Daniel B. Ricker, and Shawn D. Askew[*]

Abstract

Much research has evaluated herbicide safety on established bermudagrass turf, but information is lacking on seedling response to herbicides. Three field experiments were conducted in Blacksburg, VA, to assess turfgrass and smooth crabgrass response to selected sulfonylurea herbicides during seedling bermudagrass establishment. Herbicides injured bermudagrass 9 wk after treatment in the following order from most to least injurious: flazasulfuron = trifloxysulfuron > rimsulfuron > metsulfuron = sulfosulfuron > foramsulfuron. Herbicides applied 3 wk after seeding (WAS) were generally more injurious than when applied 1 WAS. Flazasulfuron and trifloxysulfuron-sodium controlled smooth crabgrass greater than 90% 6 WAS, and metsulfuron and rimsulfuron suppressed smooth crabgrass 76 and 84%, respectively. Foramsulfuron, metsulfuron, and sulfosulfuron appear safe to apply 1 and 3 WAS, causing very little chlorosis and no reduction in turf cover. Rimsulfuron is injurious when applied at these timings; however, long term cover is not reduced. Flazasulfuron and trifloxysulfuron-sodium are not safe to use 1 and 3 WAS unless weed pressure is extreme, and a delay in bermudagrass cover is acceptable.

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Nomenclature: Flazasulfuron; foramsulfuron; metsulfuron; rimsulfuron; sulfosulfuron; trifloxysulfuron-sodium; smooth crabgrass, *Digitaria ischaemum* (Schreb.) *ex* Muhl. DIGIS; bermudagrass, *Cynodon dactylon* (L.) Pers. 'Riviera'.

Key words: Turfgrass injury, warm-season turfgrass.

Introduction

'Riviera' is a seeded bermudagrass (SB) cultivar with superior texture, color, and outstanding cold tolerance (Anderson et al. 2002; Martin et al. 2001; NTEP 2007; Richardson et al. 2005; Taliaferro et al. 2004). Cultivars like 'Rivera' have generated interest from sports turf managers and golf course superintendents in the transitional climate zone. Shaver et al. (2006) perfected methods to establish Riviera SB using dormant seeding techniques in the transition zone. In their trials, seeding bermudagrass February through April promoted early germination and more rapid cover establishment than seeding in May. Dormant seeding on athletic fields and golf course fairways could lead to competition from perennial ryegrass (*Lolium perenne* L.) and annual bluegrass (*Poa annua* L.). Foramsulfuron, metsulfuron, rimsulfuron, sulfosulfuron, and trifloxysulfuron-sodium are currently used for perennial ryegrass removal during overseeded bermudagrass transition (Keese et al. 2005; Willis et al. 2007). Flazasulfuron is also under review for registration in turfgrass, and one attribute of this product is outstanding perennial ryegrass control in suboptimal temperatures (Willis et al. 2007).

During dormant seeding situations, germination and seedling growth is discontinuous because of variable weather patterns during that season. Dormant seeding leads to variable bermudagrass growth stages when weed-control treatments may be needed. Sulfonylurea herbicide applications during spring transition of overseeded bermudagrass may also coincide with SB establishment if turf managers are faced with winter kill or spring dead-spot disease and desire to reestablish damaged areas with SB. Previous research has not evaluated these sulfonylurea herbicides for safety to young SB.

Weed control during seedling establishment is important because seed is slow to germinate, increasing opportunity for weeds to invade developing turf (McCalla et al. 2004; McElroy et al. 2005; Patton et al. 2004). Weed competition could cause total failure of SB establishment; therefore controlling weeds at this time is essential (Christians 2004; Dunn and Diesburg 2004; Patton et al. 2004).

Recent research has been conducted with the objectives of providing weed-control solutions for SB establishment. Several herbicides are safe for use in established bermudagrass (Johnson 1987; McCarty et al. 1991), and many herbicides have been tested after uniform stolon development of SB cultivars (McCalla et al. 2004; McElroy et al. 2005; Patton et al. 2004). Information on SB response to herbicides applied during or shortly after emergence and before stolon development is minimal. Carfentrazone (Anonymous 2005) and quinclorac (Anonymous 2004) are the only herbicides registered for use during bermudagrass seedling emergence, and field trials have confirmed their safety for this use on Riviera bermudagrass (Askew et al. 2004; Patton et al. 2004).

Of the six sulfonylurea herbicides currently marketed or under evaluation for perennial ryegrass control in bermudagrass, flazasulfuron, sulfosulfuron, and trifloxysulfuron-sodium control sedges (*Cyperus* spp.) (Brecke et al. 2004; McCarty and Higingbottom 2002; McElroy et al. 2005), foramsulfuron controls goosegrass (*Eleusine indica* L.) (Busey 2004), and metsulfuron and rimsulfuron control several broadleaf weeds (Johnson 1987; Warren et al. 2005). Several of these herbicides are reported to control crabgrass (*Digitaria* spp.), especially when applied before tillering (Brecke et al. 2004). Thus, in addition to use for perennial ryegrass control concurrently with SB establishment, these herbicides may be desirable for use in SB establishment from a weed-control perspective. Effects of sulfonylurea herbicides on bermudagrass seedlings and young crabgrass control is only available for a few products and is often variable (McCalla et al. 2004; Richardson et al. 2005). More importantly, effects of these herbicides applied to germinating Riviera SB have not been reported. As adoption of new SB cultivars increase, turfgrass managers need recommendations regarding weed control during establishment of SB turf. Our objectives were to evaluate flazasulfuron, foramsulfuron, metsulfuron, rimsulfuron, sulfosulfuron, and trifloxysulfuron-sodium applied 1 and 3 weeks after seeding (WAS) for turfgrass injury and establishment and smooth crabgrass control.

Materials and Methods

Three field experiments were conducted at the Virginia Tech Golf Course in Blacksburg, VA, in 2004 and 2005. The soil type was Groseclose (fine, mixed, semiactive, mesic, Typic Hapludalfs) with 4.5% organic matter and pH 6.2. Kentucky bluegrass fairways maintained at 1.9 cm were sprayed with glyphosate 3 wk before study initiation. Each research site was core-aerated[1] with 2.5-cm cores, spaced 14.7 cm, vertical-mown with a tractor-mounted unit[2] with blades spaced 2.5 cm, and swept to remove excess clippings with a lawn sweeper[3]. Riviera bermudagrass[4] was seeded at 48.5 kg/ha pure live seed. Seeding dates were June 7, 2004, May 20, 2005, and June 15, 2005, for trials 1, 2, and 3, respectively. Plots were irrigated a maximum of twice daily until 80% bermudagrass cover was reached in nontreated plots and as needed to maintain favorable growing conditions thereafter. Cutting height was maintained at 1.9 cm, and plots were fertilized with a balanced fertilizer[5] at 24.4 kg/ha of nitrogen at seeding and every 2 wk until complete turfgrass cover.

A randomized complete block experimental design was used, and treatments were replicated four times. Treatments included a factorial arrangement of six herbicides and two application timings with a nontreated comparison. Herbicides included flazasulfuron[6], foramsulfuron[7], metsulfuron[8], rimsulfuron[9], sulfosulfuron[10], and trifloxysulfuron-sodium[11] at 35, 28, 42, 35, 34, and 29 g ai/ha, respectively. Application timings were 1 and 3 WAS. All herbicide treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 281 L/ha at 207 kPa with XR11004[12] nozzles. All herbicides were applied with non-ionic surfactant[13] at 0.25% v/v, except foramsulfuron, which was applied as a prepackaged liquid formulation with appropriate surfactant included.

Turfgrass injury and cover and smooth crabgrass control was evaluated in these trials. Ratings were recorded as a visually estimated percentage with 0% being no injury, control, or cover and 100% being death of all visible foliage, complete control, or complete cover (Frans et al. 1986). At 7 WAS, MSMA[14] was broadcast applied at 2.2 kg ai/ha to the entire trial to control smooth crabgrass in nontreated and ineffective treatments. Data variance was tested for homogeneity before ANOVA. Nontreated smooth crabgrass control and SB injury data were deleted to stabilize variance. A combined ANOVA was conducted with partitioned sums of squares to evaluate location and treatment effects and to represent the factorial treatment arrangement. Location was considered random, and mean square of treatment effects were tested using mean square associated with the random variable (McIntosh 1983). Appropriate means were separated using Fisher’s Protected LSD at P = 0.05.

Results and Discussion

Herbicide Effects on Bermudagrass Injury and Cover. The herbicide main effect was significant for SB injury and cover, for both 6 and 9 WAS; therefore, application effects were pooled for display in Table 1. Flazasulfuron and trifloxysulfuron-sodium significantly injured bermudagrass more than all other herbicides tested. Injury from flazasulfuron and trifloxysulfuron-sodium reduced turf cover at 6 and 9 WAS (Table 1). Plots treated with these herbicides did not reach 100% turf cover by 12 WAS, whereas all other treatments did reach 100% cover by that time (data not shown). In other work, in Virginia, trifloxysulfuron-sodium applications to SB 7 and 14 d after emergence injured SB and reduced turf cover. However, trifloxysulfuron-sodium applied 28 d after emergence (nonpublished data) or after uniform stolon production (McElroy et al. 2005) did not injure turfgrass nor reduce establishment. In contrast, trifloxysulfuron-sodium applied to ‘Princess 77’ SB at similar timings did not result in injury or reduce turf cover in Arizona (Murphree et al. 2006). These conflicting results are possibly due to differential soil type or SB cultivar used at the Arizona research location. Weed-control work with green kyllinga (*Kyllinga brevifolia* Rottb.) found that soil-applied trifloxysulfuron-sodium reduced shoot number of this species more than foliar application. However, soil- plus foliar-applied trifloxysulfuron-sodium provided far more reduction in shoot number than soil-applied only (McElroy et al. 2004). Greater efficiency of absorption may contribute to higher injury. Rimsulfuron injured bermudagrass and reduced turf cover at 6 WAS, but by 9 WAS, bermudagrass injury was not greater than with other herbicides, and turf cover was not reduced (Table 1). Sulfosulfuron and metsulfuron injured SB 31 and 34%, respectively, 6 WAS, but did not reduce turf cover 6 or 9 WAS (Table 1). Foramsulfuron was the safest herbicide tested, injuring SB 18% at most and maintaining high cover ratings relative to other treatments (Table 1). Foramsulfuron applications after uniform stolon development were also safe in research conducted in North Carolina, Tennessee, and Virginia (McElroy et al. 2005). Injury from foramsulfuron, sulfosulfuron, and metsulfuron was mainly chlorosis and did not result in death of seedlings or reduce bermudagrass cover 6 and 9 WAS compared to the nontreated control.

Application Timing Effects on SB Cover. A significant trial by application interaction was noted for bermudagrass cover at 6 WAS. This interaction was due to differential planting dates, emergence, and development of SB for each trial (Table 2). Lower temperatures and thus growing degree day (GDD) accumulation are typical for these early planting dates and resulted in slower germination and development of bermudagrass. Growth of bermudagrass is limited below 18 C (Horowitz 1972), and many GDD models for bermudagrass have used that temperature as a base (Patton et al. 2004; Sanderson and Moore 1999). An examination of GDD accumulation between seeding and first application showed differences that may partially explain the interaction of trial and application timing on SB cover over time. GDD accumulation at base 18 C from seeding to treatment at 1 and 3 WAS were 9 and 89, respectively, for trial 1; 0 and 83, respectively, for trial 2; and 11 and 103, respectively for trial 3. Thus, earlier planting dates resulted in lower SB cover relative to later planting dates. In trial 3, application at 3

WAS caused a reduction in turf cover when compared with application at 1 WAS (Table 2). This reduction may have been due to greater injury at 3 WAS in trial 3, although location interaction was not observed with injury data. Elevated injury from herbicides applied 3 WAS is likely due to increased bermudagrass emergence and growth rate as temperatures increased. Unlike at 3 WAS, SB typically had not fully emerged by 1 WAS (Table 2).

Smooth Crabgrass Control. Trial and application effects for smooth crabgrass control were not significant and were pooled. Flazasulfuron and trifloxysulfuron-sodium controlled smooth crabgrass greater than 90% but are not useful at 1 and 3 WAS due to high injury to young SB (Table 1). These products could be useful for crabgrass control 28 d after bermudagrass emergence or later when injury levels are lower (McElroy et al. 2005). However, single applications of trifloxysulfuron-sodium alone may only suppress crabgrass, and complete control could require sequential applications (Anonymous 2003). Metsulfuron and rimsulfuron suppressed smooth crabgrass, allowing for better SB establishment, despite injury from these herbicides (Table 1). Foramsulfuron and sulfosulfuron did not control smooth crabgrass.

Turfgrass managers have limited options for weed control during SB establishment using traditional seeding or dormant seeding techniques. Severe summer-annual weed pressure during seeded establishment can lead to total failure of turf establishment (Christians 2004; McElroy et al. 2005). Summer-annual grasses are potential problems for SB establishment. In our trials, flazasulfuron and trifloxysulfuron-sodium controlled smooth crabgrass; however, turf injury would not allow using these products at the timings tested (Table 1). Others have found flazasulfuron and trifloxysulfuron-sodium safe to apply after uniform stolon development (Askew et al. 2004; McElroy et al. 2005), and these herbicides would be good options at that timing. MSMA applied in sequential applications did not reduce turf establishment when applied after uniform stolon production and would be an effective option for crabgrass control (McElroy et al. 2005). However, the EPA recently refused reregistration of MSMA for use in turfgrass, and that product may not be available to turf managers in the future (McCarty and Estes 2007). Quinclorac may also be used for crabgrass control before uniform stolon development with minimal injury or reduced turf cover during establishment (Anonymous 2004).

Among the tested products, foramsulfuron, sulfosulfuron, and metsulfuron have the best utility for use during SB emergence. These three products aid weed-control programs for SB establishment because foramsulfuron controls goosegrass (Busey 2004), sulfosulfuron controls sedges and some broadleaf species (Askew et al. 2004; Brecke et al. 2004), and metsulfuron controls a broad spectrum of broadleaf weeds (Johnson 1987). Flazasulfuron, rimsulfuron, and trifloxysulfuron-sodium injure SB at early timings and our data agree with other reports that application of these three herbicides should be delayed until after SB is established.

Sources of Materials

[1] Turf Aerator 686. Toro Company, 8111, Lyndale Avenue South, Bloomington, MN 55420.

[2] 548 Aerator. Jacobsen, a Textron Company. 3800 Arco Corporate Drive, Charlotte, NC 28273.

[3] Agri-Fab lawn sweeper. Agri-Fab, 809 South Hamilton Street; Sullivan, IL 61951.

[4] Riviera bermudagrass. Johnston Seed Company. P.O. Box 1392, Enid, OK 73702.

[5] 10-10-10 guaranteed blend fertilizer. Southern States Cooperative, Inc., P.O. Box 26234, Richmond, VA 23260.

[6] Flazasulfuron^{TM} 75DF herbicide. ISK Biosciences Corp., 5966 Heisley Road, Mentor, OH 44061.

[7] Revolver^{TM} herbicide. Bayer Environmental Sciences, 2 T.W. Alexander Drive, Research Triangle Park, NC, 27709.

[8] Manor^{TM} 60DF herbicide. Nufarm Turf & Specialty, 150 Harvester Drive, Suite 200, Burr Ridge, IL 60527-0866.

[9] TranXit^{TM} 25DF herbicide. DuPont Professional Products, Chestnut Run Plaza/705/1N14 Centre Road, Willmington, DE 19805.

[10] Certainty^{TM} 75DF herbicide. Monsanto Company, 800 North Lindbergh Boulevard, St. Louis, MO 63167.

[11] Monument^{TM} 75WG herbicide. Syngenta Crop Protection, Inc., P. O. Box 18300, Greensboro, NC 27409.

[12] XR11004 Teejet spray nozzles. Spraying Systems Co., North Avenue, Wheaton, IL 60189.

[13] Kinetic^{TM}, a 99% nonionic organosilicate surfactant. Helena Chemical Company, 5100 Poplar Avenue, Memphis, TN 38137.

[14] Target^{TM} 6.6 herbicide. Luxemdourg – Pamol, Inc., 5100 Poplar Avenue, Suite 2700, Memphis TN 38137.

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Table 1. Herbicide effects on seedling Riviera bermudagrass cover and injury, and smooth crabgrass control, averaged over 3 trials and 2 application times[a].

		Bermudagrass injury		Bermudagrass cover		Smooth crabgrass control
Herbicide[b]	Rate	6 WAS	9 WAS	6 WAS	9 WAS	6 WAS
	g ai/ha	%				
Flazasulfuron	35	72	53	29	51	96
Foramsulfuron	28	18	3	78	94	16
Metsulfuron	42	34	7	64	92	76
Rimsulfuron	35	46	14	48	85	84
Sulfosulfuron	34	31	6	68	92	16
Trifloxysulfuron-sodium	29	74	47	27	56	92

Nontreated	-[c]	-	-	81	96	-
LSD (0.05)		14	10	14	10	9

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[a] Abbreviations: WAS, weeks after seeding; LSD, least significant difference.

[b] Herbicide were applied at 1 and 3 wk after seeding (WAS) and bermudagrass was seeded June 7, 2004, May 20, 2005, and June 15, 2005 for trials 1, 2, and 3, respectively.

[c] Nontreated check data were not included in analysis of bermudagrass injury or smooth crabgrass data because values were arbitrarily assigned and did not have variance.

Table 2. Interaction of trial and application timing on bermudagrass cover 6 WAS, averaged over 6 herbicides[a] and trial seeding dates and seedling bermudagrass growth stage at each respective application.[b]

	Bermudagrass cover 6 WAS			Growth stage at application		
Application timing[a]	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
		%			lf	
1 WAS	64	34	78	0-1	0	1-2
3 WAS	53	31	54	1-3	0-1	2-4
LSD (0.05)	NS	NS	14	-	-	-

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[a] Herbicides included flazasulfuron, foramsulfuron, metsulfuron, rimsulfuron, sulfosulfuron, and trifloxysulfuron-sodium at 35, 28, 42, 35, 34, and 29 g ai/ha, respectively.

[b] Abbreviations: WAS, weeks after seeding; lf, growth stage as number of fully expanded leaves; LSD, least-significant difference. Trials 1, 2, and 3, were seeded June 7, 2004, May 20, 2005, and June 15, 2005, respectively.

Chapter 3.

'Riviera' Bermudagrass Response to Pre-seeding Applications of Sulfonylurea Herbicides

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‘Riviera’ Bermudagrass Response to Pre-seeding Applications of Sulfonylurea Herbicides

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Abstract

Recent advancements in cold tolerance of seeded bermudagrass cultivars have allowed seeding to repair thin areas following winter kill. Areas devoid of bermudagrass are often unnoticed until herbicides are applied to remove perennial ryegrass and winter weeds from golf course fairways and athletic fields. Trials were conducted in Blacksburg, VA, with flazasulfuron, foramsulfuron, metsulfuron, rimsulfuron, sulfosulfuron, and trifloxysulfuron-sodium at 35, 28, 42, 35, 34, and 29 g ai/ha, respectively, applied 1 and 3 weeks before seeding (WBS) ‘Riviera’ bermudagrass to evaluate turf tolerance. Safety of these products can be ranked as follows: foramsulfuron = metsulfuron > rimsulfuron = sulfosulfuron > trifloxysulfuron-sodium = flazasulfuron. Results indicate foramsulfuron and metsulfuron can be used anytime prior to seeding bermudagrass, while some injury will occur from rimsulfuron and sulfosulfuron applications prior to seeding. Bermudagrass should not be seeded within 3 weeks of flazasulfuron or trifloxysulfuron-sodium treatments.

Introduction

Seeded bermudagrass cultivars have been developed with texture, color, and quality that rival many vegetative cultivars commonly used in sports turf in the transition zone. Some seeded varieties have improved cold tolerance, potentially reducing occurrence of spring dead-spot (3, 7, 14, 16). One advantage of using seeded cultivars is the ability to repair damaged turf or winter killed turf areas by seeding. Repairing extensively damaged turf with sprigs or sod from vegetative cultivars is much more expensive and time consuming than reseeding damaged areas (16).

Spring dead spot, cold temperatures, and wear may injure bermudagrass causing canopy disruption. This damage may not be observed until herbicides are used for weed control or to remove perennial ryegrass in spring. A similar situation occurs when perennial weeds are controlled with sulfonylurea herbicides revealing areas with no or thin bermudagrass cover. When faced with these situations, turf managers may desire to reseed bermudagrass into voided areas. Recent emphasis has been placed on safety and weed control during establishment of seeded bermudagrass cultivars in the transition zone (8, 10, 12, 13, 18). Several postemergent herbicides have been evaluated for safety on established bermudagrass (5, 9, 17). Carfentrazone (2) and quinclorac (1) are the only herbicides registered for use during bermudagrass seedling emergence and field trials have confirmed their safety for this use on ‘Riviera’ bermudagrass. Safety of sulfonylurea herbicides applied before seeding bermudagrass is not well documented. The objective of these studies were to evaluate flazasulfuron, foramsulfuron, metsulfuron, rimsulfuron, sulfosulfuron, and trifloxysulfuron-sodium applied three and one week before seeding ‘Riviera’ bermudagrass.

Evaluating Bermudagrass Response to Herbicides Applied Before Seeding

Three field experiments were conducted at the Virginia Tech Golf Course (VTGC) in Blacksburg, VA, in 2004 and 2005. The soil type was a Groseclose loam (clayey, mixed, mesic, Typic Hapludalfs) with 4.5% organic matter and pH 6.2 at all sites. Kentucky bluegrass fairways maintained at 1.9 cm were sprayed twice with glyphosate at 1.4 kg ai/ha, 4 and 2 weeks prior to seeding to control existing turf, weeds, and common bermudagrass. Plots were core aerated and vertical mowed in two directions before seeding 'Riviera' bermudagrass at 48.52 kg pure live seed per ha, seed was roller packed, but not mulched. Seeding dates were 7 June 2004, 20 May 2005, and 15 June 2005 for trials 1, 2, and 3, respectively, and trials will be referred to as such throughout the paper. Experiments were irrigated daily until 80% cover was reached in the control plots and as needed to maintain favorable growing conditions thereafter. Cutting height was maintained at 1.9 cm. Fertility included 48.8 kg N/ha applied as 10-10-10 at seeding, and 24.4 kg N/ha applied as 46-0-0 every other week until 80% cover was reached in the nontreated plots. For the remainder of the growing season, 24.4 kg N/ha applied as 46-0-0 was applied at monthly intervals. This fertility regime is common for seeded bermudagrass establishment in Virginia.

A randomized complete block experimental design was used and treatments were replicated four times in each trial. Treatments included a factorial arrangement of six herbicides and two application timings. Herbicides included flazasulfuron (not registered), foramsulfuron (Revolver), metsulfuron (Manor), rimsulfuron (Tranxit), sulfosulfuron (Certainty), and trifloxysulfuron-sodium (Monument) at 35, 28, 42, 35, 34, and 29 g ai/ha, respectively. Herbicides were applied 1 and 3 weeks before seeding

(WBS). Nontreated comparison treatments were included. All herbicide treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 281 liters/ha with XR8004 nozzles, and all herbicides except foramsulfuron included non-ionic surfactant at 0.25% v/v. Foramsulfuron is sold as a prepackaged mixture of the active ingredient and appropriate surfactant load.

Data collected in these trials included visual estimates of turfgrass injury and cover. Ratings were recorded as visually estimated percentage, 0% being no injury or control and 100% being death of all visible foliage. Stand counts and average number of leaves per plant were also evaluated by taking 5 subsamples per plot using a randomly selected 127-cm^2 area of interest. Variance was tested for homogeneity before ANOVA using SAS version 8.1 (SAS Institute Inc., Cary, NC). Nontreated control data was deleted in turfgrass injury data to stabilize variance, since nontreated plots were arbitrarily assigned a value of 0 for turfgrass injury. A combined ANOVA was conducted with partitioned sums of squares to evaluate location and treatment effects and to represent the factorial treatment arrangement. Location was considered random, and mean square of treatment effects was tested using mean square associated with the random variable (11). Appropriate means were separated using Fisher's protected LSD at $P = 0.05$.

Bermudagrass Response to Pre-seeding Applications of Sulfonylurea Herbicides

ANOVA reveled that application timing main effect was not significant for any data collected for any trial. Herbicide main effect was significant for data from all trial locations and all evaluation timings except the final evaluation (Table 1 and 2). The trial by herbicide interactions were significant for bermudagrass injury 4 WAS (weeks after seeding) and bermudagrass cover 4 and 6 WAS (Table 1 and 2). This interaction could be attributed to different planting dates and thus variable growing conditions for each trial. The varying growing conditions caused slower bermudagrass growth and in general slower recovery from herbicide injury. Growing degree day (GDD) accumulation at base 18°C from seeding to 1 and 4 WAS were 9 and 96, 0 and 88, and 11 and 120, respectively, for trials 1, 2, and 3. Lower temperatures and thus GDD accumulation are typical for the earlier seeding dates, these differences may partially explain the trial interactions in the early season bermudagrass injury and cover data (Table 1 and 2). Horowitz (4) concluded that bermudagrass growth is limited below 18°C, and others have used this temperature as a base temperature for bermudagrass growth models (12, 15). However, later in the growing season as temperatures increase there were no significant trial interactions for bermudagrass injury 6 WAS and cover 12 and 16 WAS. Interestingly, stand counts and leaf number did not have a significant trial interaction, indicating that each herbicide had equivalent effects on stand reduction and growth stage regardless of environmental conditions at each location (Table 1). Late season bermudagrass cover ratings did not have significant trial interaction because aggressive bermudagrass growth throughout the summer overcame the differences in injury and cover noted earlier in the season (Table 2).

Pre-seeding applications of flazasulfuron and trifloxysulfuron-sodium severely injured seeded bermudagrass, significantly reducing cover, stand count, and leaf count compared to the nontreated plots. Rimsulfuron and sulfosulfuron injured bermudagrass at unacceptable levels (greater than 30%) only in trial 2. Rimsulfuron did reduce bermudagrass cover 4 WAS at trial 2, but long term establishment was not effected by either rimsulfuron or sulfosulfuron (Table 2). Pre-seeding applications of foramsulfuron and metsulfuron did not injury bermudagrass at levels of agronomic significance, nor did they reduce establishment of bermudagrass from seed.

These data suggest turf managers that use foramsulfuron and metsulfuron for weed control or overseed removal could safely seed to repair bermudagrass within 1 week of application. Seeding bermudagrass within 3 weeks of rimsulfuron or sulfosulfuron application could result in significant injury and delayed cover establishment, however long-term establishment will not be effected. Seeding bermudagrass within 3 weeks of trifloxysulfuron-sodium and flazasulfuron applications will result in high seedling mortality and limited establishment (Table 1 and 2). Others have found short seeding intervals following applications of sulfosulfuron in cool-season turf species (6), but warm-season reseeding intervals have not been published for any of these products.

Safety of these products applied before seeding can be ranked in the following order: foramsulfuron = metsulfuron > rimsulfuron = sulfosulfuron > trifloxysulfuron-sodium = flazasulfuron. Results from these trials indicate that foramsulfuron and metsulfuron can be used anytime prior to seeding bermudagrass. Bermudagrass may be seeded after rimsulfuron and sulfosulfuron only if some injury can be tolerated, otherwise the application to seeding interval should be greater than 3 weeks. Bermudagrass should not be seeded after flazasulfuron or trifloxysulfuron-sodium applications unless the interval is much greater than 3 weeks. ‘Riviera’ bermudagrass cover did reach acceptable levels of cover by 12 WAS in plots treated with flazasulfuron and trifloxysulfuron-sodium (Table 2), however this is not expectable in most turf management situations.

Seeding bermudagrass after any herbicide application is risky, and should be avoided if possible for ideal establishment conditions. Practitioners should always consult product labels regarding proper seeding and treatment timing.

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Table 1. Pre-seeding applications of sulfonylurea herbicides to 'Riviera' bermudagrass effects on bermudagrass injury, stand counts (#), and leaf counts (#)[x]. Herbicides were applied 1 and 3 weeks before seeding, but were pooled because application timing main effect was not significant.

	Bermudagrass Injury (%)				Stand (#)[x]	Leaf (#)[x]
	4 WAS[y]			6 WAS	4 WAS	
Herbicide (g ai/ha[y])	Trial 1	Trial 2	Trial 3			
Flazasulfuron (35)	26 a[z]	56 ab	73 a	62 a	15 c	3.3 c
Foramsulfuron (28)	6 b	16 e	7 b	15 b	19 bc	4.6 a
Metsulfuron (42)	6 b	18 de	29 b	18 b	20 ab	4.5 a
Rimsulfuron (35)	9 b	43 bc	24 b	24 b	20 ab	4.3 ab
Sulfosulfuron (34)	3 b	33 cd	11 b	19 b	21 a	4.7 a
Trifloxysulfuron-sodium (29)	23 a	67 a	71 a	62 a	17 bc	3.5 bc
Nontreated	-	-	-	-	20 a	4.7 a
LSD[y]	10.7	15.4	25.6	14.6	3.7	0.8

[x] Stand # (count) is the count of bermudagrass seedlings per 127 cm^2 and leaf # (count) is presented as average number of leaves per plant in the 127 cm^2.

[y] Abbreviations: g ai/ha, grams active ingredient per hectare; WAS, weeks after seeding; LSD, least significant difference.

[z] Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (*P* = 0.05).

Table 2. Pre-seeding applications of sulfonylurea herbicides influences ‘Riviera’ bermudagrass cover. Herbicides were applied 1 and 3 weeks before seeding, but were pooled because application timing main effect was not significant.

	Bermudagrass Cover (%)							
	4 WAS[y]			6 WAS			12 WAS	16 WAS
Herbicide (g ai/ha[y])	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3		
Flazasulfuron (35)	19 b[z]	14 de	7 d	73 cb	26 c	26 b	95 bc	99
Foramsulfuron (28)	36 a	38 a	34 a	88 a	70 ab	89 a	99 a	100
Metsulfuron (42)	38 a	37 ab	18 bc	95 a	74 a	77 a	100 a	100
Rimsulfuron (35)	34 a	21 cd	23 b	86 ab	52 b	87 a	100 a	100
Sulfosulfuron (34)	41 a	29 bc	26 ab	95 a	64 ab	79 a	98 ab	100
Trifloxysulfuron-sodium (29)	21 b	10 e	10 cd	70 c	29 c	36 b	93 c	99
Nontreated	34 a	38 a	31 a	87ab	83 a	88 a	100 a	100
LSD[y]	8.8	9	9.3	14	19.3	15.2	4.6	NSD[y]

[y] Abbreviations: g ai/ha, grams active ingredient per hectare; WAS, weeks after seeding; LSD, least significant difference; NSD, no significant difference.

[z] Means in the same column followed by the same letter are not significantly different according to Fisher’s protected LSD (*P* = 0.05).

Chapter 4.

Cold Temperature Influence on Perennial Ryegrass (*Lolium perenne*) Control with Flazasulfuron, Foramsulfuron, and Trifloxysulfuron-sodium.

The following chapter was formatted to facilitate publication in *Weed Science*.

Cold Temperature Influence on Perennial Ryegrass (*Lolium perenne*) Control with Flazasulfuron, Foramsulfuron, and Trifloxysulfuron-sodium.

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Abstract

Turf managers have observed reduced efficacy of sulfonylurea herbicides applied to control perennial ryegrass in early spring. Researchers have postulated that environmental variables are the cause for the variations in effectiveness. Our research evaluated flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium applied at weekly intervals at two locations for perennial ryegrass control as affected by environmental variables. Cool temperatures were responsible for reduced speed and/or efficacy of the three tested products. When averaged over 126 observations for each herbicide, perennial ryegrass control 9 WAT was 51, 71, and 98% when treated with foramsulfuron, trifloxysulfuron-sodium, and flazasulfuron, respectively. Environmental data averaged 7 days after treatment (DAT) was found to be more correlated with herbicide efficacy than other time durations relative to the respective treatments. Among the recorded environmental parameters soil temperature yielded higher correlation coefficients than air temperature, soil moisture, leaf wetness, relative humidity, total solar radiation, and photosynthetically active radiation. Soil temperatures below 18 C reduced perennial ryegrass control 9 WAT from 78 to 31% for foramsulfuron and from 74 to 62% for trifloxysulfuron-sodium. Soil temperature did not significantly affect flazasulfuron's

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efficacy on perennial ryegrass. Temperature dependence on perennial ryegrass control can be ranked among the herbicides evaluated from most to least dependent as follows; foramsulfuron > trifloxysulfuron-sodium > flazasulfuron.

Nomenclature: Flazasulfuron; foramsulfuron; trifloxysulfuron-sodium; perennial ryegrass, *Lolium perenne* L. ‘Pennant II’.

Key words: ALS herbicide; transition, environmental influence.

Introduction

Perennial ryegrass is commonly used in the transition zone for winter overseeding bermudagrass (*Cynodon* spp.) on golf course fairways, tee boxes, and athletic fields. Winter overseeding provides color, uniform playing surface, and wear resistance which dormant bermudagrass lacks (Johnson 1976; Yelverton 2005). Perennial ryegrass often persists through summer, forming clumps that disrupt uniformity and playability. Perennial ryegrass, in clumps, is a troublesome weed in bermudagrass turf, where winter overseeding is practiced (Horgan 2001; Johnson 1976). Several sulfonylurea herbicides have been registered for selective control of perennial ryegrass from overseeded bermudagrass, and using these products for perennial ryegrass transition is standard for turf managers (Keese et al. 2005). Several turf managers in Virginia have noted failure of foramsulfuron to control perennial ryegrass during spring transition. One such instance occurred on Worsham Field, the football field for Virginia Tech. Field managers noted cool temperatures after the normally effective application of labeled rates of foramsulfuron (Jason Bowers, personal communication). Golf course managers have noted similar instances where, during fairway transition, normally effective applications of foramsulfuron did not control perennial ryegrass (Mark Vaughn, personal communication). Similar accounts have been noted across the transition zone (David Spak, personal communication).

Weather patterns in the transition zone are irregular during the time that turf managers are planning perennial ryegrass transition with applications of sulfonylurea herbicides. Turf managers may treat perennial ryegrass during ideal conditions for effective removal, and temperatures may decrease. Several research trials have evaluated environmental influence on herbicide efficacy. Aciflurofen injured showy crotalaria (*Crotalaria spectabilis* Roth) more at 27 and 35 C than at 18 C, regardless of humidity, and more at 100% than 40% relative humidity, regardless of temperature (Wills and McWhorter 1981). Wild radish (*Raphanus raphanistrum* L.) control was also improved at higher temperatures with flumetsulam and metosulam (Madafiglio 2000). Cold temperatures negatively affect annual bluegrass (*Poa annua* L.) control with bispyribac-sodium and reduce control by half at 10 C when compared to 30 C (McCullough and Hart 2006). Research evaluating temperature effects on sulfosulfuron found reduced injury of downy brome (*Bromus tectorum* L.), jointed goatgrass (*Aegilops cylindrical* Host.), and wild oat (*Avena fatua* L.) at temperatures of 5/3 C (day/night) after applications when compared to 25/23 (Olson et al. 2000). Weise et al. (2004) found that annual bluegrass and rough-stalk bluegrass (*Poa trivialis* L.) can be controlled with lower foramsulfuron rates in warmer temperatures. The foramsulfuron product label warns that rate and temperature will influence speed of perennial ryegrass removal (Anonymous 2005).

Herbicide effectiveness has been observed to be directly influenced by environmental conditions. The variability of perennial ryegrass control observed in Virginia is possibly due to environmental conditions after herbicide application. Researchers in Mississippi observed faster perennial ryegrass control with applications of six sulfonylurea herbicides at soil temperatures of 21 and 26 C than at 17, when soil temperature was measured at 10 cm (Hutto et al. 2008). Published research does not address effectiveness of flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium toward perennial ryegrass as influenced by multiple environmental factors. Our objective was to measure environmental influence on the effectiveness of flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium toward perennial ryegrass. Turf managers should be able to utilize these data in association with weather forecasts when making decisions regarding removal of winter overseeded perennial ryegrass with the tested products.

Materials and Methods

Two field experiments were conducted in Blacksburg, VA in 2006, one at the Glade Road Facility (GRF) and the other at the Turfgrass Research Center (TRC). The GRF location had a blend of 39% 'Federation', 30% 'Partner', and 29% 'Cadence' perennial ryegrass established the previous fall, and maintained at a 1.5 cm cutting height. The soil at GRF was a Duffield silt loam (fine-loamy, mixed, active, mesic, Ultic Hapludalfs)-Ernest silt loam (fine-loamy, mixed, superactive, mesic Aquic Fragiudults) complex, with 6.6 pH. The TRC location had 'Pennant II' perennial ryegrass established for 3 years, and maintained at a 7.2 cm cutting height. The soil at TRC was a Groseclose urban land complex (clayey, mixed, mesic, Typic Hapludalfs), with 6.3 pH. Fertility at both experimental locations was maintained as recommended by Virginia Tech extension soil test recommendations.

Weather stations[1] were erected at each location. Each weather station was equipped with appropriate sensors to measure air temperature, soil temperature, percent volumetric water content (VWC), leaf wetness, photosynthetically active radiation (PAR), total solar radiation (TSR), and percent relative humidity (RH). At 2 and 12 weeks after study initiation, soil temperature, VWC, PAR, and TSR data were recorded for individual plots to measure plot to plot variability and accuracy of the weather station.

These parameters did not vary more than ±5% among individual plots and the weather station at either experimental location and no individual plot adjustments were needed on the final weather data used in the analysis. Air temperature and relative humidity measurements were calibrated with an external instrumentation, but were assumed to be accurate on a plot to plot basis. Plot size was 0.9 by 1.2 m and RCB experimental design with 4 replications was used at both locations. A 3 by 21 factorial treatment arrangement was used at both locations.

Herbicide treatments included flazasulfuron[2], foramsulfuron[3], and trifloxysulfuron- sodium[4] at 26, 29, and 17 g ai/ha, respectively. Flazasulfuron and trifloxysulfuron-sodium applications included nonionic surfactant[5] at 0.25% v/v, because foramsulfuron comes prepackaged with appropriate surfactant load. Each herbicide was applied 21 times on a weekly basis starting February 28, 2006 and ending July 13, 2006. Perennial ryegrass control and cover was evaluated 2, 4, and 9 weeks after treatment (WAT) in both trials. Control ratings were recorded as visually estimated percentages, with 0% being no injury and 100% being death of all visible foliage (Frans et al. 1986). Percent perennial ryegrass cover was evaluated 9 WAT using digital image analysis as described by Richardson et al. (2001). Data were tested for homogeneity of variance and subjected to a combined ANOVA with sums of squares partitioned to reflect the split plot treatment design with 21 applications times as main plots and herbicide as subplots and to test for location effects as the random variable (McIntosh 1983). While assessing environmental parameters on an hourly basis from study initiation, masses of data were collected for analysis at each location. Consultation with Virginia Tech's statistical department revealed that multivariate analysis of variance was not possible due to discrepancies between the number of environmental data points and the number of field-assessed data points for perennial ryegrass response to herbicides. Appropriate means were subjected to linear regression analysis to determine correlations between the environmental parameters and measured perennial ryegrass response (SAS, 2004). Preliminary analysis of environmental parameters included 2304 linear regressions to compare each of 8 environmental parameters, 3 herbicides, 2 locations, and 3 evaluations times. These correlations were plotted in selected durations which accounted for environmental influence relative to each respective treatment timing. Twelve arbitrarily selected durations of environmental influence were selected that averaged the hourly data points relative to each respective application date. These durations of environmental influence included 1, 3, 7, and 14 days before, after, and before and after each respective treatment. Each regression accounted for 168 measured perennial ryegrass responses. The resulting regression plotted 21 means, representing each application timing, which were correlated with each environmental parameter at each of the 12 durations of influence for each field plot. A subsequent ANOVA was used to determine highest correlation coefficients among the 12 durations of environmental influence and the 8 environmental parameters. These correlation coefficients were separated using Fisher's Protected LSD at $p = 0.05$.

Results and Discussion

The combined ANOVA indicated both application time and herbicide were significant at 2 and 4 WAT ratings and the three-way interaction of application time by herbicide by location was significant at the 9 WAT evaluations. Visually estimated perennial ryegrass control and digitally estimated perennial ryegrass cover were pooled over locations for 2 and 4 WAT data and separated by location for 9 WAT data. Of the 12 arbitrarily selected durations of environmental influence, ANOVA determined that highest correlation coefficients were achieved when hourly environmental data were averaged 7 days after application. For example, when averaged over 8 environmental parameters and using perennial ryegrass control 2 WAT as the response variable, highest correlation coefficients for the 12 durations of environmental influence were 0.40, 0.34, and 0.29 for 7 days after, 14 days after, and 7 days before and after application, respectively. ANOVA revealed that other durations of environmental influence resulted in lower correlation coefficients than 7 days after treatment (data not shown). In the interest of brevity these numerous correlation coefficients will not be presented and the remainder of the results and discussion will focus on environmental parameters averaged 7 days after treatment. Olson et al. (2000) also observed that temperature after application was more influential on weed efficacy than temperature before application with sulfosulfuron. No published research has evaluated how specific environmental parameters in various durations after treatment influence weed control.

Regression equations and correlations coefficients for the 8 tested parameters using 7 days after application as the duration of environmental influence are displayed in Table 1. Highest correlation coefficients were 0.6 or greater and occurred with soil temperature, air temperature, and application time. Minor differences in coefficient of determination (R^2) were observed among herbicides, however Julian d, soil temperature, air temperature, and relative humidity had consistently higher R^2 than other parameters. Among the recorded environmental parameters, soil temperature at 7.5 cm had the highest correlation with perennial ryegrass responses (Table 1). Air temperature and relative humidity did explain a significant amount of variability and regression analysis resulted in significant regression equations. However, none of these equations resulted in higher R^2 than did soil temperature, which was the environmental parameter that best explains perennial ryegrass response to each herbicide. While environmental parameters explain much of these data, the nature of seasonal changes over the duration of the application timings of the experiment also allow for correlations with application timing. Time in Julian d resulted in correlation coefficients slightly higher than any environmental parameters (Table 1). Overall, application time in Julian d and soil temperature at 7.5 cm best explain variability in perennial ryegrass control with the tested products. These environmental factors will be the focus of the remaining discussion.

A strong correlation was observed between percent control and soil temperature. The three tested herbicides controlled perennial ryegrass better with increasing soil temperatures 2 and 4 WAT (Figures 1 and 2). Each degree C increase in soil temperature resulted in a 3 to 4% increase in perennial ryegrass control 2 WAT. At 4 WAT, perennial ryegrass control increases approximately 2% for each degree C for all herbicides (Figure 2). These data indicate that soil temperature following application has similar impact on speed of activity for all three products. Applications at 17 C resulted in significantly less control than applications at 20 C and higher temperatures in Mississippi (Hutto 2008). Research conducted in Virginia found that covering plots treated with foramsulfuron with turf blankets increased perennial ryegrass control compared to noncovered plots treated with the same foramsulfuron rate, apparently because of increased soil temperature (Willis et al. 2007).

Interactions for both location and herbicide were observed for perennial ryegrass control 9 WAT. Perennial ryegrass control with flazasulfuron and trifloxysulfuron-sodium showed no response to soil temperature 9 WAT. However, with foramsulfuron perennial ryegrass control increased 4.4 and 1.5%, at GRF and TRC locations respectively, for each degree C increase in soil temperature 9 WAT (Data not shown).

Application time also correlated well with perennial ryegrass cover. Perennial ryegrass cover 9 WAT is a strong indication of long-term perennial ryegrass control and agrees with our visual assessments of perennial ryegrass control at 9 WAT (data not shown). A location interaction was observed for these data. Flazasulfuron decreased perennial ryegrass cover best of the tested products, having less that 5% living perennial ryegrass remaining in treated plots 9 WAT at both locations. Long-term perennial ryegrass cover reduction with flazasulfuron was nearly complete and not affected by low soil temperatures. Trifloxysulfuron-sodium did not reduce perennial ryegrass cover as consistently as flazasulfuron at 9 WAT, but trifloxysulfuron-sodium did reduce perennial ryegrass cover regardless of soil temperature or application timing (Figure 3 and 4). This lack of consistency indicates that some other factor or combination of factors was responsible for the variability in perennial ryegrass control with trifloxysulfuron-sodium. These studies used a medium rate of trifloxysulfuron-sodium and possibly higher rates could have yielded more consistent reductions in perennial ryegrass cover. Foramsulfuron displayed the most distinct trends in response to soil temperature regarding reduction in perennial ryegrass cover over the course of the trial. At TRC perennial ryegrass cover had a less distinct response to foramsulfuron as affected by soil temperature than at GRF. This difference could be the result of the higher cutting heights at the TRC location.

When averaged over all 168 observations for each herbicide, perennial ryegrass control 9 WAT was 51, 71, and 98% when treated with foramsulfuron, trifloxysulfuron-sodium, and flazasulfuron, respectively (data not shown). Simple t-test's ($ά = 0.05$) were preformed to determine a threshold level of soil temperature for application of these products for perennial ryegrass control. The total 168 observations were pooled and separated based on soil temperature. From regression analysis with perennial ryegrass control and soil temperature, a trend of higher perennial ryegrass control evaluations was noted at soil temperatures higher than 18 C. Perennial ryegrass control 2 and 4 WAT was significantly lower for temperatures below 18 C for the three herbicides. Also, no significant differences in perennial ryegrass control at 2 and 4 WAT were observed among herbicides when grouped into above and below 18 C (Table 2). Flazasulfuron controlled perennial ryegrass 97 and 99% when temperatures were below and above 18 C, respectively, at 9 WAT. Soil temperature below 18° C significantly reduced perennial ryegrass control with foramsulfuron and trifloxysulfuron-sodium. Foramsulfuron activity on perennial ryegrass was most sensitive to soil temperature. Flazasulfuron controlled perennial ryegrass statistically more than both trifloxysulfuron-sodium and foramsulfuron regardless of temperature (Table 2). Temperature dependence of perennial ryegrass control can be ranked among tested herbicides from most to least dependant as follows; foramsulfuron > trifloxysulfuron > flazasulfuron.

Sources of Materials

[1] WatchDog Model 2800™ Weather Station. Spectrum Technologies, Inc., 12360 South Industrial Drive, Plainfield, IL 60585.

[2] Flazasulfuron™ 75DF herbicide. ISK Biosciences Corp., 5966 Heisley Road, Mentor, OH 44061.

[3] Revolver™ herbicide. Bayer Environmental Sciences, 2 T.W. Alexander Drive, Research Triangle Park, NC, 27709.

[4] Monument™ 75WG herbicide. Syngenta Crop Protection, Inc., P. O. Box 18300, Greensboro, NC 27409.

[5] Kinetic™, a 99% nonionic organosilicate surfactant. Helena Chemical Company, 5100 Poplar Avenue, Memphis, TN 38137.

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Table 1. Influence of environment on herbicide efficacy toward perennial ryegrass control 2 WAT.[a]

			Regression parameter[b]		
Herbicide	Environmental parameter	Unit of measure	Equation	p	R^2
Flazasulfuron	Application Time	Julian Day	$y = 4.18x - 5.51$	<0.0001	0.78
	Air Temperature	°C	$y = 3.68x - 12.67$	<0.0001	0.68
	Soil Temperature	°C	$y = 3.76x - 17.21$	<0.0001	0.74
	Leaf Wetness	0 (dry) to 15 (wet)	$y = 8.1x + 5.3$	0.0003	0.3
	PAR	$\mu M/m^2/s$	$y = 0.04x + 19.4$	0.1	0.07
	Solar Radiation	wat/m^2	$y = 0.08x + 19.4$	0.1	0.07
	Volumetric Water Content	%	$y = 3.59x - 15.7$	0.0006	0.27
	Relative Humidity	%	$y = 1.5x - 72.2$	<0.0001	0.5
Foramsulfuron	Application Time	Julian Day	$y = 3.97x - 6.21$	<0.0001	0.76
	Air Temperature	°C	$y = 3.53x - 14.3$	<0.0001	0.64
	Soil Temperature	°C	$y = 3.62x - 18.28$	<0.0001	0.72
	Leaf Wetness	0 (dry) to 15 (wet)	$y = 8.53x - 0.50$	<0.0001	0.35
	PAR	$\mu M/m^2/s$	$Y = 0.04x + 18.49$	0.14	0.05
	Solar Radiation	wat/m^2	$y = 0.07x + 18.2$	0.13	0.06
	Volumetric Water Content	%	$y = 3.58x - 19.7$	0.0003	0.28

	Relative Humidity	%	$y = 1.54x - 78.9$	<0.0001	0.56
Trifloxysulfuron-sodium	Application Time	Julian Day	$y = 3.24x + 0.78$	<0.0001	0.63
	Air Temperature	°C	$y = 2.88x - 5.75$	<0.0001	0.54
	Soil Temperature	°C	$y = 2.96x - 9.05$	<0.0001	0.6
	Leaf Wetness	0 (dry) to 15 (wet)	$y = 6.47x + 7.74$	0.0007	0.25
	PAR	µM/m^2/s	$y = 0.04x + 18.7$	0.12	0.06
	Solar Radiation	wat/m^2	$y = 0.06x + 18.3$	0.1	0.06
	Volumetric Water Content	%	$y = 2.57x - 4.42$	0.005	0.18
	Relative Humidity	%	$y = 1.22x - 55.5$	<0.0001	0.44

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[a] Abbreviations: PAR, photosynthetically active radiation; WAT, weeks after treatment.

[b] These data were pooled over Glade Road Research Facility and Turfgrass Research Center locations

Table 2. Perennial ryegrass control above and below 18 C with flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium, pooled over GRF and TRC locations.[a]

		Perennial ryegrass control								
	Time (WAT)	2 WAT			4 WAT			9 WAT		
	Temperature (C)	<18	>18	p	<18	>18	p	<18	>18	p
Herbicide	Rate (g ai/ha)	%								
Flazasulfuron	26	24	74	<0.0001	74	97	<0.0001	97	99	0.2013
Foramsulfuron	29	19	70	<0.0001	64	87	0.0021	31	78	<0.0001
Trifloxysulfuron-sodium	17	22	63	<0.0001	59	84	0.0064	62	74	0.0039
LSD	-	NSD	NSD	-	NSD	NSD	-	11	7	-

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[a] Abbreviations: GRF, Glade Road Research Facility; LSD, least significant difference; NSD, no significant difference; TRC, Turfgrass Research Center; WAT, weeks after treatment.

Figure 1. Perennial ryegrass control with flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium 2 WAT as influenced by soil temperature at a 7.5 cm depth, averaged 1 WAT.

Figure 2. Perennial ryegrass control with flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium 4 WAT as influenced by soil temperature at a 7.5 cm depth averaged 1 WAT.

Figure 3. Perennial ryegrass cover plotted by treatment time in Julian d when treated with flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium at GRF location 9 WAT.

Figure 4. Perennial ryegrass cover plotted by treatment time in Julian d when treated with flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium at TRC location 9 WAT.

Figure 1. Perennial ryegrass control with flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium 2 WAT as influenced by soil temperature at a 7.5 cm depth averaged 1 WAT.

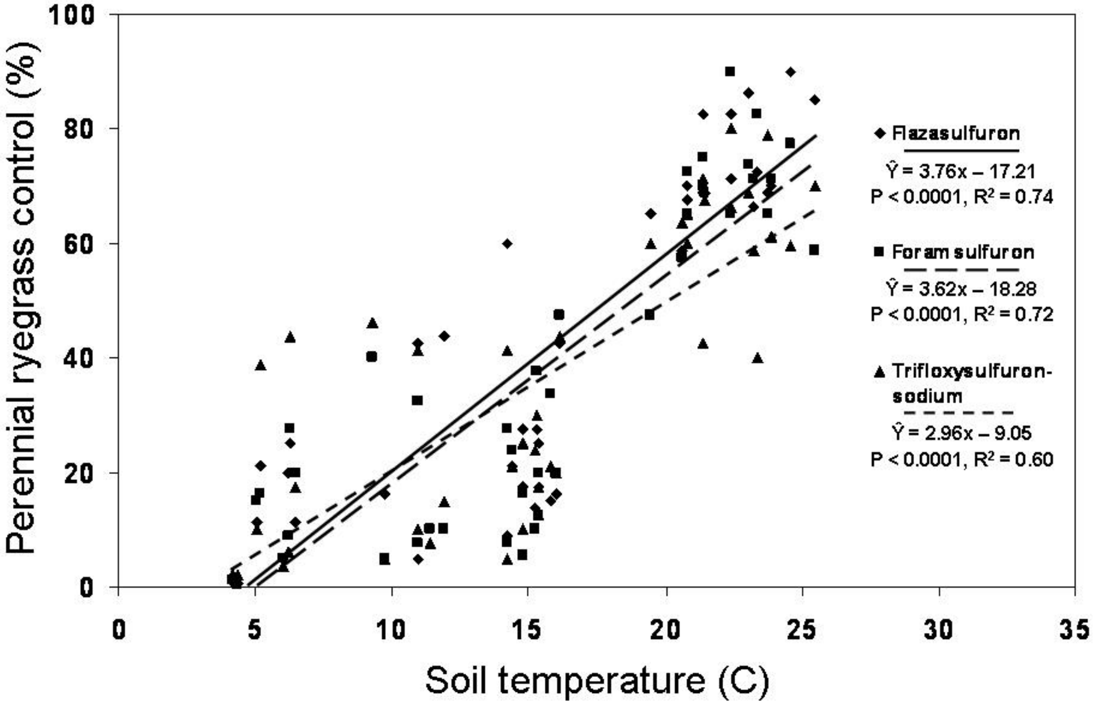


Figure 2. Perennial ryegrass control with flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium 4 WAT as influenced by soil temperature at a 7.5 cm depth averaged 1 WAT.

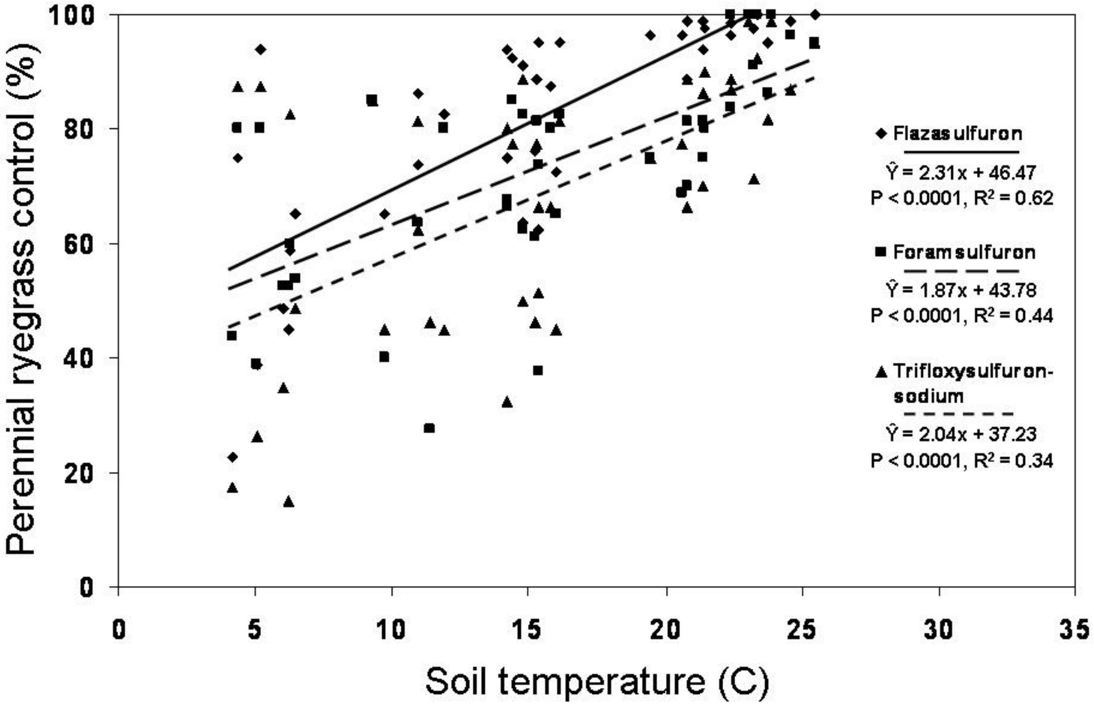


Figure 3. Perennial ryegrass cover plotted by treatment time in Julian d when treated with flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium at GLD location 9 WAT.

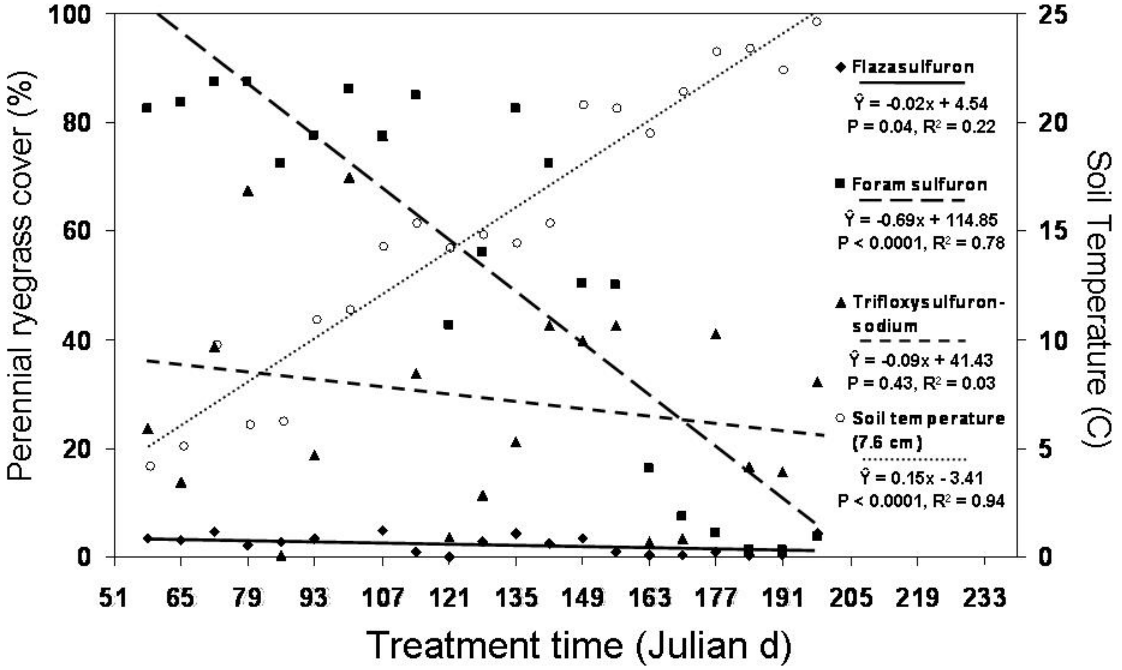
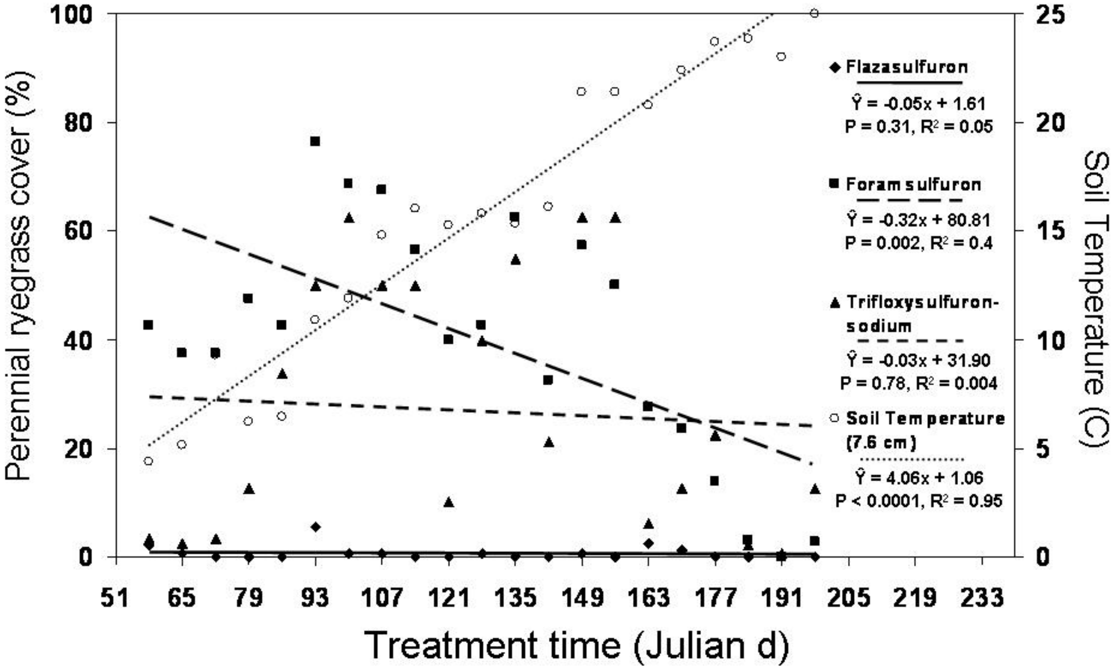


Figure 4. Perennial ryegrass cover plotted by treatment time in Julian d when treated with flazasulfuron, foramsulfuron, and trifloxysulfuron-sodium at TRC location 9 WAT.



Chapter 5.

Absorption and Translocation of Flazasulfuron Applied to Shoots and Roots of Perennial Ryegrass

The following chapter was formatted to facilitate publication in *Weed Science*.

Absorption and Translocation of Flazasulfuron Applied to Shoots and Roots of Perennial Ryegrass

John B. Willis and Shawn D. Askew [*]

Abstract

Studies were conducted to evaluate absorption and translocation of ^{14}C flazasulfuron in perennial ryegrass when applied to roots or foliage. Most recovered ^{14}C was not absorbed by plants. When averaged over harvest time main plots, relative differences in mobility of ^{14}C were evident. Radioactivity absorbed by roots was transolocated both to other roots and acropetally to leaves. Radioactivity absorbed by foliage remained mostly in the treated leaf and did not translocate to other foliage nor basipettally to roots. Roots treated with 14C-flazasulfuron absorbed 41% of recovered ^{14}C while 25% of recovered ^{14}C moved from treated roots to foliage. It appears root absorption is an important component of flazasulfuron efficacy since most of the ^{14}C remained in treated foliage and root absorbed ^{14}C moved rapidly to foliage.

Nomenclature: Flazasulfuron; perennial ryegrass, *Lolium perenne* L. ‘Celebration’.

Key words: Herbicide movement; herbicide translocation; sulfonylurea.

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Introduction

Several sulfonylurea herbicides have been registered for selective perennial ryegrass control in overseeded bermudagrass (*Cynodon dactylon* L.) turf (Keese 2005). Flazasulfuron or SL-160 is currently registered for use in grape (*Vitis* L.), citrus, sugarcane (*Saccharum* L.), and other non-crop areas (Yoshii 2003). Bermudagrass and zoysiagrass (*Zoysia japonica* L.) tolerance has been observed by several researchers in the US (Askew et al. 2006a; Beam et al. 2004; Brecke et al. 2008; Hutto et al. 2008a). Flazasulfuron is registered and will soon be marketed for use in turfgrass in the US for selective control of cool-season grasses, nutsedge (*Cyperus* sp. L.), kyllinga (*Kyllinga* sp. L.), and several broadleaves (Askew et al. 2006b). Research conducted in Blacksburg, VA concluded that perennial ryegrass control with flazasulfuron was more consistent than control with foramsulfuron and trifloxysulfuron-sodium at soil temperatures below 17° C (Willis et al. 2007). Hutto et al. (2008) also found that temperatures above 20 C lead to more rapid perennial ryegrass control with flazasulfuron. It was postulated that residual herbicide activity in soil could have contributed to increased efficacy during cold temperatures (Hutto et al. 2008, Willis et al. 2007).

Although selective placement studies have been preformed with several sulfonylurea herbicides, no attempt has been made to evaluate flazasulfuron absorption into plant foliage or roots. Foliar and soil plus foliar applications of foramsulfuron were concluded to be much more important than soil only applications for annual bluegrass (*Poa annua* L.) and goosegrass (*Eleusine indica* L.) control. In these trials root absorption of foramsulfuron was far less important than foliar absorption, however, no attempt was made to quantify the amount of foramsulfuron absorbed by either roots or foliage of plants (Walker 2006). Trifloxysulfuron-sodium was found to control green kyllinga (*Kyllinga brevifolia* Rottb.) better with soil only applications than foliar only applications, however no attempts were made to quantify the amount of trifloxysulfuron-sodium absorbed by either plant foliage or roots (McElroy et al. 2004). Many studies have evaluated foliar absorption of herbicides, however few have attempted to quantify root absorption of herbicides. Several cool-season turf and grassy weed species had substantial foliar and root absorption of bispyribac-sodium. The authors concluded that differential absorption among the species contributed to the selectivity of bispyribac-sodium among the species tested (Lycan and Hart 2006). Root absorption of trifloxysulfuron-sodium by torpedograss (*Panicum repens* L.) was observed to be more efficient than foliar absorption and thus contributing as much or possibly more to control than foliar absorption (Williams et al. 2003). Little is known about absorption of flazasulfuron in susceptible species.

Although flazasulfuron is used postemergent for perennial ryegrass control, foliar absorption is likely not the only source of entry into plants since both leaf and root absorption occur with trifloxysulfuron-sodium in torpedograss (Williams et al. 2003). No published research has evaluated importance of flazasulfuron absorption nor the importance of root verses foliar absorption of flazasulfuron in perennial ryegrass. Root absorption is likely a contributing factor for flazasulfuron efficacy. Field research in Virginia observed severe injury to seeded bermudagrass from flazasulfuron applications 1 and 3 weeks before seeding, where very little foliar absorption was likely (Willis et al. 2008). The importance of perennial ryegrass root and foliar absorption of flazasulfuron has not been characterized. Our objectives were to quantify the absorption and translocation of ^{14}C flazasulfuron into perennial ryegrass foliage and roots.

Materials and Methods

Plant Material. Well established ‘Celebration’ perennial ryegrass plants were harvested from a fairway with a cutting height of 2 cm and soil type Groseclose urban land complex (clayey, mixed, mesic, Typic Hapludalfs) with 6.3 pH. Plants were thinned to a single tiller and pruned so that each had one unexpanded leaf and two older leaves, all 0.5 to 0.75 cm long. Pruned plants were transplanted to 50-ml screw-cap centrifuge tubes containing 25% modified Hoagland’s solution, which was replaced daily during the acclimation period. Plants were allowed to acclimate for 10 d in a growth chamber with 21/18 C day/night temperature and a 300 μmol/m^2/sec PAR during a 14 h day period. Experimental design was randomized complete block with four replications, and plants were blocked by size. Two repetitions were conducted concurrently in separate growth chambers. Plants receiving a foliar treatment remained in the centrifuge tube and Hoagland’s solution was checked and replenished daily over the course of the experiment. The perennial ryegrass leaf immediately below the newest expanding leaf was spotted with 5 μl ^{14}C labeled flazasulfuron. The ^{14}C flazasulfuron of 85% specific activity was dissolved in acetonitrile, and 5 μl contained 200,000 DPM of radioactivity. Plants receiving root treatment had the same amount of ^{14}C labeled flazasulfuron placed into a 1.5 ml vial and filled with Hoagland’s solution. A single root was trained into this vial. Hoagland’s solution was replenished daily in both the centrifuge tube and the 1.5 ml vial. Non-radiolabeled herbicide was not applied to plants.

Absorption and Translocation. Plants were harvested at 0.17, 4, 24, 48, and 96 hrs after treatment (HAT) with flazasulfuron. For each replication, one foliar treated and one root treated plant were harvested at each harvest timing. Plants receiving foliar treatment of flazasulfuron were partitioned into treated leaf, other leaves, and roots, while plants receiving root treatment of flazasulfuron were partitioned into treated root, other roots and foliage. Treated leaves were cut at the point where the treated leaf blade joins the leaf sheath. Treated roots were cut at the point where that root joined the root bundle as close to the crown as possible. Plant foliage and roots were separated below the crown where the roots meet the single tiller. Treated leaves and roots, respectively, were immediately submersed in a vial containing 10 ml of 50:50 methanol-distilled water and shaken for 30 sec to remove readily available herbicide from the leaf surface. Next, plants were shaken for 10 sec using the same procedure in chloroform to remove any herbicide bound to the cuticle layer. A one ml aliquot of each leaf surface rinsate, treated Hoagland's solution, and Hoagland's solution in which plants were growing was added to 20 ml of scintillation cocktail[1] and radioactivity counts were determined utilizing liquid scintillation spectroscopy (LSS). The plant partitions were then air dried at 60 C for at least 24 hours, oxidized using a biological oxidizer[2], and assayed for total radioactivity via LSS.

Statistical Analysis. Data were transformed from DPM to percent of recovered ^{14}C for treated leaf, other foliage or roots, and nontreated foliage or roots. Repetition 1 and 2 had 75 and 78% recovery of applied ^{14}C, respectively. Data were subjected to a combined ANOVA using the GLM procedure in SAS statistical software (SAS 2004). Experiment repetition was considered a random variable in the combined analysis and mean squares were tested appropriately for a split plot treatment design where harvest times were main plots, and a factorial arrangement of split plots, application placement by plant partitions (McIntosh 1983). Regression analyses were conducted for foliage and root application by harvest timing where appropriate. Other effects were separated using Fisher's Protected LSD test at P=0.05. Data variance was tested before ANOVA and percentage data were transformed to the arcsine of the square-root where appropriate.

Results and Discussion

The combined ANOVA revealed no significant interaction among repetitions for the percent recovered radioactivity data. However, harvest time, plant partition, and application placement were all significant effects for the percent ^{14}C recovery data in the analysis. The two-way interaction of plant partition and part treated were also significant as well as the three way interaction. The main effect plant partition interaction is displayed in Table 1. When averaged over the harvest time main plots, relative differences in mobility of ^{14}C were evident. Radioactivity absorbed by roots was translocated both to other roots and acropetally. Radioactivity absorbed by foliage remained mostly in the treated leaf and did not translocate to other foliage nor basipettally (Table 1).

The three way interaction for foliar application is displayed in Figure 1 and root application is displayed in Figure 2. When applied to foliage, leaf wash radioactivity decreased over time as treated leaf radioactivity increased. By 96 HAT 19% of recovered ^{14}C moved into the treated leaf, while very little moved from the treated leaf to other plant parts. When applied to roots, root wash radioactivity decreased over time as treated root and foliage radioactivity increased. Most recovered ^{14}C was not absorbed by plants. Significant amounts of root applied ^{14}C did move into the treated root. Over time ^{14}C applied to roots moved throughout other roots and foliage, with 24% of absorbed ^{14}C having moved into plant foliage by 96 hr compared to a total of 21% of applied ^{14}C moving into the treated leaf. In other research 56% of absorbed trifloxysulfuron-sodium remained in torpedograss roots while the remainder was translocated to other plant parts while only 29% of foliar applied product was absorbed (Williams et al. 2003). Root absorption of bispyribac-sodium with annual and rough-stalk bluegrass translocated 77 and 80% of root absorbed ^{14}C to foliage (Lycan and Hart 2006). Selective placement studies with green kyllinga concluded that trifloxysulfuron-sodium controlled this weed better when applied to soil than when applied to foliage, but the highest control occurred when applied to both soil and foliage (McElroy et al. 2004). The same research indicated that halosulfuron did not control green kyllinga unless applied to both soil and foliage, and applications to soil or foliage alone did not significantly control green kyllinga. Quinclorac was readily absorbed into torpedograss roots (54%) while minimal foliar absorption was observed (Williams et al. 2004).

Selective placement studies have not been conducted on perennial ryegrass or with flazasulfuron. This is the first published work evaluating flazasulfuron absorption and translocation using radiotracer techniques. Although metabolism data would be needed to make conclusions relative to parent flazasulfuron movement, it appears that root absorption is an important component of flazasulfuron efficacy since most of the ^{14}C applied to leaves remained in treated foliage while root absorbed ^{14}C moved rapidly to foliage. One limitation of this research is the use of hydroponics, which allowed flazasulfuron exposure to plant roots exclusive of soil particles. Field observations supported the importance of root uptake of flazasulfuron (Willis et al. 2008). Similar work with trifloxysulfuron-sodium also concluded that soil absorption was an important mechanism of herbicide uptake for weed control (McElroy et al. 2004; Williams et al. 2003).

Acknowledgments

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Sources of Materials

[1] ScintiVerse®. Fisher Scientific Company L. L. C., 2000 Park Lane, Pittsburg, PA 15275.

[2] BO306 Biological Sample Oxidizer. Packard Instrument Co., 800 Research Parkway, Meriden, CT 06450.

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Table 1. Translocation of ^{14}C after labeled flazasulfuron was applied to foliage and root. Displayed mean is an average of all harvest times for both foliage and root treatment[a].

	Recovered ^{14}C	
Treated part	Foliage	Root
Translocation	——— % ———	
Not absorbed	89a[b]	78a
Treated leaf/root	9a	9a
Other leaves/roots	2a	4a
Non-treated Roots/leaves	0b	9a
$LSD_{0.05}$	6	4

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[a] Abbreviations: LSD, least significant difference.

[b] Use lower case letters to separate significant differences (0.05) in rows and LSD at the bottom to compare among columns.

Figure 1. Recovery of ^{14}C in plant partitions after applying ^{14}C flazasulfuron to perennial ryegrass foliage.

Figure 2. Recovery of ^{14}C in plant partitions after applying ^{14}C flazasulfuron to perennial ryegrass root.

Figure 1. Recovery of ^{14}C in plant partitions after application of ^{14}C flazasulfuron to perennial ryegrass foliage.

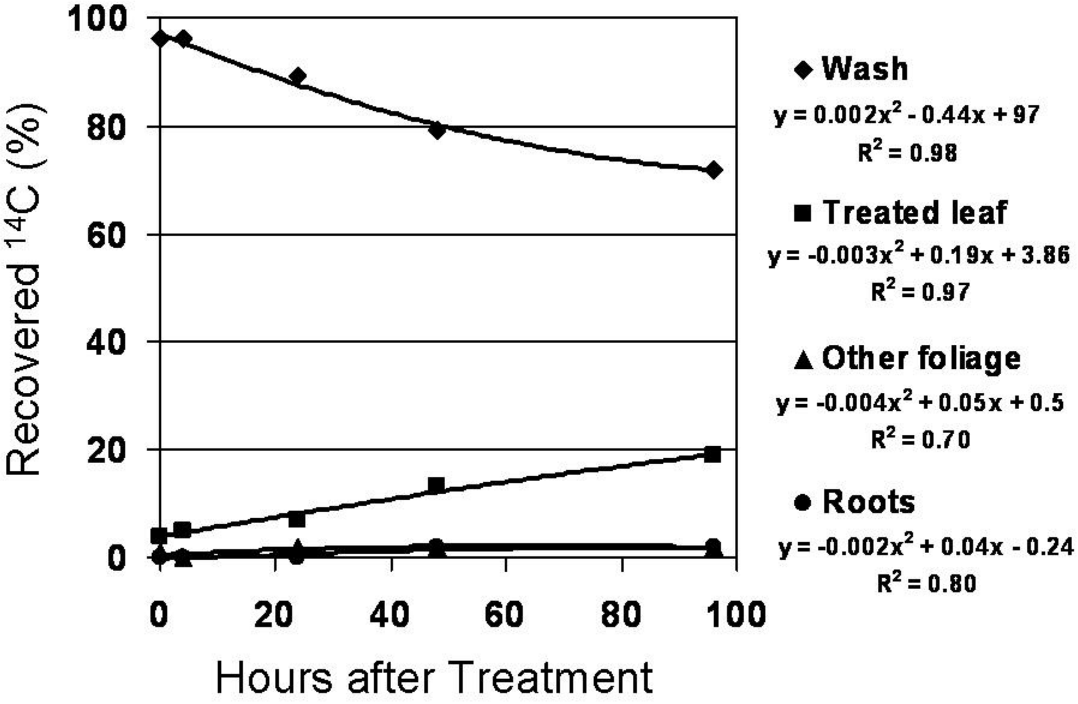

Figure 2. Recovery of ^{14}C in plant partitions after application of ^{14}C flazasulfuron to perennial ryegrass root.