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Herbicide Regimens for Creeping Bentgrass Control in Kentucky Bluegrass

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***Abstract*. Creeping bentgrass (CBG; *Agrostis stolonifera* L.) is a problematic weed of cool-season turfgrass. The herbicide mesotrione is often used for selective control, but CBG often recovers from sequential applications. Research evaluated the efficacy of mesotrione-based sequential application regimens for CBG control in kentucky bluegrass (*Poa pratensis* L.) over a 2-year period. In two separate experiments, identical herbicide regimens were initiated in Oct. 2014 or May 2015 and then reapplied to the same plots in Oct. 2015 or May 2016, respectively. Regimens consisted of various sequential application regimens of mesotrione alone (totaling 560 g·ha^{-1} annually), three sequential applications of mesotrione (175 g·ha^{-1}) tank-mixed with either triclopyr ester (560 or 1120 g·ha^{-1}) or amicarbazone (50 or 100 g·ha^{-1}), and topramezone (32 or 37 g·ha^{-1}) tank-mixed with triclopyr ester (1120 g·ha^{-1}). At the end of each 2-year experiment, the most effective treatments did not eliminate CBG completely. Among treatment regimens initiated in the fall, the most effective treatments reduced CBG cover 49% to 73% at the conclusion of the experiment in Oct. 2016. At the conclusion of the spring experiment in May 2017, the most effective treatments reduced CBG cover 66% to 94%. Topramezone + triclopyr tank mixtures were less effective than mesotrione-containing treatments on most dates. Mesotrione + amicarbazone tank mixtures reduced CBG more effectively than mesotrione alone, but these tank mixtures also caused severe kentucky bluegrass injury. CBG cover reductions from mesotrione + triclopyr tank mixtures and mesotrione alone were generally similar. Among mesotrione-only regimens, there were no consistent differences in CBG cover reduction. This research indicates that turf managers using a selective herbicide regimen to control CBG in kentucky bluegrass should apply mesotrione at the maximum annual use rate (560 g·ha^{-1}) in two to four sequential applications at 2- to 3-week intervals.**

CBG is a problematic weed in lawns, parks, and golf course roughs in much of the northern United States. This perennial weed can spread quickly as a result of its stoloniferous growth habit. A desirable grass at mowing heights less than 1.5 cm, CBG is usually considered a weed in turfgrass maintained at 2 cm or higher, because it becomes puffy and unattractive (Branham et al., 2005). Nonselective herbicides such as glyphosate can be used for CBG control, but a single application does not always provide commercially acceptable control (Askew et al., 2004). Nonselective herbicides also cause unsightly bare patches after application, and reseeding desirable turfgrass is required. Triclopyr ester can suppress CBG selectively, but it is less effective than mesotrione and can cause tall fescue (*Festuca arundinacea* Schreb.) injury at rates required for suppression (Dernoeden et al., 2008).

Mesotrione is a p-hydroxyphenylpyruvate dioxygenase (HPPD) inhibiting herbicide first registered in 2008 for use on most cool-season turfgrass species at single and annual application rates up to 280 g·ha^{-1} and 560 g·ha^{-1}, respectively (Anonymous, 2011; Mitchell et al., 2001). Mesotrione can control or suppress CBG in perennial ryegrass (*Lolium perenne* L.), kentucky bluegrass (*Poa pratensis* L.), and tall fescue. Research demonstrated consistently that sequential mesotrione applications provide more CBG control than single applications (Branham et al., 2005; Dernoeden et al., 2008; Jones and Christians, 2007; Xie et al., 2011). Jones and Christians (2007) demonstrated that 2week mesotrione reapplication intervals provided more CBG control than 6-week intervals. Branham et al. (2005) found that CBG control with mesotrione was inconsistent. In their research, mesotrione applied twice at 280 g·ha^{-1} at a 3-week interval in late spring provided 13% and 97% control in 2003 and 2004, respectively, at 3 months after initial treatment (MAIT). The cause of this year-to-year variability was not clear, although three sequential applications of 420 g mesotrione/ha (more than registered use rates) provided more consistent control. The number of sequential applications did not affect CBG control in Maryland and Connecticut as two, three, or four sequential applications of mesotrione at 140 or 210 g·ha^{-1} provided similar (>90%) CBG control at 3 to 4 MAIT (Dernoeden et al., 2008). Using lower mesotrione rates than other researchers, Xie et al. (2011) demonstrated that tank mixing mesotrione with urea ammonium nitrate (UAN) improved CBG control provided by three sequential applications of mesotrione at 56 or 70 g·ha^{-1}. Three sequential applications of mesotrione + UAN at 70 g·ha^{-1} provided 97% or more CBG control from late-summer applications compared with less than 80% control without UAN. Although most researchers evaluated spring or summer applications, Beam et al. (2006) evaluated fall applications and observed more than 90% control from two sequential applications of mesotrione at 280, 170, and 60 g·ha^{-1}.

The efficacy of mesotrione-based tank mixtures for CBG control has not been investigated. Dernoeden et al. (2008) found that triclopyr ester alone provided CBG suppression but did not examine tank mixtures of mesotrione + triclopyr ester. Tank mixtures of triclopyr ester and HPPD-inhibiting herbicides can reduce bleaching symptoms and improve common bermudagrass (*Cynodon dactylon* L.) and smooth crabgrass [*Digitaria ischaemum* (Schreb) Schreb ex Muhl.] control (Brosnan and Breeden, 2013; Yu and McCullough, 2016).

Amicarbazone is a photosystem II (PSII)-inhibiting herbicide registered for annual bluegrass (*Poa annua* L.) control in kentucky bluegrass and CBG at up to 100 g·ha^{-1} and 50 g·ha^{-1} per application, respectively (Anonymous, 2012; Dayan et al., 2009). Amicarbazone can cause transient sublethal injury to both CBG and kentucky bluegrass at 100 g·ha^{-1} (McCullough et al., 2010). Given that synergy between sublethal rates of other PSII-inhibiting herbicides and HPPD-inhibiting herbicides has been demonstrated previously, investigating tank mixtures of mesotrione and amicarbazone for creeping bentgrass control is warranted (Woodyard et al., 2009).

Research investigating herbicides for tough-to-control perennial weeds such as dallisgrass (*Paspalum dilatatum* L.) and common bermudagrass often evaluates treatment responses for several months or more after the last herbicide application to assess regrowth from perennial structures (Brosnan and Breeden, 2013; Henry et al., 2007). However, with the exception of Jones and Christians (2007) and Xie et al. (2011), previous CBG control research evaluated efficacy for only 2 to 4 months after the final application (Beam et al., 2006; Branham et al., 2005; Dernoeden et al., 2008). Furthermore, we are not aware of research investigating multiyear sequential application programs. Our communications with practitioners suggest CBG recovers from single-year sequential mesotrione application regimens and that

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evaluating the efficacy of 2-year regimens is warranted.

The objective of this research was to evaluate 2-year sequential application regimens of mesotrione alone and in tank mixes with triclopyr ester or amicarbazone.

Materials and Methods

Two separate trials were conducted over a 2-year period from 2014 to 2017 on a mature stand of 'Midnight II' kentucky bluegrass infested with an unknown CBG variety at the Rutgers Plant Science Research and Extension Farm in Freehold, NJ. CBG patches were relatively large (estimated to be 0.3–0.6 m in diameter) and phenotypically distinct when the trial began. It is not known whether the source of the infestation is natural or accidental (e.g., seeder contaminated with CBG seed). The site was mown weekly during the growing season at 6.3 cm and irrigated as necessary to prevent wilt. The soil was a Homdel sandy loam (fine loamy, mixed, active, mesic Aquic Hapludults) with a pH of 6.4.

Various sequential herbicide regimens containing mesotrione (Tenacity 4SC; Syngenta Professional Products, Greensboro NC), topramezone (Pylex 2.8SC, BASF Corp., Research Triangle Park, NC), triclopyr ester (Turflon Ester; Dow AgroSciences LLC, Indianapolis, IN), or amicarbazone (Xonerate 70WDG; Arysta LifeScience North America LLC, Cary, NC) were evaluated. Herbicide treatments containing mesotrione were applied with nonionic surfactant (Activator 90; Loveland Products Inc., Loveland, CO) at 0.25% v/v, and those containing topramezone were applied with MSO (Brandt M.S.O.; Brandt Consolidated, Inc., Springfield, IL) at 1% v/v. Nine herbicide treatments and a nontreated control (hereafter, control) were evaluated. Treatments described in Table 1 consisted of mesotrione applied in two, three, and four sequential applications alone; three sequential applications of mesotrione (175 g·ha^{-1}) tank-mixed with triclopyr ester (hereafter, triclopyr) at 560 and 1120 g·ha^{-1}; four sequential applications of mesotrione (140 g·ha^{-1}) tank-mixed with amicarbazone at 2- or 3-week intervals; and two or three sequential applications of topramezone at 32 or 37 g·ha^{-1} tank-mixed with triclopyr at 1120 g·ha^{-1}. The cumulative mesotrione rate for all regimens was equal to the registered maximum yearly use rate of 560 g·ha^{-1} (Anonymous 2011).

For the first and second experiments, regimens were initiated on 10 Oct. 2014 (hereafter, fall experiment) and 7 May 2015 (hereafter, spring experiment), respectively. To evaluate the cumulative effects of these regimens over 2 years, the trial areas were maintained and the application regimens were applied to the same plots for fall and spring experiments on 14 Oct. 2015 and 28 Apr. 2016, respectively. Treatments were applied with a water carrier at 374 L·ha^{-1} using a CO_2-pressurized sprayer with a single nozzle (TeeJet AI9504EVS; Spraying Systems Co., Roswell, GA). Plots measured 0.9 × 3.1 m, with a 0.3-m nontreated strip surrounding each plot. Treatments were arranged in a randomized complete block design with four replications. CBG recovery from herbicide treatments was observed to be nodes previously present in the plot recovering from the herbicide, and not healthy stolons from outside the treated area growing into the treated area.

CBG cover was evaluated visually on a 0% (no visible CBG) to 100% (complete CBG cover) scale before treatments were applied and throughout the experiments in each plot. CBG cover on each date was transformed to a percent change of the initial cover using the following equation:

$$Y = \left(1 - \frac{A}{B}\right) \times 100,$$

where Y represents CBG control, A represents CBG cover on the date for which CBG control is being assessed, and B represents CBG cover on the initial assessment date before treatments were applied. This method was used because CBG cover was not consistent in each plot when the experiment began. On the initial assessment date, the mean values of CBG cover in all plots were 55% and 56% for the fall and spring trials, respectively. Kentucky bluegrass injury was assessed on a scale of 1 to 9, where 1 is complete bleaching or necrosis and 9 is no bleaching or necrosis at 2, 5, 7, and 9 weeks after treatment (WAT) in both years of the spring experiment. For the fall experiment, kentucky bluegrass injury was evaluated at 6 and 9 WAT in 2014 and at 2, 3, 6, and 7 WAT in 2015. CBG injury was evaluated on a 0% (i.e., no bleaching or necrosis) to 100% (i.e., complete bleaching or necrosis) scale at 2, 3, and 6 weeks after initial treatment (WAIT) of the fall experiment in 2014 and 2015. For the spring experiment, CBG injury was evaluated at 2, 4, and 6 WAT only in 2015 because of insufficient CBG cover in certain treatments that prevented assessment. Herbicide injury assessment was used to evaluate initial herbicide efficacy whereas cover was used to evaluate CBG control. Treatments in both experiments were evaluated until 104 WAIT. All data were subjected to analysis of variance in SAS 9.3 (Statistical Analysis Software, Inc., Cary, NC) using the GLM procedure with main effects and all possible interactions tested using the appropriate expected mean square values as described by McIntosh (1983). Model assumptions were tested through residual analysis (Shapiro–Wilk statistic) in SAS. Fisher's protected least significant difference ($\alpha \leq 0.05$) was used to separate means. Kentucky bluegrass injury data were subjected to square root transformation; however, nontransformed means are presented for clarity.

Results and Discussion

Treatment-by-experiment interactions were detected; therefore, data from fall and spring experiments are presented separately. On the day before fall and spring experiments were initiated, there were no statistical differences in CBG cover between treatments.

Fall experiment. CBG injury was less than 50% at 2 WAIT in 2014 and 2015 (Table 2). By 6 WAIT in 2014, four applications of mesotrione at 140 g·ha^{-1} caused more injury (95%) than all other treatments except mesotrione + amicarbazone tank mixtures. At 6 WAT in 2015, CBG injury was generally similar across treatments. The CBG injury observed at 6 WAIT from two applications of mesotrione at 280 g·ha^{-1} in this experiment (95%) is similar to the observations of Beam et al. (2006) after two sequential fall applications of mesotrione at 280 g·ha^{-1}. According to contrasts, three applications of the mesotrione + triclopyr tank mixtures caused more injury than three applications of mesotrione alone (175 g·ha^{-1}) at 6 WAIT in 2014 and 2015. Although previous research by

Table 1. Herbicide treatments applied to kentucky bluegrass (*Poa pratensis* L.) infested with creeping bentgrass (*Agrostis stolonifera* L.). For the fall experiment, the treatment regimen began on 10 Oct. 2014 and 14 Oct. 2015. The same regimen started on 7 May 2015 and 28 Apr. 2016 at an adjacent site for the spring experiment. For both the fall and spring experiments, each plot was subjected to these treatment regimens for 2 consecutive years.

Treatment no.	Herbicide	Rate (g·ha^{-1})	No. of applications	Application interval (wk)
1	Mesotrione^{z}	280	2	3
2	Mesotrione	175	3	3
3	Mesotrione	140	4	2
4	Mesotrione + triclopyr ester	175 + 560	3	3
5	Mesotrione + triclopyr ester	175 + 1,120	3	3
6	Mesotrione + amicarbazone	140 + 50	4	2
7	Mesotrione + amicarbazone	140 + 100 fb 140 + 0^{y}	2	4
8	Topramezone + triclopyr ester	32 + 1,120	3	3
9	Topramezone + triclopyr ester	37 + 1,120	2	3

[z] Mesotrione-containing treatments were tank-mixed with a nonionic surfactant at 0.25% v/v. Topramezone-containing treatments were tank-mixed with a methylated seed oil at 1.0% v/v.

[y] Regimen of mesotrione (140 g·ha^{-1}) + amicarbazone (100 g·ha^{-1}) followed by mesotrione only (140 g·ha^{-1}) 2 weeks later.

Brewer et al. (2017) demonstrated that mesotrione causes more CBG injury than topramezone, CBG injury from topramezone + triclopyr tank mixtures was similar to mesotrione + triclopyr tank mixtures on all observation dates in 2014 and 2015.

Despite differences in CBG injury at 6 WAIT in 2014, most treatments reduced CBG cover similarly at 30 WAIT in May 2015 (Table 3). By 40 WAIT in July 2015, two and four applications of mesotrione alone as well as mesotrione + triclopyr and mesotrione + amicarbazone tank mixtures reduced CBG cover similarly (30% to 63%). Tank mixtures of topramezone and triclopyr did not reduce cover compared with the control 40 WAIT. In Oct. 2015, just before treatments were reapplied 52 WAIT, only two and four applications of mesotrione at 280 or 140 g·ha^{-1}, three applications of mesotrione + triclopyr at 560 g·ha^{-1}, and the mesotrione + amicarbazone at 100 g·ha^{-1} regimens reduced CBG cover compared with the control; cover reductions were 14% to 34%.

In May 2016 (24 weeks after the year 2 applications), four applications of mesotrione at 140 g·ha^{-1} and tank mixtures of mesotrione + triclopyr reduced CBG cover by 90% or more compared with a 52% reduction from three applications of topramezone + triclopyr ester. Trends observed in July 2016 were similar to those observed in May 2016.

At the conclusion of the experiment in Oct. 2016 at 104 WAIT (46 weeks after the last year 2 application in Fall 2015), CBG cover in the control increased by 72% from Oct. 2014, and all treatments reduced CBG cover compared with the control. Mesotrione applied at twice at 280 g·ha^{-1} or four times at 140 g·ha^{-1} as well as both mesotrione + triclopyr tank mixtures and the mesotrione + amicarbazone at 100 g·ha^{-1} regimens reduced CBG cover similarly, by 49% to 73%, whereas topramezone + triclopyr mixtures reduced CBG by less than 20% at 104 WAIT.

Spring experiment. All treatments caused CBG injury (22% to 50%) at 2 and 4 WAIT in 2015 (Table 4). By 6 WAIT in June 2015, several treatments—including two applications of mesotrione at 280 g·ha^{-1}, three applications of mesotrione + triclopyr (1120 g·ha^{-1}), and mesotrione + amicarbazone tank mixtures—caused more than 75% CBG injury.

In general, the mesotrione + amicarbazone (100 g·ha^{-1}) regimen reduced CBG cover more than other treatments throughout the 2-year experiment (Table 5). This regimen

Table 2. Creeping bentgrass (*Agrostis stolonifera* L.) injury in the fall experiment after herbicide treatment in 2014 and 2015. The herbicide treatment regimen was initiated on 10 Oct. 2014 and again on 14 Oct. 2015 on the same plots. Injury was determined by evaluating creeping bentgrass visually on a 0% (no injury) to 100% (complete bleaching or necrosis) scale relative to the nontreated control. Preplanned contrasts were conducted to determine whether the control from three sequential applications of mesotrione + triclopyr ester tank mixtures was different (α = 0.05) from three sequential applications of mesotrione (175 g·ha^{-1}) alone and whether four sequential applications of mesotrione + amicarbazone tank mixtures was different from four sequential applications of mesotrione (140 g·ha^{-1}) alone.

	Creeping bentgrass injury (%)					
	2 WAIT		3 WAIT		6 WAIT	
Treatment	2014	2015	2014	2015	2014	2015
Mesotrione (280 g·ha^{-1}) 2×[z]	40 ab[y]	16 a	40 ab	48 abc	75 b	82 ab
Mesotrione (175 g·ha^{-1}) 3×	25 cd	19 a	28 bc	38 a-d	45 d	78 b
Mesotrione (140 g·ha^{-1}) 4×	35 abc	10 a	33 abc	41 a-d	95 a	85 ab
Mesotrione + triclopyr (175 + 560 g·ha^{-1}) 3×	20 d	16 a	23 c	25 d	58 cd	85 ab
Mesotrione + triclopyr (175 + 1,120 g·ha^{-1}) 3×	23 cd	16 a	30 abc	29 cd	68 bc	88 a
Mesotrione + amicarbazone (140 + 50 g·ha^{-1}) 4×	48 a	19 a	43 a	54 a	100 a	88 a
Mesotrione + amicarbazone (140 + 100 fb 140 + 0 g·ha^{-1}) 2×	40 ab	22 a	40 ab	51 ab	95 a	85 ab
Topramezone + triclopyr (32 + 1,120 g·ha^{-1}) 3×	27 bcd	13 a	30 abc	31 bcd	65 bc	82 ab
Topramezone + triclopyr (37 + 1,120 g·ha^{-1}) 2×	20 d	19 a	25 c	22 d	63 bc	82 ab
Nontreated control	0 e	0 a	0 d	0 e	0 e	0 c
Contrast triclopyr ester tank mix vs. mesotrione (175 g·ha^{-1}) alone	NS	NS	NS	NS	**	*
Contrast amicarbazone tank mix vs. mesotrione (140 g·ha^{-1}) alone	NS	NS	NS	NS	NS	NS

[z] Indicates the number of times each treatment was applied. For more information on treatment regimens, see Table 1.

[y] Means followed by the same letter do not differ according to Fisher's protected least significant difference (α = 0.05).

fb = followed by; triclopyr = triclopyr ester; WAIT = weeks after initial treatment.

NS, *, ** Nonsignificant or significant when α ≤ 0.05 or 0.01, respectively.

Table 3. Change in creeping bentgrass (*Agrostis stolonifera* L.) cover in the fall experiment after herbicide treatment. The herbicide treatment regimen was initiated on 10 Oct. 2014 and again on 14 Oct. 2015 on the same plots. The control was determined by evaluating creeping bentgrass cover in each plot and transforming this value to be expressed as a percentage increase or decrease relative to the initial creeping bentgrass cover determined in each plot on 10 Oct. 2014. Preplanned contrasts were conducted to determine whether the control from three sequential applications of mesotrione + triclopyr ester tank mixtures was different (α = 0.05) from three sequential applications of mesotrione (175 g·ha^{-1}) alone and whether four sequential applications of mesotrione + amicarbazone tank mixtures was different from four sequential applications of mesotrione (140 g·ha^{-1}) alone.

	Creeping bentgrass cover reduction (%)					
Treatment	May 2015 (30 WAIT, 24 WALT)	July 2015 (40 WAIT, 34 WALT)	Oct. 2015 (52 WAIT, 46 WALT)	May 2016 (82 WAIT, 24 WALT)	July 2016 (92 WAIT, 34 WALT)	Oct. 2016 (104 WAIT, 46 WALT)
Mesotrione (280 g·ha^{-1}) 2×[z]	93 a[y]	38 ab	17 ab	81 ab	83 a	49 ab
Mesotrione (175 g·ha^{-1}) 3×	67 bc	7 bcd	–12 abc	79 ab	70 a	15 bc
Mesotrione (140 g·ha^{-1}) 4×	89 a	58 a	34 a	97 a	97 a	59 ab
Mesotrione + triclopyr (175 + 560 g·ha^{-1}) 3×	89 a	36 ab	16 ab	92 a	95 a	61 ab
Mesotrione + triclopyr (175 + 1,120 g·ha^{-1}) 3×	82 ab	42 ab	–3 abc	90 a	97 a	73 a
Mesotrione + amicarbazone (140 + 50 g·ha^{-1}) 4×	80 ab	30 abc	–20 bc	77 ab	84 a	22 bc
Mesotrione + amicarbazone (140 + 100 fb 140 + 0 g·ha^{-1}) 2×	88 ab	63 a	14 ab	80 ab	92 a	61 ab
Topramezone + triclopyr (32 + 1,120 g·ha^{-1}) 3×	72 abc	0 cde	–7 abc	64 ab	62 ab	18 bc
Topramezone + triclopyr (37 + 1,120 g·ha^{-1}) 2×	54 c	–21 de	–42 c	52 b	26 b	–16 c
Nontreated control	–16 d	–35 e	–39 c	–23 c	–39 c	–72 d
Contrast triclopyr ester tank mix vs. mesotrione (175 g·ha^{-1}) alone	*	*	NS	NS	NS	NS
Contrast amicarbazone tank mix vs. mesotrione (140 g·ha^{-1}) alone	NS	NS	NS	NS	NS	NS

[z] Indicates the number of times each treatment was applied. For more information on treatment regimens, see Table 1.

[y] Means followed by the same letter do not differ according to Fisher's protected least significant difference (α = 0.05).

fb = followed by; triclopyr = triclopyr ester; WAIT = weeks after initial treatment; WALT = weeks after last treatment.

NS, * Nonsignificant or significant when α ≤ 0.05, respectively.

Table 4. Creeping bentgrass (*Agrostis stolonifera* L.) injury in the spring experiment after herbicide treatment in 2015. The herbicide treatment regimen was initiated on 7 May 2015 and again on 28 Apr. 2016 on the same plots. Injury was determined by evaluating creeping bentgrass visually on a 0% (no injury) to 100% (complete bleaching or necrosis) scale relative to the nontreated control. Injury was not evaluated in 2016 as a result of insufficient creeping bentgrass cover in some plots, which prevented injury assessment. Preplanned contrasts were conducted to determine whether the control from three sequential applications of mesotrione + triclopyr ester tank mixtures was different (α = 0.05) from three sequential applications of mesotrione (175 g·ha^{-1}) alone, and whether four sequential applications of mesotrione + amicarbazone tank mixtures was different from four sequential applications of mesotrione (140 g·ha^{-1}) alone.

	Creeping bentgrass injury (%)					
Treatment	2 WAIT		4 WAIT		6 WAIT	
Mesotrione (280 g·ha^{-1}) 2×[z]	50	a[y]	32	a	72	abc
Mesotrione (175 g·ha^{-1}) 3×	38	ab	26	a	54	d
Mesotrione (140 g·ha^{-1}) 4×	38	ab	38	a	57	cd
Mesotrione + triclopyr (175 + 560 g·ha^{-1}) 3×	25	b	29	a	66	bcd
Mesotrione + triclopyr (175 + 1,120 g·ha^{-1}) 3×	22	b	29	a	79	ab
Mesotrione + amicarbazone (140 + 50 g·ha^{-1}) 4×	28	b	37	a	82	ab
Mesotrione + amicarbazone (140 + 100 fb 140 + 0 g·ha^{-1}) 2×	35	ab	41	a	85	a
Topramezone + triclopyr (32 + 1,120 g·ha^{-1}) 3×	29	b	35	a	82	ab
Topramezone + triclopyr (37 + 1,120 g·ha^{-1}) 2×	22	b	28	a	66	bcd
Nontreated control	0	c	0	b	0	e
Contrast triclopyr ester tank mix vs. mesotrione (175 g·ha^{-1}) alone	NS		NS		*	
Contrast amicarbazone tank mix vs. mesotrione (140 g·ha^{-1}) alone	NS		NS		**	

[z] Indicates the number of times each treatment was applied. For more information on treatment regimens, see Table 1.

[y] Means followed by the same letter do not differ according to Fisher's protected least significant difference (α = 0.05).

fb = followed by; triclopyr = triclopyr ester; WAIT = weeks after initial treatment.

NS, *, **Nonsignificant or significant when $\alpha \leq 0.05$ or 0.01, respectively.

Table 5. Change in creeping bentgrass (*Agrostis stolonifera* L.) cover in the spring experiment after herbicide treatment. The herbicide treatment regimen was initiated on 7 May 2015 and again on 28 Apr. 2016 on the same plots. Control was determined by evaluating creeping bentgrass cover in each plot and transforming this value to be expressed as a percentage increase or decrease relative to the initial creeping bentgrass cover determined in each plot on 7 May 2015. Preplanned contrasts were conducted to determine whether the control from three sequential applications of mesotrione + triclopyr ester tank mixtures was different (α = 0.05) from three sequential applications of mesotrione (175 g·ha^{-1}) alone, and whether four sequential applications of mesotrione + amicarbazone tank mixtures was different from four sequential applications of mesotrione (140 g·ha^{-1}) alone.

	Creeping bentgrass cover reduction (%)											
Treatment	July 2015 (11 WAIT, 5 WALT)		Nov. 2015 (27 WAIT, 21 WALT)		May 2016 (52 WAIT, 47 WALT)		July 2016 (63 WAIT, 5 WALT)		Oct. 2016 (77 WAIT, 17 WALT)		May 2017 (104 WAIT, 46 WALT)	
Mesotrione (280 g·ha^{-1}) 2×[z]	42	b[y]	46	abc	47	ab	68	a	50	b	90	ab
Mesotrione (175 g·ha^{-1}) 3×	36	b	39	bcd	62	ab	75	a	70	ab	44	bcd
Mesotrione (140 g·ha^{-1}) 4×	55	ab	34	bcd	68	a	96	a	90	ab	27	cde
Mesotrione + triclopyr (175 + 560 g·ha^{-1}) 3×	45	b	12	cde	61	ab	81	a	71	ab	66	abc
Mesotrione + triclopyr (175 + 1,120 g·ha^{-1}) 3×	63	ab	71	ab	66	ab	100	a	87	ab	90	abc
Mesotrione + amicarbazone (140 + 50 g·ha^{-1}) 4×	64	ab	43	bcd	59	ab	94	a	90	ab	69	abc
Mesotrione + amicarbazone (140 + 100 fb 140 + 0 g·ha^{-1}) 2×	100	a	94	a	90	a	100	a	96	a	94	a
Topramezone + triclopyr (32 + 1,120 g·ha^{-1}) 3×	68	ab	45	abcd	57	ab	64	a	47	b	20	cde
Topramezone + triclopyr (37 + 1,120 g·ha^{-1}) 2×	–17	c	–25	e	–11	c	0	b	–25	c	–19	de
Nontreated control	–12	c	–4	de	12	bc	–17	b	–27	c	–26	e
Contrast triclopyr ester tank mix vs. mesotrione (175 g·ha^{-1}) alone	NS		NS		NS		NS		NS		NS	
Contrast amicarbazone tank mix vs. mesotrione (140 g·ha^{-1}) alone	NS		NS		NS		NS		NS		NS	

[z] Indicates the number of times each treatment was applied. For more information on treatment regimens, see Table 1.

[y] Means followed by the same letter do not differ according to Fisher's protected least significant difference (α = 0.05).

fb = followed by; triclopyr = triclopyr ester; WAIT = weeks after initial treatment; WALT = weeks after last treatment.

NSNonsignificant when $\alpha \leq 0.05$.

reduced CBG cover by 90% or more at every evaluation through 104 WAIT in May 2017. CBG cover reductions provided by mesotrione-only regimens were statistically similar to on many rating dates. Among mesotrione-only treatments, the mesotrione application regimen did not affect CBG cover reductions from 11 to 77 WAIT. The efficacy of mesotrione-only treatments at 27 WAIT (34% to 46% cover reduction) was slightly less than that reported by Xie et al. (2011), but much lower than that observed by Dernoeden et al. (2008), who observed more than 90% reductions from spring and summer applications of similar mesotrione regimens. However, by 52 WAIT, when treatments were reapplied, the 47% CBG cover reduction from two applications of mesotrione at 280 g·ha^{-1} was similar to the 54% control observed by Jones and Christians (2007) 1 year after treatment. By 77 WAIT in Oct. 2016, mesotrione-containing treatments reduced CBG cover from 50% to 96%, whereas topramezone-containing treatments reduced cover by less than 50%. Two sequential applications of topramezone + triclopyr did not reduce CBG cover compared with the control on any evaluation date.

According to contrast statements, CBG cover reductions provided by the mesotrione–triclopyr and mesotrione–amicarbazone regimens were not different from comparable mesotrione-only regimens on any rating date.

Kentucky bluegrass injury. In the fall experiment, only treatments containing amicarbazone caused kentucky bluegrass injury at 6 and 9 WAIT in 2014 (data not presented). Injury from amicarbazone-containing treatments was also apparent at 2, 3, and 6 WAIT, but not at 7 WAIT, for the fall experiment in 2015 (Table 6). All treatments containing triclopyr at 1120 g·ha^{-1} caused injury at 7 WAIT in 2015.

Although a direct statistical comparison cannot be made, more injury was observed in the spring than in the fall experiment. In the spring experiment, treatments containing mesotrione alone and mesotrione + triclopyr at 560 g·ha^{-1} did not cause injury compared with the control on any date in 2015 (Table 7). Treatments containing amicarbazone, mesotrione + triclopyr at 1120 g·ha^{-1}, and topramezone + triclopyr caused injury on some dates in 2015. In Spring 2016, injury was generally more severe at 5, 7, and 9 WAT than in 2015. Amicarbazone-containing treatments caused more injury than all other treatments at 5 WAT, and injury was also observed at 7 and 9 WAT in 2016. Similar to the fall experiment, all treatments containing triclopyr at 1120 g·ha^{-1} caused injury at 5, 7,

Table 6. Kentucky bluegrass (*Poa pratensis* L.) injury after herbicide treatments in the fall experiment. The herbicide treatment regimen was initiated on 10 Oct. 2014 and again on 14 Oct. 2015 on the same plots. Kentucky bluegrass injury was assessed on a scale of 1 to 9, where 1 is complete bleaching or necrosis and 9 is no bleaching or necrosis. Kentucky bluegrass injury is presented for 2015 only.

	Kentucky bluegrass injury (1–9)							
Treatment	2 WAT		3 WAT		6 WAT		7 WAT	
Mesotrione (280 g·ha^{-1}) 2×[z]	8.5	ab[y]	8.5	a	9.0	a	9.0	a
Mesotrione (175 g·ha^{-1}) 3×	8.8	a	8.5	a	8.8	a	8.8	a
Mesotrione (140 g·ha^{-1}) 4×	9.0	a	9.0	a	8.3	ab	8.8	a
Mesotrione + triclopyr (175 + 560 g·ha^{-1}) 3×	9.0	a	9.0	a	8.0	ab	8.5	a
Mesotrione + triclopyr (175 + 1,120 g·ha^{-1}) 3×	9.0	a	9.0	a	7.3	bc	7.3	bc
Mesotrione + amicarbazone (140 + 50 g·ha^{-1}) 4×	7.8	b	7.3	b	6.5	cd	8.5	a
Mesotrione + amicarbazone (140 + 100 fb 140 + 0 g·ha^{-1}) 2×	6.8	c	7.0	b	6.0	d	8.0	ab
Topramezone + triclopyr (32 + 1,120 g·ha^{-1}) 3×	9.0	a	9.0	a	8.3	ab	7.3	bc
Topramezone + triclopyr (37 + 1,120 g·ha^{-1}) 2×	9.0	a	9.0	a	7.3	bc	6.8	c
Nontreated control	9.0	a	9.0	a	9.0	a	9.0	a

[z] Indicates the number of times each treatment was applied. For more information on treatment regimens, see Table 1.

[y] Means followed by the same letter do not differ according to Fisher's protected least significant difference ($\alpha = 0.05$).

fb = followed by; triclopyr = triclopyr ester; WAT = weeks after treatment.

Table 7. Kentucky bluegrass (*Poa pratensis* L.) injury after herbicide treatments in the spring experiment. The herbicide treatment regimen was initiated on 7 May 2015 and again on 28 Apr. 2016 on the same plots. Kentucky bluegrass injury was assessed on a scale of 1 to 9, where 1 is complete bleaching or necrosis and 9 is no bleaching or necrosis.

	Kentucky bluegrass injury (1–9)															
	2 WAT				5 WAT				7 WAT				9 WAT			
Treatment	2015		2016		2015		2016		2015		2016		2015		2016	
Mesotrione (280 g·ha^{-1}) 2×[z]	9.0	a[y]	7.0	b	9.0	a	6.3	ab	9.0	a	7.8	ab	9.0	a	7.8	ab
Mesotrione (175 g·ha^{-1}) 3×	9.0	a	8.3	a	8.8	a	5.5	b	8.3	a	6.0	dc	9.0	a	7.0	bc
Mesotrione (140 g·ha^{-1}) 4×	9.0	a	9.0	a	9.0	a	6.3	ab	8.5	a	7.0	bc	9.0	a	7.5	ab
Mesotrione + triclopyr (175 + 560 g·ha^{-1}) 3×	9.0	a	8.5	a	8.8	a	5.3	bc	8.0	ab	6.0	dc	9.0	a	5.8	dc
Mesotrione + triclopyr (175 + 1,120 g·ha^{-1}) 3×	9.0	a	8.8	a	8.3	ab	4.3	cd	6.3	c	5.0	de	9.0	a	4.3	de
Mesotrione + amicarbazone (140 + 50 g·ha^{-1}) 4×	9.0	a	9.0	a	7.5	bc	2.0	e	8.3	a	2.0	f	9.0	a	4.5	de
Mesotrione + amicarbazone (140 + 100 fb 140 + 0 g·ha^{-1}) 2×	9.0	a	8.8	a	7.3	bc	2.3	e	8.5	a	4.5	e	9.0	a	6.5	bc
Topramezone + triclopyr (32 + 1,120 g·ha^{-1}) 3×	9.0	a	9.0	a	7.2	c	3.8	d	7.0	bc	4.5	e	9.0	a	3.8	e
Topramezone + triclopyr (37 + 1,120 g·ha^{-1}) 2×	9.0	a	8.3	a	7.5	bc	6.3	ab	8.0	ab	5.8	cde	9.0	a	7.0	bc
Nontreated control	9.0	a	9.0	a	9.0	a	7.3	a	9.0	a	9.0	a	9.0	a	9.0	a

[z] Indicates the number of times each treatment was applied. For more information on treatment regimens, see Table 1.

[y] Means followed by the same letter do not differ according to Fisher's protected least significant difference ($\alpha = 0.05$).

fb = followed by; triclopyr = triclopyr ester; WAT = weeks after treatment.

and 9 WAIT in 2016. The injury was likely caused by the triclopyr, as previous research by Brewer et al. (2017) demonstrated that topramezone and mesotrione cause little to no kentucky bluegrass injury.

Although we cannot make a direct statistical comparison between fall and spring experiments in our research, amicarbazone + mesotrione caused more kentucky bluegrass injury than in the spring than in the fall experiment. This is contrary to previous research that observed more injury from fall amicarbazone applications (McCullough et al., 2010). However, severe kentucky bluegrass injury from amicarbazone in 2016 may have been caused by daily warm air temperatures (>30 °C) for 4 d after the 4-WAIT sequential applications in 2016. Temperatures ranged from 15 to 24 °C for 4 d after the 4-WAIT sequential applications in 2015, when less injury was observed. McCullough et al. (2010) reported that kentucky bluegrass is three times as sensitive to amicarbazone at 30 °C compared with 20 °C.

At the end of each 2-year experiment, the most effective treatments did not eliminate CBG completely. Among treatment regimens initiated in the fall, the most effective treatments reduced CBG cover 49% to 73% at the conclusion of the 2-year experiment, whereas CBG cover increased by 72% in the control. At the conclusion of the spring experiment in May 2017, the most effective treatments reduced CBG cover 66 to 94%, whereas CBG cover increased by 26% in control plots. Topramezone–triclopyr tank mixtures were less effective than mesotrione-containing treatments on most dates and caused slight kentucky bluegrass injury in Fall 2015 and in both years of the spring experiment. Mesotrione + amicarbazone tank mixtures reduced CBG cover more than mesotrione alone on certain dates in the spring experiment only; these tank mixtures also caused more kentucky bluegrass injury than other treatments, especially in Spring 2016, when severe injury was observed. CBG cover reductions provided by sequential applications of mesotrione + triclopyr were similar to sequential applications of mesotrione alone. All three mesotrione-only application regimens reduced CBG cover similarly in the spring experiment, but some inconsistent differences were observed among mesotrione regimens in the fall experiment.

Previous research has also reported inconsistent efficacy among various application regimens for CBG and annual bluegrass control across experiment locations and years, but differences were not explained consistently by environmental conditions or other measured variables (Branham et al., 2005; Reicher et al., 2011; Skelton et al., 2012). Variable CBG control could also be attributed to differences in the size and maturity of CBG patches. In our research, CBG patches were 0.3 to 0.6 m in diameter when the experiments were initiated as a result of a natural or simulated natural CBG infestation. These large patches may be more difficult to control than smaller patches seeded to create artificial infestations. The size of CBG patches in other research was not reported. Xie et al. (2011) reported a 2-year-old CBG infestation whereas Jones and Christians (2007) generally observed less control and reported a 20-year-old infestation, but other variables between these research projects make it difficult to draw conclusions about whether old infestations are more difficult to control than newer infestations.

This research indicates that turf managers opting for selective CBG control in kentucky bluegrass should apply mesotrione at the maximum annual use rate (560 g·ha^{-1}) in two to four sequential applications at 2- to 3-week intervals. Our research indicates that tank mixing triclopyr with mesotrione does not improve control. This research also suggests that regimens initiated in the spring, after CBG is actively growing, or in the fall (i.e., October) will provide similar control. Fall application regimens may be more conducive to combining herbicide regimens and kentucky bluegrass interseeding. The efficacy of mesotrione regimens and interseeding should be evaluated in future research. The mesotrione + amicarbazone treatment at 100 g·ha^{-1} followed by the mesotrione regimen should also be investigated further.

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