

ORIGINAL RESEARCH ARTICLE

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Herbicide tolerance in 11 grass species for minimal-to-no-mow golf course rough

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Abstract

Research was conducted to determine the tolerance of 11 grass species used in minimal-to-no-mow turf areas to three postemergence herbicides applied at one- and twofold the maximum label rates in 2018 and 2019. Grasses were transplanted into field plots in West Lafayette, IN, in 2018 and 2019, allowed time to establish (~1–2 mo), and then either treated with one application of quinclorac, sethoxydim, and topramezone at two rates or not treated. All 11 grass species had acceptable tolerance ($\leq 20\%$ injury) to quinclorac applied at 0.845 kg acid equivalent (a.e.) ha^{-1} . Quinclorac at 1.69 kg a.e. ha^{-1} produced moderate injury ($\geq 21\%$ injury) on only little bluestem [*Schizachyrium scoparium* (Michx.) Nash.], prairie dropseed [*Sporobolus heterolepis* (A. Gray) A. Gray], and switchgrass (*Panicum virgatum* L.). Strong creeping red fescue (*Festuca rubra* L. ssp. *rubra* Gaudin), which had $\leq 5\%$ injury from all three herbicides, exhibited the greatest tolerance among grass species tested. With the exception of strong creeping red fescue, sethoxydim significantly injured all other grass species. Injury from topramezone varied among grass species and herbicide rates. Grasses tolerant ($\leq 20\%$ injury) to topramezone at both rates were big bluestem (*Andropogon gerardii* Vitman), broomsedge bluestem (*Andropogon virginicus* L.), indiagrass [*Sorghastrum nutans* (L.) Nash], strong creeping red fescue, and tall fescue [*Festuca arundinacea* Schreb.; syn. *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.]. Tolerance among species was variable to quinclorac, sethoxydim, and topramezone, and thus turf managers should first identify desired grass species prior to herbicide application.

1 | INTRODUCTION

Golf course turf surrounding the putting green, tee, and fairway of each hole is called “rough” (Beard & Beard, 2005). Golf courses typically have two different rough areas: a primary rough, which is mown between 3.8 and 10.2 cm and causes moderate difficulty in golfer strokes, and a secondary

rough, which is more often located in out-of-play areas, imposes increased difficulty for golfers, and can resemble a grassland or other natural habitat. These secondary rough areas often resemble more “natural areas,” which consist of native or undisturbed grasslands containing grasses, forbs, or wildflowers; riparian areas; buffer strips; and other landscape areas. A 2015 survey estimated that there are 931,509 ha of golf facility land in the United States, of which 26% is composed of natural areas (Gelernter et al., 2017). Furthermore,

Abbreviations: a.e., acid equivalent; DAA, days after application.

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21% of the total natural acreage consisted of native grasslands of these natural, native, or nonmowed areas (Gelernter et al., 2017). Secondary golf course rough areas that contain grasses, forbs, and wildflowers are colloquially referred to by a variety of names including “native areas,” “native rough,” “naturalized areas,” “natural rough,” “naturalized rough,” “minimal mow,” or “no mow” areas by turf managers (e.g., golf course superintendents). Herein, we will refer to these areas as “minimal-to-no-mow areas.” These areas on the golf course are maintained with minimal to no inputs (e.g., pesticides, fertilizer, irrigation, or mowing), and efforts to convert mowed turf to increase the acreage of these areas on golf courses continues to be promoted as an approach to not only reduce overall inputs and maintenance costs (Gross & Eckenrode, 2012; Lyman et al., 2007), but also support plant biodiversity, wildlife, pollinators, and other beneficial insects (Colding & Folke, 2009; Dobbs & Potter, 2015, 2016; Nelson, 1997; Tanner & Gange, 2005; Terman, 1997).

Although minimal-to-no-mow areas on the golf course are generally maintained with fewer inputs than other areas of the golf course, some inputs are occasionally still required. These inputs may include mowing one to two times a year or more depending on site preferences and expectations or weed control with herbicides to eradicate unwanted, encroaching vegetation and promote desired plant species. However, weed control can be challenging in these minimal-to-no-mow areas because there is often a large biodiversity of perennial species, both warm-season (C_4) and cool-season (C_3) grasses, planted within sites (Nelson, 1997; Tallarico & Voigt, 2004; Voigt & Tallarico, 2004). Open-field burning can be an effective weed control option; however, some regions have restrictions due to concerns over air pollution and public safety issues (Nelson, 1997; Enrolled Senate Bill 528, 2009). Past researchers (Cavanaugh et al., 2011; Maddox et al., 2007) have reported that early management responses to reduce weed competition are a key component for successful establishment or conversion to these areas. Depending on site and environmental conditions, these minimal-to-no-mow areas may become infested over time with invasive weeds, especially graminoids, which will negatively affect both the aesthetic and functional properties of these areas. Although there are many recommended grass species for these areas (Christians et al., 2017; Tallarico & Voigt, 2004; Voigt, 2007), there have been few studies that have investigated over-the-top applications of graminicides for selective postemergence control (Johnston et al., 2016; Marble et al., 2018). Therefore, the safety of postemergence graminicides on multiple grass species for minimal-to-no-mow areas requires further evaluation to help educate turf managers on potential weed control options and promote the potential for greater biodiversity of grass species in minimal-to-no-mow areas.

Topramezone {[3-(4,5-dihydro-3-isoxazolyl)-2-methyl-4-(methylsulfonyl)phenyl](5-hydroxy-1-methyl-1H-pyrazol-4-

Core Ideas

- Information is needed on the herbicide tolerance of grass species used on golf courses.
- Eleven grasses species were tolerant to quinclorac applied at a rate 0.845 kg acid equivalent ha^{-1} .
- Sethoxydim significantly injured 10 of 11 grass species.
- Injury from topramezone varied among grass species and herbicide rates.
- Turf managers must identify desired grasses prior to herbicide selection and application.

yl)methanone} is a 4-hydroxyphenylpyruvate dioxygenase (4-HPPD) inhibiting herbicide registered for use in turf in the last decade that offers excellent control of many annual grass and broadleaf weed species (Elmore et al., 2013; Grossmann & Ehrhardt, 2007; Soltani et al., 2012). However, further evaluation of its safety on other species is needed. Other long-existing chemistries, such as sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one}, an acetyl CoA carboxylase (ACCase) inhibiting herbicide, and quinclorac (3,7-dichloro-8-quinolinecarboxylic acid), a substituted quinolinecarboxylic acid herbicide, have been intensively studied with crop injury variable by species (Darwent & Lefkovitch, 1995; Grossman, 1998; Grossmann & Kwiatkowski, 2000; Hubbard & Whitwell, 1991). Consequently, there is still a need to evaluate these herbicides on multiple less commonly used grass species, which may often be growing as polycultures in minimal-to-no-mow areas on golf courses. The objective of this research was to evaluate the tolerance of 11 grass species used in minimal-to-no-mow turf areas to three postemergence herbicides applied at use label and twofold recommended label rates.

2 | MATERIALS AND METHODS

2.1 | Treatments and data analysis

Field experiments in full sun areas were conducted in 2018 (Year 1) and 2019 (Year 2) at the W.H. Daniel Turf-grass Research and Diagnostic Center in West Lafayette, IN (40°26'31" N; 86°55'47" W). The soil was a Mahalasville-Treaty silty clay loam (fine-silty, mixed, superactive, mesic Typic Argiaquoll) with a soil pH of 6.7 and 42.0 g kg^{-1} organic matter, 68.0 mg P kg^{-1} (Bray-1 method), and 232 mg K kg^{-1} . Research plots (1.5 × 3.0 m with 1.0-m borders) containing 11 grass species maintained as a minimal-to-no-mow

TABLE 1 Influence of herbicide treatments on big bluestem injury in 2018 and 2019 and quality in 2019 from 0 to 28 d after application (DAA)

Big bluestem		2018		2019			
Treatment ^a	Rate	Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	3b ^c	5c	7d	8cd	9.0a	8.0a
Quinclorac	1.690	10b	17bc	12c	15c	8.3a	7.0ab
Sethoxydim	0.413	12b	27b	35b	48b	7.7a	3.7c
Sethoxydim	0.845	30a	42a	45a	68a	5.7b	3.0c
Topramezone	0.037	8b	7c	7cd	8cd	9.0a	7.0ab
Topramezone	0.073	2b	8c	7cd	8cd	8.3a	6.3b
Nontreated	–	3b	13c	5d	7d	8.7a	8.0a
<i>p</i> value		.0029	.0004	<.0001	<.0001	.0022	<.0001

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years, and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

secondary golf course rough area were used to investigate the effect of herbicide treatments within each species. The 11 grass species tested were (a) big bluestem (*Andropogon gerardii* Vitman), broomsedge bluestem (*Andropogon virginicus* L.), (c) buffalograss [*Buchloe dactyloides* (Nutt.) Engelm; syn. *Bouteloua dactyloides* (Nutt.) J.T. Columbus], (d) indiangrass [*Sorghastrum nutans* (L.) Nash], (e) little bluestem [*Schizachyrium scoparium* (Michx.) Nash.], (f) prairie dropseed [*Sporobolus heterolepis* (A. Gray) A. Gray], (g) purple lovegrass [*Eragrostis spectabilis* (Pursh) Steud.], (h) sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], (i) strong creeping red fescue (*Festuca rubra* L. ssp. *rubra* Gaudin), (j) switchgrass (*Panicum virgatum* L.), and (k) turf-type tall fescue [*Festuca arundinacea* Schreb.; syn. *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.]. With the exception of strong creeping red fescue and tall fescue, which were obtained locally, other grass species were purchased (Cardno). All of the grass species were warm-season (C₄) grasses except for tall fescue and strong creeping red fescue, which were cool-season (C₃) grasses. With the exception of tall fescue, which was introduced in North America, all of the grass species are native to North America (Braun et al., 2020; Darke, 1999). Prior to the experiment in Year 1, all plants were grown in a greenhouse for ~1.5 mo until fully rooted in liners and then transplanted (two plugs per plot on 0.2-m spacing) into field plots on 15 June 2018. Any plants that had unacceptable quality after Year 1 were transplanted into plots from an adjacent field nursery on 20 May 2019 for Year 2 of the experiment. Plots were mown only once in the spring at 10 cm prior to 100% spring green-up, and the 1.0-m borders were mown monthly at 10 cm.

Treatments were arranged in a randomized complete-block design with three blocks. Seven herbicide treatments including a nontreated check and two rates of quinclorac, sethoxydim, and topramezone were applied with a CO₂-pressurized boom sprayer equipped XR TeeJet 8003VS nozzle (Spraying Systems Company) calibrated to deliver 813 L ha⁻¹ at 207 kPa (Table 1) on 23 Aug. 2018 and 11 June 2019. The 2018 treatment application date corresponded to 67 d after transplanting, and the 2019 treatment application date corresponded to either 22 d after transplanting or 359 d after original 2018 transplanting, dependent on species. The low and high rates (kg a.i. ha⁻¹) were based on the label recommended and twice the label recommended rate, respectively, for a broadcast application rate for perennial and annual weed control on the herbicide use label (USEPA Reg. No. 7969-272; USEPA Reg. No. 7969-327; USEPA Reg. No. 7969-398).

Plant injury (0–100%) in both years and plant quality (1–9 scale, where 9 = highest quality or health) in only 2019 were visually estimated for each species when treatments were initiated and every 14 d after application (DAA). A separate analysis for each grass species was conducted for each year to limit confounding effects from plant maturity differences between years. Data were subjected to ANOVA using GLIMMIX procedure of SAS (v.9.4, SAS Institute, Inc) with block as a random effect. Means were separated with Fisher's Protected LSD test ($\alpha = .05$) when the *F*-tests were significant ($P \leq .05$). After analysis, overall categorical ratings of “tolerant” (i.e., acceptable plant injury of $\leq 20\%$), “moderately tolerant” (21 to 35% plant injury), and “sensitive” ($\geq 35\%$ plant injury) were developed based on plant injury and quality ratings across both experiment years.

Species	Quinclorac (0.845 kg a.e. ha ⁻¹)	Quinclorac (1.690 kg a.e. ha ⁻¹)	Sethoxydim (0.413 kg a.i. ha ⁻¹)	Sethoxydim (0.845 kg a.i. ha ⁻¹)	Topramezone (0.037 kg a.i. ha ⁻¹)	Topramezone (0.073 kg a.i. ha ⁻¹)
Big bluestem	Tolerant	Tolerant	Sensitive	Sensitive	Tolerant	Tolerant
Broomsedge	Tolerant	Tolerant	Sensitive	Sensitive	Tolerant	Tolerant
Buffalograss	Tolerant	Tolerant	Moderately tolerant	Sensitive	Moderately tolerant	Sensitive
Indiangrass	Tolerant	Tolerant	Sensitive	Sensitive	Tolerant	Tolerant
Little bluestem	Tolerant	Moderately tolerant	Sensitive	Sensitive	Tolerant	Moderately tolerant
Prairie dropseed	Tolerant	Moderately tolerant	Moderately tolerant	Sensitive	Sensitive	Sensitive
Purple lovegrass	Tolerant	Tolerant	Sensitive	Sensitive	Tolerant	Moderately tolerant
Sideoats grama	Tolerant	Tolerant	Sensitive	Sensitive	Sensitive	Sensitive
Strong creeping red fescue	Tolerant	Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
Switchgrass	Tolerant	Sensitive	Sensitive	Sensitive	Sensitive	Sensitive
Tall fescue	Tolerant	Tolerant	Sensitive	Sensitive	Tolerant	Tolerant

FIGURE 1 Overall categorical ratings, based on plant injury and quality data, for one application of herbicide treatments tested on various grasses in 2018 and 2019. Generally, ratings of “tolerant,” “moderately tolerant,” and “sensitive” correspond to observed responses of $\leq 20\%$, 21–35%, and $\geq 35\%$ plant injury, respectively, across both experiment years. Turf practitioners should be cautious conducting sequential applications during the same growing season as it could exacerbate injury on the desirable grasses

3 | RESULTS AND DISCUSSION

3.1 | Big bluestem

The greatest injury in big bluestem occurred with the sethoxydim, especially at the higher application rate, consistently across both years, whereas the other two herbicides at both application rates resulted in $<10\%$ injury, with the exception of quinclorac at the higher application rate (Table 1 and Figure 1). Quinclorac applied at 1.69 kg acid equivalent (a.e.) ha⁻¹ also resulted in $<20\%$ injury. Our results align with past reports of up to 63% injury of young big bluestem plants in the field with application of sethoxydim at 0.213 kg a.i. ha⁻¹ (Peters et al., 1989). Similarly, Smith et al. (2015) reported minimal injury of big bluestem with topramezone at 30.6 g a.i. ha⁻¹ applied 70 d after planting in a greenhouse screening experiment. Lym (2016) reported big bluestem seedlings were tolerant quinclorac in greenhouse screenings. Based on

our results combined with past research, big bluestem appears to be tolerant of both topramezone and quinclorac at either application rate in this experiment and sethoxydim should not be recommended for use on big bluestem swards because it will result in $>30\%$ injury.

3.2 | Broomsedge bluestem

Similar to big bluestem, broomsedge bluestem was also more severely affected by sethoxydim at either application rate compared with the other herbicide treatments (Table 2 and Figure 1). Although overall plant quality for the broomsedge bluestem population was subpar with ≤ 4.7 plant quality means across all treatments in 2019, we feel confident that we were still able to effectively assess herbicide treatment effects on plant injury (Table 2). Marble et al. (2018) reported no injury of broomsedge bluestem with one or two applications

TABLE 2 influence of herbicide treatments on broomsedge bluestem injury in 2018 and 2019 and quality in 2019 from 0–28 d after application (DAA)

Broomsedge bluestem							
Treatment ^a	Rate	2018		2019		Plant quality ^b	
		Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	2c ^c	5c	5	2bc	2.7	4.7a
Quinclorac	1.690	5bc	20bc	2	3bc	2.0	3.3ab
Sethoxydim	0.413	15ab	38ab	7	7b	2.3	2.3b
Sethoxydim	0.845	23a	55a	15	18a	2.5	2.0b
Topramezone	0.037	3c	3c	2	3bc	2.7	4.7a
Topramezone	0.073	0c	5c	3	3bc	1.3	3.3ab
Nontreated	–	0c	5c	7	0c	2.3	2.3b
<i>p</i> value		.0031	.0003	.1993	.0014	.5694	.0240

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

TABLE 3 Influence of herbicide treatments on buffalograss injury in 2018 and 2019 and quality in 2019 from 0 to 28 d after application (DAA)

Buffalograss							
Treatment ^a	Rate	2018		2019		Plant quality ^b	
		Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	0c ^c	8c	5	2	9.0	8.3a
Quinclorac	1.690	2c	3c	3	3	8.0	8.0ab
Sethoxydim	0.413	8bc	32ab	13	15	7.0	5.0bc
Sethoxydim	0.845	22ab	43a	15	10	8.7	4.3c
Topramezone	0.037	28a	25abc	3	10	8.3	7.3abc
Topramezone	0.073	27ab	37a	10	8	7.0	5.0bc
Nontreated	–	2c	10bc	5	3	8.3	8.0ab
<i>p</i> value		.0178	.0147	.1445	.1675	.1560	.0451

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

of topramezone applied at either 0.05 or 0.10 kg a.i. ha⁻¹; however, a slight reduction in growth did occur with both rates at one of two sites. To our knowledge, little research has investigated broomsedge bluestem tolerance to quinclorac and sethoxydim, and the consistent results across both experimental years indicate acceptable plant injury ($\leq 20\%$) from topramezone or quinclorac herbicides applied rates in this experiment, but greater plant injury will likely occur with application of sethoxydim.

3.3 | Buffalograss

Buffalograss exhibited injury from multiple herbicides and rates in 2018, but there were minimal injury and differences among treatments in 2019 (Table 3 and Figure 1). Particularly, both sethoxydim and topramezone at the higher application rates in this experiment resulted in greatest plant injury in 2018, and the lower application rates these same herbicides generally exhibited similar or less plant injury. Plant injury

TABLE 4 Influence of herbicide treatments on indiagrass injury in 2018 and 2019 and quality in 2019 from 0 to 28 d after application (DAA)

Indiagrass		2018		2019			
Treatment ^a	Rate	Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	8c ^c	28	5c	12c	9.0a	9.0a
Quinclorac	1.690	10c	15	8bc	10c	8.0ab	8.0b
Sethoxydim	0.413	27ab	50	22ab	25b	6.3c	3.7c
Sethoxydim	0.845	33a	55	30a	42a	6.7bc	3.0c
Topramezone	0.037	13bc	27	3c	15bc	8.7a	8.3ab
Topramezone	0.073	7c	10	5c	7c	8.3a	9.0a
Nontreated	–	5c	27	5c	10c	8.3a	8.3ab
<i>p</i> value		.0083	.2849	.0209	.0005	.0176	<.0001

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

ranged from 0 to 15% and there was no differences among treatments in 2019, which may have been because of a more mature stand of buffalograss compared with 2018. However, quality ratings at 28 DAA in 2019 revealed lower buffalograss quality when treated with topramezone at 0.073 kg a.i. ha⁻¹ and sethoxydim at either application rate, which reflects similar plant responses as 2018. The severe and moderate injury of buffalograss from application of sethoxydim in 2018 and 2019, respectively, is similar to past research by McCarty and Colvin (1992), who reported unacceptable buffalograss quality from sethoxydim applied at 0.56 kg a.i. ha⁻¹. Although buffalograss is not listed as tolerant to topramezone on the use label (USEPA Reg. No. 7969-327), results from both years demonstrate a moderate tolerance of topramezone applied at a lower rate, which is one of the first known reports of the effects of application of topramezone on buffalograss. Overall, quinclorac, at either application rate, was the only herbicide that consistently provided minimal buffalograss injury in both years, which is in agreement with past research by Fry and Upham (1994), Goss et al. (2006), Li et al. (2017), and McCarty and Colvin (1992), who all reported minimal to no phytotoxicity or decline in turf quality of established or seedling buffalograss when sprayed with similar or lower rates of quinclorac.

3.4 | Indiagrass

Similar to the treatment effects observed with big bluestem and broomsedge bluestem, indiagrass was sensitive to sethoxydim at either application rate in both years (Table 4 and Figure 1). Topramezone and quinclorac did not pro-

duce significant injury and there were no differences between the low and high application rate within either herbicide in both years. Similarly, Marble et al. (2018) reported indian-grass to have moderate tolerance to topramezone, which they found acceptable injury ($\leq 20\%$) when applied at either 0.05 or 0.10 kg a.i. ha⁻¹ with one application, but greater injury when a second application was applied at one of two field sites. Hubbard and Whitwell (1991) reported 18% injury and significant reduction in plant height of indiagrass from application of sethoxydim at 0.4 kg a.i. ha⁻¹. This is one of the first known reports on the effects of quinclorac applied to indiagrass. Based on results, application of sethoxydim to minimal-to-no-mow golf course rough areas containing indiagrass should be avoided, and instead alternative options would be to use single applications of label recommended rates of either topramezone or quinclorac.

3.5 | Little bluestem

Regardless of application rate, sethoxydim herbicide generally resulted in $>30\%$ injury to little bluestem at 14–28 DAA in both years and therefore should not be recommended for use in turf areas where this species is present (Table 5 and Figure 1). The higher rates of either topramezone or quinclorac applied in this experiment generally resulted in numerically higher injury, but this effect was not consistent across years, nor were they statistically different from the lower rate of each herbicide. Marble et al. (2018) reported little bluestem to have a high tolerance to topramezone when applied at once or twice at application rates of 0.05 or 0.10 kg a.i. ha⁻¹. Literature is lacking on little bluestem tolerance to sethoxydim

TABLE 5 Influence of herbicide treatments on little bluestem injury in 2018 and 2019 and quality in 2019 from 0 to 28 d after application (DAA)

Little bluestem							
Treatment ^a	Rate	2018		2019			
		Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	3b ^c	3	7c	5b	9.0	8.3a
Quinclorac	1.690	8b	33	10c	13b	6.3	5.7bc
Sethoxydim	0.413	17ab	33	23b	35a	5.3	4.0cd
Sethoxydim	0.845	35a	38	55a	52a	6.0	3.3d
Topramezone	0.037	3b	5	7c	12b	7.0	6.0bc
Topramezone	0.073	17ab	25	8c	7b	7.0	6.0bc
Nontreated	–	3b	8	7c	7b	8.0	7.0ab
<i>p</i> value		.0241	.0692	<.0001	.0004	.1958	.0043

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

TABLE 6 Influence of herbicide treatments on prairie dropseed injury in 2018 and 2019 and quality in 2019 from 0 to 28 d after application (DAA)

Prairie dropseed							
Treatment ^a	Rate	2018		2019			
		Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	0 ^c	0	0c	0b	9.0a	7.0a
Quinclorac	1.690	25	48	5c	13b	3.0cd	2.5d
Sethoxydim	0.413	2	32	8bc	17b	4.3bc	2.7c
Sethoxydim	0.845	5	40	13bc	78a	2.0d	1.0e
Topramezone	0.037	10	80	28b	70a	2.5cd	1.0e
Topramezone	0.073	35	92	65a	95a	2.0d	1.0e
Nontreated	–	3	33	2c	0b	6.0b	4.3b
<i>p</i> value		.2689	.0783	.0016	.0026	.0043	<.0001

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

or quinclorac and neither use label mentions this species (USEPA Reg. No. 7969-272; USEPA Reg. No. 7969-398). Results indicate label rates of topramezone and quinclorac could be used, with reduced likelihood of plant injury, in minimal-to-no-mow golf course rough areas containing little bluestem; however, minor injury could be observed if there is spray overlap.

3.6 | Prairie dropseed

Applications of topramezone, regardless of application rate, and sethoxydim at the higher application rate resulted in the severe injury to prairie dropseed in both years (Table 6 and Figure 1). A greater variation among treatment response in 2018 resulted in no statistical differences; however, a similar

TABLE 7 Influence of herbicide treatments on purple lovegrass injury in 2018 and 2019 and quality in 2019 from 0 to 28 d after application (DAA)

Purple lovegrass							
Treatment ^a	Rate	2018		2019		Plant quality ^b	
		Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	0c ^c	3	10c	5b	8.5	6.0a
Quinclorac	1.690	0c	3	5c	8b	5.0	3.7bc
Sethoxydim	0.413	5bc	5	57b	22b	6.0	4.3ab
Sethoxydim	0.845	15a	10	77a	82a	5.3	2.0c
Topramezone	0.037	3c	0	7c	7b	7.7	6.0a
Topramezone	0.073	13ab	0	3c	23b	4.7	4.0abc
Nontreated	–	0c	0	13c	17b	5.7	5.0ab
<i>p</i> value		.0134	.1783	<.0001	.0002	.4081	.0201

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

numerical trend is evident as the 2019 results. Furthermore, prairie dropseed appeared to be consistently tolerant to application of quinclorac at the lower rate (i.e., label rate) in both years. To this point, there has been little research conducted on herbicide tolerance, especially those included herein, of prairie dropseed. This research highlights that quinclorac applied at label rate is one potential herbicide option for weed control for sites incorporating this species.

3.7 | Purple lovegrass

Application of sethoxydim at either rate and topramezone at the higher rate resulted in slightly higher injury in purple lovegrass in 2018, and this injury was more pronounced in 2019 (Table 7 and Figure 1). Marble et al. (2018) reported a low-to-moderate tolerance of topramezone applied once or twice at rates of 0.05 or 0.10 kg a.i. ha⁻¹ on two *Eragrostis* spp., but purple lovegrass was not included. Hubbard and Whitwell (1991) reported 42% injury and significant reduction in plant height of an *Eragrostis* spp. at 28 DAA of sethoxydim applied at 0.4 kg a.i. ha⁻¹. One lovegrass species, weeping lovegrass [*Eragrostis curvula* (Shrad.) Ness], is listed on the sethoxydim use label for control at application rates of 0.28–0.47 kg a.i. ha⁻¹ (USEPA Reg. No. 7969-398), which likely explains the high injury observed in 2019 at both application rates. Similar to a few other grasses in this experiment, neither the quinclorac use label (USEPA Reg. No. 7969-272) nor the topramezone use label (USEPA Reg. No. 7969-327) mention purple lovegrass; however, based on our results, it should be listed as tolerant, especially at label rates. Results from the current

experiment indicate quinclorac at multiple application rates or topramezone at the lower rate (i.e., label rate) should be safe options for minimal-to-no-mow golf course rough areas containing purple lovegrass.

3.8 | Sideoats grama

Sideoats grama was severely injured in both years when either sethoxydim or topramezone was applied, regardless of application rate (Table 8 and Figure 1). Meanwhile, application of quinclorac at either application rate resulted in $\leq 20\%$ injury in both years and could be a potential option for weed control in sites containing sideoats grama. Compared with the other *Bouteloua* species included in this experiment (buffalograss), it appears sideoats grama has a similar or slightly lower tolerance to these three studied herbicides and rates. However, overall comparison with past research is difficult because little work on sideoats grama tolerance to herbicides has been conducted, especially those included in this experiment.

3.9 | Strong creeping red fescue

Strong creeping red fescue was tolerant of all herbicide treatments in both years and overall average plant injury never exceeded 5%, which indicates there may be more weed control options for turfgrass managers compared to other species in this experiment (Table 9 and Figure 1). Multiple subspecies of the *Festuca rubra* complex, including strong creeping red fescue, have been reported to be tolerant to sethoxydim at

TABLE 8 Influence of herbicide treatments on sideoats grama injury in 2018 and 2019 and quality in 2019 from 0 to 28 d after application (DAA)

Sideoats grama							
Treatment ^a	Rate	2018		2019		Plant quality ^b	
		Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	5d ^c	10c	8b	15b	4.7	7.3a
Quinclorac	1.690	8d	20bc	8b	8b	6.0	7.3a
Sethoxydim	0.413	13cd	30bc	52a	27b	5.0	5.0ab
Sethoxydim	0.845	33bc	55ab	60a	75a	4.3	2.3bc
Topramezone	0.037	68a	83a	35ab	68a	3.7	3.0bc
Topramezone	0.073	45ab	75a	52a	87a	3.3	1.0c
Nontreated	–	3d	8c	8b	18b	7.0	6.3a
<i>p</i> value		.0011	.0028	.0053	.0018	.3814	.0044

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

TABLE 9 Influence of herbicide treatments on strong creeping red fescue injury in 2018 and 2019 and quality in 2019 from 0 to 28 d after application (DAA)

Strong creeping red fescue							
Treatment ^a	Rate	2018		2019		Plant quality ^b	
		Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	0 ^c	0	3	0	9.0	9.0
Quinclorac	1.690	0	0	5	2	7.3	8.0
Sethoxydim	0.413	0	5	0	2	6.3	6.7
Sethoxydim	0.845	0	0	2	0	7.0	7.3
Topramezone	0.037	0	0	2	0	9.0	9.0
Topramezone	0.073	0	0	5	0	9.0	9.0
Nontreated	–	0	0	2	0	8.7	7.7
<i>p</i> value		1.000	1.000	.3338	.6084	.1666	.0854

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

multiple application rates similar to this experiment (Brewster & Spinney, 1989; Butler & Appleby, 1986; Darwent & Lefkovitch, 1995). Both quinclorac and topramezone applications have been listed to be effective for controlling summer annual grasses and safe for use in fine fescues (Patton et al., 2021). Further, strong creeping red fescue included in this experiment is one of five commonly used fine fescue taxa in turfgrass systems that are often utilized together in mix-

tures (Braun et al., 2020). Therefore, we are in agreement with Braun et al. (2020), who mention a need for further research to investigate herbicide tolerance differences among the five fine fescue taxa to differentiate and reduce the likelihood of making inaccurate claims for the entire fine fescue grouping. Our results demonstrate the three studied herbicides can be safely applied to turf areas containing strong creeping red fescue.

TABLE 10 Influence of herbicide treatments on switchgrass injury in 2018 and 2019 and quality in 2019 from 0 to 28 d after application (DAA)

Switchgrass		2018		2019			
Treatment ^a	Rate	Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	23b ^c	22b	10de	10b	9.0	8.0ab
Quinclorac	1.690	43ab	53ab	18cd	48a	7.0	5.3bc
Sethoxydim	0.413	63a	62a	33bc	53a	6.7	3.3c
Sethoxydim	0.845	62a	80a	47ab	65a	7.7	3.7c
Topramezone	0.037	53a	67a	48ab	63a	5.7	3.7c
Topramezone	0.073	35ab	68a	52a	65a	7.7	4.3c
Nontreated	–	17b	18b	2e	3b	9.0	8.7a
<i>p</i> value		.0180	.0251	<.0001	.0005	.4096	.0143

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

3.10 | Switchgrass

Switchgrass was severely injured from all of the herbicide treatments except quinclorac applied at a lower rate (i.e., label rate) of 0.845 kg a.e. ha⁻¹ in both years (Table 10 and Figure 1). Past research has reported generally unacceptable switchgrass injury from topramezone applied at either 0.05 or 0.10 kg a.i. ha⁻¹ (Marble et al., 2018), sethoxydim applied at 0.22 kg a.i. ha⁻¹ (Peters et al., 1989), sethoxydim applied at 0.4 kg a.i. ha⁻¹ (Hubbard & Whitwell, 1991), and sethoxydim applied at 0.213 kg a.i. ha⁻¹ (Smith et al., 2015). Boydston et al. (2010) and Curran et al. (2011) both reported relatively little injury on switchgrass from application of quinclorac at rates up to 0.56 kg a.e. ha⁻¹. Similarly, Lym (2016) reported switchgrass seedlings to be tolerant of quinclorac at lower application rates in a greenhouse experiment. In combination with past research, these results indicate there may be fewer weed control options for turf areas containing switchgrass compared with other commonly used perennial grass species.

3.11 | Turf-type tall fescue

Turf-type tall fescue was tolerant of both application rates of either topramezone or quinclorac, which all resulted in $\leq 7\%$ overall injury in both years (Table 11 and Figure 1). However, sethoxydim at both a low and high application rate resulted in $\geq 30\%$ injury at 28 DAA in both years and significantly reduced overall tall fescue quality, and therefore sethoxydim is not recommended for use in turf areas containing tall fes-

cue. Tall fescue tolerance to topramezone and quinclorac was similar to that in previous research on tall fescue seedlings or during establishment (Johnston et al., 2016; McElroy & Breen, 2006; Willis et al., 2006). In addition, the low tolerance of tall fescue to sethoxydim was similar to previous research with sethoxydim (Brewster & Spinney, 1989; Peters et al., 1989).

4 | CONCLUSIONS

Results from this experiment not only build upon past research involving the studied grass species or herbicides but also provide novel information on the tolerance of these 11 grass species to the examined herbicides and rates, particularly for species such as broomsedge bluestem, buffalograss, indian-grass, little bluestem, prairie dropseed, purple lovegrass, and sideoats grama, for which these herbicides and rates had not been previously investigated. As expected, results demonstrate differences in species tolerance to herbicides and herbicide rates. Quinclorac applied once at the lower (i.e., label) rate of 0.845 kg a.e. ha⁻¹ was the only herbicide treatment that provided acceptable injury ($\leq 20\%$) on all 11 species. With the exception of strong creeping red fescue, sethoxydim at both herbicides rates significantly injured all other grass species. Furthermore, strong creeping red fescue was the only species tested that appeared to be tolerant to all of three herbicides and herbicide rates in this experiment, which may suggest this species should continue to be used in minimal-to-no-mow areas. Injury from topramezone varied among grass species and herbicide rate. Although this research investigated the tolerance of the grass species receiving only one applica-

TABLE 11 Influence of herbicide treatments on turf-type tall fescue injury in 2018 and 2019 and quality in 2019 from 0 to 28 d after application (DAA)

Tall fescue		2018		2019			
Treatment ^a	Rate	Plant injury ^b		Plant injury ^b		Plant quality ^b	
		14 DAA	28 DAA	14 DAA	28 DAA	0 DAA	28 DAA
	kg a.i. or a.e. ha ⁻¹	%				1–9	
Quinclorac	0.845	0c ^c	0c	2	5b	9.0a	8.0a
Quinclorac	1.690	0c	2c	0	7b	9.0a	7.3a
Sethoxydim	0.413	12a	90a	5	30a	6.0b	3.3b
Sethoxydim	0.845	5b	65b	7	40a	7.3b	3.3b
Topramezone	0.037	0c	7c	3	3b	9.0a	8.3a
Topramezone	0.073	0c	2c	0	2b	9.0a	8.3a
Nontreated	–	0c	0c	0	5b	9.0a	7.7a
<i>p</i> value		<.0001	<.0001	.0834	.0006	.0022	<.0001

^aQuinclorac (Drive XLR8, BASF Corporation), sethoxydim (Segment II, BASF Corporation), topramezone (Pylex, BASF Corporation); all herbicide treatments included a crop oil concentrate at 2.3 L ha⁻¹. Quinclorac rate is listed as kg acid equivalent (a.e.) ha⁻¹, and sethoxydim and topramezone rates are listed as kg a.i. ha⁻¹.

^bPlant injury was visually estimated on a 0–100% scale in both years and plant quality was visually estimated on a 1–9 scale, where 9 = highest quality or health in Year 2 only.

^cMeans within a column with a common letter or no letters are not significantly different according to Fisher's protected LSD ($\alpha = .05$).

tion, which is typical of these minimal-to-no-mow areas, turf practitioners should be cautious when conducting sequential applications during the same growing season, as it could exacerbate injury on the desirable grasses. Regardless, additional research is needed on the tolerance of grass species to subsequent applications of these herbicides for more difficult-to-control weeds.

Biodiversity of grass species in minimal-to-no-mow golf course rough areas may help promote ecological sustainability and enhance aesthetics on golf courses by using species with varying abiotic and biotic stress tolerances. This research highlights the importance of identifying and understanding the composition of grass species in polycultures being maintained as minimal-to-no-mow golf course rough. More specifically, understanding the grass species present in managed areas, the turf manager can then reduce the likelihood of injury by selecting the herbicide and rate that is most safe for the entire or majority of plant species present in the area. Overall, this research builds upon past research and presents new data on tolerance differences among grass species for quinclorac, sethoxydim, and topramezone. Golf course superintendents who need to control weeds, especially with broadcast applications, in minimal-to-no-mow areas should first identify the species and their significance in the area prior to herbicide selection and application.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

Aaron J. Patton: Conceptualization; Funding acquisition; Investigation; Project administration; Supervision; Writing-review & editing. Ross C. Braun: Data curation; Formal analysis; Investigation; Visualization; Writing-original draft; Writing-review & editing. Ryan C. Bearss: Writing-original draft. Geoffrey P. Schortgen: Methodology; Resources.

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