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Bermudagrass (*Cynodon dactylon*) Control with Topramezone and Triclopyr

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Common bermudagrass is a problematic weed within tall fescue turfgrass. Field research was conducted from 2010 to 2012 in Knoxville, TN, evaluating the efficacy of sequential applications of topramezone (12.5 and 25 g ha^{-1}), triclopyr (1,120 g ha^{-1}), and mixtures of topramezone + triclopyr for bermudagrass control in tall fescue turf. Sequential applications of fenoxaprop + triclopyr (100 + 1,120 g ha^{-1}) were included for comparison. Three applications of each treatment were applied at 21-d intervals during July, August, and September of 2010 and 2011. Plots were stripped to receive tall fescue interseeding at 0 or 490 kg ha^{-1} during September 2010 and 2011. Bermudagrass control with topramezone + triclopyr mixtures was greater than topramezone or triclopyr applied alone 14 wk after initial treatment (WAIT) each year. In the second year of this study, topramezone + triclopyr mixtures controlled bermudagrass 27 to 50% compared to 27% for fenoxaprop + triclopyr by 52 WAIT. However, bermudagrass control with topramezone + triclopyr mixtures increased to 88 to 92% by 52 WAIT when accompanied with tall fescue interseeding at 490 kg ha^{-1}. Future research should evaluate effects of interseeding on the efficacy of different herbicides for weed control in cool- and warm-season turf.

Nomenclature: Fenoxaprop, topramezone, triclopyr, common bermudagrass, *Cynodon dactylon* (L.) Pers.; tall fescue, *Lolium arundinaceum* (Schreb.) S. J. Darbyshire.

Key words: Efficacy, HPPD, interseeding, turf, turfgrass.

Cynodon dactylon es una maleza problemática en el césped *Lolium arundinaceum*. Se realizaron investigaciones de campo entre 2010 y 2012 en Knoxville, TN, para evaluar la eficacia de aplicaciones secuenciales de topramezone (12.5 y 25 g ha^{-1}), triclopyr (1,120 g ha^{-1}), y mezclas de topramezone + triclopyr para el control de *C. dactylon* en *L. arundinaceum*. Aplicaciones secuenciales de fenoxaprop + triclopyr (100 + 1,120 g ha^{-1}) fueron incluidas como comparación. Tres aplicaciones de cada tratamiento fueron realizadas a intervalos de 21 días durante Julio, Agosto y Septiembre de 2010 y 2011. Las parcelas fueron preparadas para recibir una entre-siembra de *L. arundinaceum* a 0 ó 490 kg ha^{-1} durante Septiembre 2010 y 2011. El control de *C. dactylon* con mezclas de topramezone + triclopyr fue mayor que topramezone o triclopyr aplicados solos, 14 semanas después del tratamiento inicial (WAIT) cada año. En el segundo año de este estudio, las mezclas de topramezone + triclopyr controlaron *C. dactylon* 27 a 50% en comparación a 27% con fenoxaprop + triclopyr a 52 WAIT. Sin embargo, el control de *C. dactylon* con mezclas de topramezone + triclopyr incrementó a 88 a 92% a 52 WAIT cuando estuvo acompañado por la entre-siembra de *L. arundinaceum* a 490 kg ha^{-1}. Investigaciones futuras deberían evaluar los efectos de la entre-siembra sobre la eficacia de diferentes herbicidas para el control de malezas en céspedes de clima cálido y frío.

Bermudagrass is one of the most troublesome weeds in the southern United States (Webster and Nichols 2012). Differential growth rates during summer can result in bermudagrass encroachment into weaker tall fescue turf. The presence of bermudagrass in a tall fescue sward can reduce turf quality due to differences in leaf color, texture, and growth habit. This reduction is particularly noticeable in winter when bermudagrass foliage becomes brown during dormancy, while tall fescue retains green color year-round (Johnson and Carrow 1995).

Herbicidal inhibitors of acetyl-CoA carboxylase (ACCase; E.C. 6.4.1.2) have been used for selective bermudagrass suppression in desirable turf. Efficacy with sequential applications of fenoxaprop, fluazifop, and metamifop has been reported (Cudney et al. 1997; Doroh et al. 2011; Johnson and Carrow 1995; Lewis et al. 2010). The pyridine herbicide triclopyr can also suppress bermudagrass and enhance the activity of ACCase inhibitors when applied in mixtures (Cudney et al. 1997; Doroh et al. 2011; Lewis et al. 2010).

Topramezone is an inhibitor of *p*-hydroxyphenylpyruvate dioxygenase (HPPD; EC 1.13.11.27) registered for weed control in corn (*Zea mays* L.) (Anonymous 2006). In a greenhouse study involving three HPPD-inhibiting herbicides (mesotrione, topramezone, and tembotrione), Brosnan et al. (2011) observed that topramezone and tembotrione bleached common bermudagrass leaf tissues to a greater degree than mesotrione. This response was accompanied by greater reductions in total chlorophyll (chlorophyll *a* + *b*), β-carotene, lutein, and total xanthophyll cycle pigment concentrations (zeaxanthin + antheraxanthin + violaxanthin) in bermudagrass leaf tissue. Reductions were greatest from 14 to 21 d after treatment, thus providing a physiological basis for applying these herbicides at 14- to 21-d intervals. Additionally, the researchers observed that topramezone and tembotrione increased the percentage of zeaxanthin + antheraxanthin in the total xanthophyll pigment pool after peak visual bleaching was observed and surmised that this might be a mechanism allowing bermudagrass to recover from HPPD-inhibiting herbicide injury. Elmore et al. (2011) observed a similar response on hybrid bermudagrass and

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concluded that topramezone was the most active of the three HPPD herbicides because the lowest topramezone rate tested (18 g ha^{-1}) reduced lutein and total xanthophyll pigment concentrations greater than the lowest tembotrione and mesotrione rates during periods of maximum activity. Necrosis was not observed by Brosnan et al. (2011) or Elmore et al. (2011), suggesting that HPPD inhibitors might need to be applied in mixtures with other herbicides to provide long-term bermudagrass control.

Interseeding to increase desirable turf density can reduce weed populations by limiting voids in a turf canopy available for weed establishment (Watschke and Engel 1994). Several researchers have demonstrated that seeding alone will not affect weed populations unless chemical or biological weed control techniques are implemented (Elford et al. 2008; Larsen et al. 2004; Larsen and Fischer 2005). For example, Abu-Dieyeh and Watson (2007) reported that the combination of overseeding and applying the plant pathogen *Sclerotinia minor* reduced dandelion (*Taraxacum officinale* G. H. Weber ex Wiggers) and white clover (*Trifolium repens* L.) populations more than than overseeding or *Sclerotinia minor* applied alone.

Topramezone might provide turf managers with a new option for managing bermudagrass infestations in cool-season turfgrass. Practices such as combining topramezone with triclopyr or interseeding cool-season turfgrass following topramezone treatment might enhance bermudagrass control. However, field data describing bermudagrass control efficacy with topramezone are limited. Therefore, the principal objective of this research was to evaluate the efficacy of topramezone for bermudagrass control in tall fescue turf. A secondary objective was to determine the effects of triclopyr and interseeding on bermudagrass control with topramezone.

Materials and Methods

Field research was conducted on a mature stand of tall fescue naturally infested with common bermudagrass at the University of Tennessee (Knoxville) from July 2010 to July 2012. Turf was established upon a Sequatchie loam soil (fine-loamy, siliceous, semiactive, thermic humic Hapludult), measuring 6.2 in soil pH and 2.1% in organic matter content. Turf was mowed with a rotary mower at a height of 5.1 cm with clippings returned. The site received 49 kg N ha^{-1} from a complete fertilizer (24 N : 6 P_2O_5 : 12 K_2O; Harrell's LLC, Lakeland, FL 33815) during the spring of 2010 and 2011. Irrigation was applied in supplement to natural rainfall.

Plots (1.5 by 3.0 m) were arranged in a strip-plot design with three replications. Whole plots received herbicide applications on July 21, August 12, and September 1 in 2010 and 2011 (Table 1). This 3-wk interval was selected because previous research illustrated that topramezone activity on common bermudagrass declines from 21 to 28 d after treatment (Brosnan et al. 2011). Treatments were applied with a CO_2-powered boom sprayer calibrated to deliver 281 L ha^{-1} using 8002 flat-fan nozzles (TeeJet, Spraying Systems Co., Wheaton, IL). A nontreated check was included in each replication for comparison. Tall fescue (cv. 'Falcon III') was interseeded as a strip (1 m wide) through all plots in each replication 3 wk after the final herbicide application each year. A slit-seeder (Ryan® Mataway® overseeder/dethatcher; Schiller Grounds Care Inc., Johnson Creek, WI 53038) was used to deliver seed at 490 kg ha^{-1}. Immediately after seeding, all plots received 49 kg P_2O_5 ha^{-1} from a complete fertilizer (24 N : 6 P_2O_5 : 12 K_2O; Harrell's LLC) and were irrigated to promote tall fescue seed germination.

Table 1. Herbicide treatments included in a field study evaluating selective bermudagrass control in tall fescue turf in Knoxville, TN from 2010 to 2012.

Treatment[a]	Rate
	g ha^{-1}
Topramezone[b]	12.5
	25.0
Topramezone + triclopyr[c]	12.5 + 1,120
	25.0 + 1,120
Fenoxaprop[d] + triclopyr	100 + 1,120
Triclopyr	1120

[a] Treatments applied July 21, August 12, and September 1 in both 2010 and 2011.

[b] BAS 670 (BASF Corporation). All topramezone-containing treatments included a methylated seed oil surfactant (BASF Corporation) at 1% v/v.

[c] Turflon Ester (Dow AgroSciences, Indianapolis, IN 46268).

[d] Acclaim Extra (Bayer Environmental Sciences, Research Triangle Park, NC 27709) included a nonionic surfactant (Activator-90, Loveland Products, Greeley, CO 80631) at 0.25% v/v.

After all experimental treatments had been applied during 2010 and 2011, the experimental site was managed to maximize tall fescue aesthetic and functional quality in 2012. Plots received an application of quinclorac (Drive XLR8; BASF Corporation. Research Triangle Park, NC 27709) + pendimethalin (Pendulum AquaCap; BASF Corporation) at 840 + 3,360 g ha^{-1} on May 17, 2012 to control smooth crabgrass [*Digitaria ischaemum* (Schreb.) Schreb. ex Muhl.]. Additionally, pyraclostrobin (Insignia SC; BASF Corporation) was applied at 556 g ha^{-1} to manage brown patch (causal agent: *Rhizoctonia solani* Kühn). Nutrient applications, irrigation, and mowing practices in 2012 were the same as those implemented in 2010 and 2011.

Data Collection and Analysis. Bermudagrass control and tall fescue injury were assessed relative to the nontreated check on a percent scale, where 0 equaled no control or turf injury and 100 equaled complete plant death. To capture short-term activity, these data were collected on each whole plot 2, 5, 8, and 14 WAIT each year. Bermudagrass control data were also collected from each subplot at 52 WAIT each year to determine long-term control efficacy and effects of interseeding. Grid counts were also made 52 WAIT each year to provide a quantitative assessment of the bermudagrass population in each subplot. A 100 by 100 cm grid containing 81 squares (10 by 10 cm) was placed in the center of each subplot. The presence or absence of bermudagrass within each square was recorded. Grid count data are expressed as a percent change relative to the nontreated check using the equation, % change = [1 − (count in treated plot/count in nontreated check)]100.

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Table 2. Bermudagrass control 2, 5, 8, and 14 wk after applying herbicide treatments to a tall fescue turf stand in Knoxville, TN during 2010 and 2011.

		Bermudagrass control							
		2010				2011			
Herbicide[a]	Rate	2 WAIT[b]	5 WAIT	8 WAIT	14 WAIT	2 WAIT	5 WAIT	8 WAIT	14 WAIT
	g ha^{-1}	%							
Topramezone	12.5	5	27	47	0	27	37	47	6
	25	18	37	72	17	80	37	73	23
Topramezone + triclopyr	12.5 + 1,120	28	68	92	47	77	73	97	70
	25 + 1,120	33	87	96	67	83	88	98	90
Fenoxaprop + triclopyr	100 + 1,120	22	30	43	23	78	33	82	57
Triclopyr	1,120	8	23	33	13	47	30	43	30
$LSD_{0.05}$		10	13	9	27	14	19	12	20

[a] Herbicides were applied sequentially on July 21, August 12, and September 1 in both 2010 and 2011. Topramezone-containing treatments included a methylated seed oil surfactant (BASF Corporation) at 1% v/v. Fenoxaprop-containing treatments included a nonionic surfactant (Activator-90, Loveland Products) at 0.25% v/v.

[b] Abbreviations: WAIT, weeks after initial treatment.

Bermudagrass control and tall fescue injury data were arcsine square-root transformed to stabilize variance (Ahrens et al. 1990) prior to being subjected to analysis of variance, with main effects and all possible interactions tested using the appropriate expected mean square values described by McIntosh (1983). Interpretations were not different from nontransformed data; therefore, nontransformed means are presented for clarity. Treatment means were separated using Fisher's protected least significant difference (LSD) test at the $\alpha = 0.05$ level.

Results and Discussion

Year-by-treatment interactions were detected in bermudagrass control data. Therefore, data from each year were analyzed and presented separately. No tall fescue injury was observed on any evaluation date (data not presented).

Short-Term Control. Sequential applications of topramezone did not provide effective bermudagrass control in this study (Table 2). By 8 WAIT, the 12.5 and 25 g ha^{-1} rates of topramezone controlled bermudagrass 47 and 72% each year; however, control with these treatments decreased to $\leq$ 23% by 14 WAIT. In a greenhouse experiment, Brosnan et al. (2011) observed 57% bleaching of 'Riviera' bermudagrass with a single application of topramezone at 25 g ha^{-1} decrease to 3% by 35 d after application. The researchers hypothesized that increases in zeaxanthin and antheraxanthin could be a mechanism by which common bermudagrass recovers from topramezone-induced injury.

Triclopyr significantly increased bermudagrass control with topramezone in both years of this study (Table 2). On every evaluation date, bermudagrass control with the 12.5 g ha^{-1} rate of topramezone + triclopyr (1,120 g ha^{-1}) was greater than topramezone or triclopyr applied alone; a similar response was observed with the 25 g ha^{-1} rate of topramezone as well. By 14 WAIT, topramezone + triclopyr mixtures controlled bermudagrass 47 to 67% in 2010 and 70 to 90% in 2011. Comparatively, control with sequential applications of fenoxaprop + triclopyr only measured 23% and 57% on the same assessment dates in 2010 and 2011, respectively.

Long-Term Control. Visual assessments of bermudagrass control were made 52 WAIT each year; on the same dates, grid counts were taken to assess changes in the bermudagrass population present in each plot (Table 3). No treatment controlled bermudagrass 52 WAIT in 2010, and no significant differences in bermudagrass population change were detected. Population changes ranged from −15% to 16% relative to the nontreated check.

A significant herbicide-by-interseeding interaction was detected in bermudagrass control and population change data collected 52 WAIT in 2011 (Table 3). Interseeding tall fescue at 490 kg ha^{-1} increased bermudagrass control with topramezone (25 g ha^{-1}), topramezone + triclopyr, and fenoxaprop + triclopyr compared to applying these herbicides without interseeding. Population change data supported these visual assessments of control because applications of topramezone (25 g ha^{-1}), topramezone + triclopyr, and fenoxaprop + triclopyr combined, with interseeding, reduced bermudagrass populations 49 to 62%. When these treatments were applied without interseeding, bermudagrass populations increased 4 to 67% relative to the nontreated check.

It is unclear from these interseeding data why significant differences in bermudagrass control and population change were only apparent 52 WAIT in 2011 and not 2010. It should be noted that short-term control (i.e., 2 WAIT) for all treatments was greater in 2011 compared to 2010, suggesting that sensitivity to applied treatments might have been greater during the second year of the study (Table 2). Moreover, no practices were implemented to promote the summer survival of tall fescue interseeded in fall 2010. This choice was made to prevent potential interactions with experimental treatments applied during the second year of the study. Invasion of other weed species (e.g., smooth crabgrass) and fungal pathogens (e.g., brown patch) during the summer of 2011 could have reduced tall fescue density and competitiveness, thus creating a more favorable environment for bermudagrass encroachment. Although tall fescue cover in strip-plots receiving interseeding ranged from 80 to 95% 1 mo after seeding in 2010 (data not presented), grid counts revealed that tall fescue cover substantially declined by 52 WAIT (July 21, 2011). Plots receiving no

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Table 3. Bermudagrass control and population change 52 WAIT (weeks after initial [herbicide] treatments) and interseeding to a tall fescue turf stand in Knoxville, TN during 2010 and 2011.

			2010		2011	
Interseeding[a]	Herbicide[b]	Rate	Bermudagrass control	Bermudagrass population change[c]	Bermudagrass control	Bermudagrass population change
kg ha^{-1}		g ha^{-1}	%			
0	topramezone	12.5	0	14	17	49
		25	0	−15	17	37
	topramezone + triclopyr	12.5 + 1,120	0	−9	27	67
		25 + 1,120	0	−7	50	4
	fenoxaprop + triclopyr	100 + 1,120	0	15	27	47
	triclopyr	1,120	0	−2	20	−11
490	topramezone	12.5	0	16	20	−35
		25	0	−15	73	−53
	topramezone + triclopyr	12.5 + 1,120	0	8	88	−59
		25 + 1,120	0	−5	92	−62
	fenoxaprop + triclopyr	100 + 1,120	0	7	62	−49
	triclopyr	1,120	0	2	43	−17
LSD_{005}			NS	NS	23	51

[a] Tall fescue (cv. 'Falcon III') was interseeded as a strip (1-m-wide) through all plots in each replication 3 wk after the final herbicide application each year using a slit-seeder at 0 or 490 kg ha^{-1}.

[b] Herbicides were applied sequentially on July 21, August 12, and September 1 in both 2010 and 2011. Topramezone-containing treatments included a methylated seed oil surfactant (BASF Corporation) at 1% v/v. Fenoxaprop-containing treatments included a nonionic surfactant (Activator-90, Loveland Products) at 0.25% v/v.

[c] A 100 × 100 cm grid containing 81 squares (10 × 10 cm) was placed in the center of each subplot. The presence or absence of bermudagrass in each square was recorded. Grid count data are expressed as a percent change relative to the nontreated check using the formula, % change = (1 − [count in treated plot/count in nontreated check]) * 100. Population change data were made 52 WAIT (weeks after initial treatment) in 2010 and 2011.

herbicide treatment and interseeding in 2010 contained only 31% tall fescue 52 WAIT and were not different from nontreated check plots receiving no interseeding (34% tall fescue).

In 2012, practices to maximize the summer survival of tall fescue were implemented after all 2011 data had been collected. By 52 WAIT (July 21, 2012) interseeding improved bermudagrass control with topramezone (25 g ha^{-1}), topramezone + triclopyr, and fenoxaprop + triclopyr applications (Table 3). Additionally, bermudagrass populations in nontreated check plots declined from ∼68% 52 WAIT in 2010 (July 21, 2011) to ∼23% 52 WAIT in 2011 (July 21, 2012). This response suggests that practices to maximize summer survival of tall fescue (e.g., controlling smooth crabgrass and brown patch) render the sward more competitive against bermudagrass. Ferrell et al. (2003) concluded that azoxystrobin applications to control brown patch in tall fescue rendered the sward more competitive against smooth crabgrass, thus improving efficacy of pendimethalin applications.

Data in the current trial illustrate that triclopyr enhances bermudagrass control with topramezone when the two herbicides are applied sequentially in mixtures at 21-d intervals. Mixtures of topramezone + triclopyr controlled bermudagrass greater than mixtures of fenoxaprop + triclopyr on the majority of evaluation dates in this 2-yr study. Efficacy of topramezone + triclopyr treatments was enhanced by fall interseeding of tall fescue in a single year of this study. Bermudagrass control with topramezone + triclopyr mixtures measured 88 to 92% 52 WAIT when accompanied with tall fescue interseeding at 490 kg ha^{-1} in 2011 compared to 27 to 52% without interseeding. Future research should evaluate effects of interseeding on the efficacy of different herbicides for weed control in cool- and warm-season turf.

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