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APPLIED TURFGRASS SCIENCE

Effects of preemergence herbicides on establishment of little bluestem and sideoats grama golf course rough

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Abstract

Native warm-season grass (NWSG) roughs provide environmental and aesthetic value to golf courses; however, weed competition is a constraint during establishment. This research evaluated the effects of common turfgrass preemergence herbicides on establishment of newly seeded 1:1 mixture of little bluestem [*Schizachyrium scoparium* (Michx.) Nash] and sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.] (14.3 lb total seed acre^{-1}) rough. Herbicides applied immediately after drill-seeding included: atrazine (1.0 lb a.i. acre^{-1}), dimethenamid-P (1.5 lb acre^{-1}), dithiopyr (0.38 lb acre^{-1}), imazapic (0.06 lb acre^{-1}), indaziflam (0.029 lb acre^{-1}), isoxaben (1.0 lb acre^{-1}), S-metolachlor (2.48 lb acre^{-1}), oxadiazon (4.0 lb acre^{-1}), pendimethalin (1.47 lb acre^{-1}), prodiamine (0.75 lb acre^{-1}), and simazine (1.0 lb acre^{-1}). Effects upon NWSG plant density and biomass, as well as smooth crabgrass [*Digitaria ischaemum* (Schreb.) Schreb. ex Muhl.] control, were evaluated in 2017 and 2018. Across years, imazapic, dimethenamid, oxadiazon, and metolachlor controlled crabgrass >90%. In 2017, little bluestem plant density assessed 4 months after treatment was 2 to 13 times greater in imazapic-treated plots than all other treatments except for those treated with isoxaben and simazine. Application of imazapic resulted in greater little bluestem aboveground biomass than all other herbicide treatments, except simazine, in 2017. In 2018, imazapic resulted in greater little bluestem plant density than the untreated control, atrazine, prodiamine, oxadiazon, isoxaben, or simazine. Although it was a minor component of the sward, sideoats grama was generally tolerant of imazapic. Imazapic application during seeded establishment of little bluestem and sideoats grama golf course rough provides acceptable crop tolerance and smooth crabgrass control.

1 | INTRODUCTION

Golf's modern focus on environmental and economic sustainability has led to increased interest in native-grass rough systems. This interest is primarily driven by the perception that native grasses require fewer inputs, such as

Abbreviations: MAT, months after treatment; NWSG, native warm-season grass.

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TABLE A Useful conversions

To convert Column 1 to Column 2, multiply by	Column 1 suggested unit	Column 2 SI unit
9.35	US gallon per acre, gal/acre	liter per hectare, L/ha

fertilizer, herbicides, and water, to survive and thrive (Martin, 2004). Native areas on golf courses also provide habitat for birds and other wildlife (Terman, 1997).

Native warm-season grasses (NWSGs), such as little bluestem and sideoats grama, are popular choices for low-maintenance golf course roughs within the southeastern United States. Yet, like many NWSG species, they are slow to establish, making them susceptible to weed competition (Martin, Moomaw, & Vogel, 1982; McKenna, Wolf, & Lentner, 1991).

Minimizing weed pressure using appropriate cultural practices and/or herbicides may benefit NWSG rough establishment. Various preemergence herbicides improve NWSG establishment by reducing competition with weeds. For instance, atrazine enhances establishment of switchgrass (*Panicum virgatum* L.) and big bluestem (*Andropogon gerardii* Vitman) (Hintz et al., 1998; Martin et al., 1982). Masters (1995) reported that metolachlor increases stand density and yield of newly seeded big bluestem and sand bluestem (*Andropogon hallii* Hack.). Imazethapyr improves establishment of big and little bluestem (Masters, Nissen, Gaussoin, Beran, & Stougaard, 1996), and imazapic improves establishment of big (Beran, Masters, Gaussoin, & Rivas-Pantoja, 2000) and little bluestem, as well as indiangrass [*Sorgastrum nutans* (L.) Nash.] (Washburn & Barnes, 2000).

While research demonstrates that preemergence herbicides can be used during NWSG establishment, the effects of commonly used turfgrass preemergence herbicides is largely unknown. Preemergence herbicides may be valuable tools for establishment of NWSG; however, practitioner requirements, labeling restrictions, and available herbicides often differ between those of a golf course and those of other industries (e.g., seed production, rangeland and conservation management, utility and transportation rights-of-way, etc.).

Our objectives were to determine the effects of commonly used turfgrass preemergence herbicides (and rates) on the establishment of newly seeded little bluestem and sideoats grama grown in polyculture, as well as the effects upon smooth crabgrass control.

Core Ideas

- Native warm-season grass roughs provide environmental and aesthetic value to golf courses.
- Weed competition is a major constraint during native warm-season grass establishment.
- Preemergence herbicides are valuable tools for establishment of native warm-season grass rough.
- Imazapic applied directly after seeding is safe on little bluestem and sideoats grama.
- Imazapic controls smooth crabgrass when applied directly after seeded establishment of rough.

2 | MATERIALS AND METHODS

Research was conducted at the Mississippi State University R.R. Foil Plant Science Research Center near Starkville, MS, in 2017 and 2018. The experimental design was a randomized complete block with four replications repeated twice in time. Treatments (Table 1) included 11 herbicides and an untreated control. Experimental units for each treatment replicate were 6.6- by 9.8-ft plots. The site was a native Marietta fine sandy loam (a fine-loamy, siliceous, active, Fluvaquentic Eutrudept) soil with pH 7.4 and 4.9% organic matter. Prior to study initiation each year, existing vegetation was eliminated with broadcast application of glyphosate (Roundup PowerMax, 1.26 kg a.e. ha^{-1}, Monsanto), and the site was tilled and leveled using a Blecavator 5V175 (Blec Global Ltd.). A 1:1 seed mix (by weight) of little bluestem and sideoats grama was seeded at a 0.25-inch furrow depth using a Truax Flex II 88 grass seed drill (Truax Company) at 14.3 lb total seed $acre^{-1}$ on 9 Apr. 2017 and 16 Apr. 2018. Herbicide treatments were applied immediately after seeding using a CO_2–pressurized backpack sprayer within a water carrier volume of 40 gallons $acre^{-1}$ (11004 flat-fan spray nozzles, TeeJet, Spraying Systems Co.). The study area received 0.25 inch of overhead irrigation 1 h after treatment. Plant density (plants m^{-2}, which is equivalent to plants per 10.76 ft^2) for each species was assessed 2 and 4 months after treatment (MAT). Aboveground biomass per species was assessed 6 MAT by hand shearing individual plants (2 inches above ground level) within each experimental unit and drying at 104 °F for 72 h. Visual control of crabgrass was assessed 2 MAT, with 0% = no control and 100% = complete control. Crabgrass plant density and biomass were not measured; however, control ratings were based upon visual estimates of population reduction relative to the untreated control. Untreated plots were dominated by crabgrass, with many hundreds of plants per experimental unit. Data were subject to analysis of variance ($\alpha = .05$) using SAS PROC GLIMMIX (SAS version 9.4, SAS Institute). Basic model assumptions were confirmed. Means were separated using Tukey's Honestly Significant Difference test ($\alpha = .05$).

TABLE 1 Common turfgrass preemergence herbicides evaluated for effect on drill-seeded little bluestem and sideoats grama rough at the Mississippi State University R.R. Foil Plant Science Research Center near Starkville, MS, in 2017 and 2018. Herbicide treatments were applied immediately after seeding on 9 Apr. 2017 and 16 Apr. 2018 within a water carrier volume of 40 gallons acre^{-1}

Active ingredient	Active ingredient rate		Trade name	Manufacturer	Formulation	Product rate
	lb a.i. acre^{-1}	kg a.i. ha^{-1}				acre^{-1}
–	–	–	untreated control	–	–	–
Atrazine	1.0	1.12	Aatrex 4 L	Syngenta Crop Protection	4 lb gal^{-1}	2 pt
Dimethenamid-P	1.5	1.68	Tower	BASF Corporation	6 lb gal^{-1}	32 fl oz
Dithiopyr	0.38	0.42	Dimension 2 EW	Corteva AgriScience	2 lb gal^{-1}	1.5 pt
Imazapic	0.06	0.07	Plateau	BASF Corporation	2 lb gal^{-1}	4 fl oz
Indaziflam	0.029	0.0327	Specticle FLO	Bayer CropScience	0.622 lb gal^{-1}	6 fl oz
Isoxaben	1.0	1.12	Gallery 75 DF	Corteva AgriScience	75%	1.33 lb
S-metolachlor	2.48	2.78	Pennant Magnum	Syngenta Crop Protection	7.62 lb gal^{-1}	2.6 pt
Oxadiazon	4.0	4.5	Ronstar 50 WSP	Bayer CropScience	50%	8 lb
Pendimethalin	1.47	1.65	Pendulum AquaCap	BASF Corporation	3.8 lb gal^{-1}	3.1 pt
Prodiamine	0.75	0.84	Barricade 4 L	Syngenta Crop Protection	4 lb gal^{-1}	24 fl oz
Simazine	1.0	1.12	Princep 4L	Syngenta Crop Protection	4 lb gal^{-1}	2 pt

Note. Liquid formulations applied in a broadcast-foliar with water carrier. Dry flowable formulations applied in a broadcast-foliar with water carrier.

3 | RESULTS

3.1 | Little bluestem

A year × treatment interaction was significant for little bluestem plant density and biomass; therefore, these data are presented by year. When assessed 2 MAT in 2017, imazapic resulted in greater little bluestem plant density (1.8 plants m^{-2}) than all other herbicide treatments (≤0.5 plants m^{-2}) (Table 2). By 4 MAT, the only herbicide resulting in a greater plant density than that of the untreated control (2.6 plants m^{-2}) was imazapic (5.5 plants m^{-2}). However, simazine (4.7 plants m^{-2}) or isoxaben (3.4 plants m^{-2}) application resulted in plant densities similar to that of imazapic. Atrazine and dimethenamid were the only other herbicide treatments that resulted in >2.5 little bluestem plants m^{-2}.

In 2017, imazapic application resulted in greater little bluestem aboveground biomass (123 g m^{-2}) than that of the untreated control (43 g m^{-2}) (Table 3). Simazine resulted in similar aboveground biomass (83 g m^{-2}) to imazapic and the untreated control.

When assessed 2 MAT in 2018, only imazapic resulted in greater little bluestem plant density (5 plants m^{-2}) than the untreated control (1 plant m^{-2}) (Table 2). Dimethenamid (3 plants m^{-2}), metolachlor (3 plants m^{-2}), pendimethalin (2 plants m^{-2}), dithiopyr (2 plants m^{-2}), and indaziflam (2 plants m^{-2}) were the only other herbicide treatments with plant densities greater than 1 plant m^{-2}. By 4 MAT, no treatment differences were observed, and plant densities were between 2 and 5 plants m^{-2} for all treatments.

In 2018, little bluestem aboveground biomass failed to differ due to treatment (33–79 g m^{-2}) (Table 3).

3.2 | Sideoats grama

A year × treatment interaction was significant for sideoats grama plant density and biomass; therefore, data are presented by year. When assessed 2 MAT in 2017, sideoats grama plant densities failed to differ due to treatment (Table 4). Plant densities were ≤0.5 plants m^{-2} across all treatments. When assessed 4 MAT, metolachlor and indaziflam resulted in sideoats grama plant densities less than that of the untreated control (1.7 plant m^{-2}), while all other treatments resulted in plant densities similar to that of the untreated control.

In 2017, atrazine increased sideoats grama aboveground biomass (43 g m^{-2}) relative to prodiamine, metolachlor, indaziflam, pendimethalin, and dimethenamid treatments (0.1–3 g m^{-2}) but had similar biomass to the dithiopyr, oxadiazon, imazapic and isoxaben treatments and the untreated control (23 g m^{-2}) (Table 3).

When assessed 2 MAT in 2018, imazapic resulted in greater sideoats grama plant density than that of metolachlor but equivalent plant density to all other treatments, including the untreated control (Table 4). Atrazine, dithiopyr, prodiamine, oxadiazon, imazapic, and simazine treatments resulted in plant densities between 2 and 4 plants m^{-2}, while pendimethalin, dimethenamid, isoxaben, imazapic, and metolachlor herbicide treatments resulted in <1 plant m^{-2}.

TABLE 2 Preemergence herbicide treatment effects (2017 and 2018) on little bluestem plant density 2 and 4 months after treatment (MAT). Herbicide treatments were applied on 9 Apr. 2017 and 16 Apr. 2018 at the Mississippi State University R.R. Foil Plant Science Research Center near Starkville, MS

Treatment	Plant density			
	2017		2018	
	2 MAT	4 MAT	2 MAT	4 MAT
	plants m^{-2}			
Untreated control	0.5 b	2.6 bcd	1 b	2 a
Atrazine	0.5 b	2.7 bcd	0.5 b	3 a
Dimethenamid-P	0.1 b	2.6 bcd	3 ab	5 a
Dithiopyr	0.04 b	1 d	2 ab	2 a
Imazapic	1.8 a	5.5 a	5 a	4 a
Indaziflam	0 b	0.9 d	2 ab	3 a
Isoxaben	0.2 b	3.4 abc	0.6 b	2 a
S-metolachlor	0 b	1.9 cd	3 ab	5 a
Oxadiazon	0 b	0.4 d	1 b	4 a
Pendimethalin	0.1 b	0.7 d	2 ab	4 a
Prodiamine	0 b	0.9 d	1 b	2 a
Simazine	0.4 b	4.7 ab	0.8 b	2 a

Note. 1 m^2 = 10.76 ft^2. Within columns, means followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference ($\alpha = .05$).

TABLE 3 Preemergence herbicide treatment effects (2017 & 2018) on little bluestem (LB) and sideoats grama (SO) biomass 6 months after treatment (MAT). Herbicide treatments were applied on 9 Apr. 2017 and 16 Apr. 2018 at the Mississippi State University R.R. Foil Plant Science Research Center near Starkville, MS. Individual species were hand sheared within each experimental unit, then dried at 104 °C for 72 h

Treatment	Biomass			
	2017		2018	
	LB	SO	LB	SO
	g m^{-2}			
Untreated control	43 bc	23 ab	33 a	–
Atrazine	46 bc	43 a	40 a	–
Dimethenamid-P	38 bc	1 b	70 a	–
Dithiopyr	23 c	19 ab	63 a	–
Imazapic	123 a	11 ab	66 a	–
Indaziflam	21 c	0.5 b	61 a	–
Isoxaben	52 bc	18 ab	36 a	–
S-metolachlor	37 bc	0.1 b	79 a	–
Oxadiazon	13 c	15 ab	49 a	–
Pendimethalin	14 c	3 b	65 a	–
Prodiamine	17 c	3 b	47 a	–
Simazine	83 ab	18 ab	37 a	–

Note. 1 g m^{-2} = 0.035 oz 10.76 ft^{-2}. Within columns, means followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference ($\alpha = .05$).

TABLE 4 Preemergence herbicide treatment effects (2017 & 2018) on sideoats grama plant density 2 and 4 months after treatment (MAT). Herbicide treatments were applied on 9 Apr. 2017 and 16 Apr. 2018 at the Mississippi State University R.R. Foil Plant Science Research Center near Starkville, MS

Treatment	Plant density			
	2017		2018	
	2 MAT	4 MAT	2 MAT	4 MAT
	plants m^{-2}			
Untreated control	0.2 a	1.7 ab	3 ab	3 abc
Atrazine	0.4 a	2.6 a	2 ab	2 abcd
Dimethenamid-P	0 a	0.01 bc	0.6 ab	0.5 cd
Dithiopyr	0.1 a	1 abc	2 ab	1 bcd
Imazapic	0.5 a	0.8 bc	4 a	4 a
Indaziflam	0 a	0 c	0.2 ab	0.8 bcd
Isoxaben	0.1 a	1.4 abc	0.6 ab	1 abcd
S-metolachlor	0 a	0 c	0 b	0 d
Oxadiazon	0.1 a	0.6 bc	3 ab	3 ab
Pendimethalin	0 a	0.2 bc	0.9 ab	1 bcd
Prodiamine	0.04 a	0.2 bc	2 ab	2 abcd
Simazine	0.2 a	1.4 abc	4 a	3 abc

Note. 1 m^2 = 10.76 ft^2. Within columns, means followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference ($\alpha = .05$).

Due to intense weed pressure in 2018, sideoats grama could not be distinguished from associated weeds in order to be harvested. Results are omitted.

3.3 | Crabgrass control

Crabgrass control was similar across replication years; therefore, 2017 and 2018 data were pooled. When visually assessed 2 MAT, all herbicides controlled crabgrass greater than the untreated control (Table 5). Dimethenamid, dithiopyr, imazapic, indaziflam, metolachlor, oxadiazon, and pendimethalin controlled crabgrass ≥77%, while atrazine, isoxaben, prodiamine, and simazine controlled crabgrass ≤63%.

4 | DISCUSSION

Weed competition, which leads to decreased native grass establishment, is a common problem. It is, therefore, crucial for superintendents to communicate realistic expectations with stakeholders when NWSG stands are incorporated into the landscape. In many instances, establishing NWSG swards that are functional and aesthetically pleasing is a 3- to 4-yr-long process, and contrary to

TABLE 5 Effects of preemergence herbicide treatments on visual control of crabgrass 2 months after treatment (MAT). Herbicide treatments were applied on 9 April, 2017 and 16 April, 2018 at the Mississippi State University R.R. Foil Plant Science Research Center near Starkville, MS

Treatment	Visual control
	%
Untreated control	0 d
Atrazine	43 c
Dimethenamid-P	94 a
Dithiopyr	77 abc
Imazapic	95 a
Indaziflam	87 ab
Isoxaben	48 bc
S-metolachlor	93 a
Oxadiazon	94 a
Pendimethalin	89 ab
Prodiamine	63 abc
Simazine	60 abc

Note. Control (%) was pooled across years. Visual control = 0–100% scale, with 0% = no control and 100% = complete control.
Within columns, means followed by the same letter are not significantly different according to Tukey's Honestly Significant Difference ($\alpha = .05$).

popular belief, these areas are not maintenance free. Rapid establishment and herbicide tolerance should be considered when choosing NWSG species.

The results presented here suggest that 0.06 lb imazapic acre^{-1} applied directly after seeding is well tolerated by little bluestem and may be used to adequately control smooth crabgrass (95% control across years) during establishment. Although sideoats grama was a minor component of the sward, it was also generally tolerant of imazapic. Various imidazolinone herbicides, including imazapic, have demonstrated tolerance on a broad range of native grass species. For instance, preemergence application of 0.06 lb imazapic acre^{-1} resulted in favorable little bluestem, big bluestem, and indiangrass establishment (Washburn & Barnes, 2000) and improved forage yields of big bluestem seeded with Illinois bundleflower [*Desmanthus illinoensis* (Michx.) MacMill. ex B.L. Rob. & Fernald] (Beran et al., 2000). Several native cool-season grasses are also tolerant of imazapic. For instance, preemergence application of 0.03 or 0.06 lb imazapic acre^{-1} on green needlegrass [*Nassella virifula* (Trin. & Rupr.) Barkworth] and slender wheatgrass [*Elymus trachycaulus* (Link) Gould ex Shinners] resulted in similar germination rates and plant density to that of the untreated control, except for decreased density of green needlegrass at the highest rate (Bahm & Barnes, 2011). Imazapic (marketed in the United States as Plateau, BASF Corporation) is labeled for use in non-cropland, including golf courses and non-residential turf (BASF Corporation, 2011).

Atrazine, isoxaben, or simazine at 1.0 lb a.i. acre^{-1} rates did not negatively impact little bluestem or sideoats grama establishment; however, these herbicides provided relatively limited control of crabgrass (≤60% control). Atrazine and simazine are both photosystem II inhibiting herbicides (Shaner, 2014) that are commonly used for pre- and post-emergence control of turfgrass weeds. Simazine tolerance has been documented on established stands of buffalograss [*Buchloe dactyloides* (Nutt.) J.T. Columbus] and has been included in various trials in Australia and New Zealand for native grass establishment (Garden, Jones, Friend, Mitchell, & Fairbrother, 1996; Harrington & Gregory, 2009; Lodge, McMillan, Schipp, & Cook, 1994). However, its use is not widely documented in establishment of other NWSGs of the United States. Atrazine, however, has been used more widely during establishment of NWSG. Martin et al. (1982) evaluated 1.0, 2.0, and 3.0 lb atrazine acre^{-1} applied preemergence in the fall and spring on soils with differing pH and organic matter content. In general, switchgrass and big bluestem had little stand reduction, but indiangrass, sideoats grama, and sand lovegrass [*Eragrostis trichodes* (Nutt.) Alph. Wood] had sparse stands due to atrazine application. Likewise, Bahler et al. (1984) reported mixed results with atrazine applied to switchgrass, as well as two species not native to North America: plains bluestem [*Bothriochloa ischaemum* (L.) Keng] and Caucasian bluestem [*Bothriochloa caucasica* (Trin.) C.E. Hubbard].

Isoxaben has previously been demonstrated to be safe on established buffalograss (Dotray & McKenney, 1996) but may limit lateral growth according to a 1-yr study conducted by Harivandi, Elmore, & Wu (1993). Isoxaben provides acceptable preemergence control of many broadleaf weeds but poor control of many annual grasses (Neal & Senesac, 1990).

Polycultures of multiple NWSG species have been suggested for various reasons, including their ability to compete with weeds (Brown, Rice, & Claassen, 1998; Bugg, Brown, & Anderson, 1997; Tilman, 1997). Brown et al. (1998) suggested that a polyculture of species with various rooting characteristics would be more likely to successfully compete with weeds because of their ability to preempt niche occupation. For these reasons, greater diversity and site-specific plant suitability may lead to more rapid ground cover. In the southeastern United States, sideoats grama is included in mixtures primarily to provide cover until little bluestem fully establishes. Sideoats grama germinates more rapidly than little bluestem and has been suggested as a "nurse crop" to aid in weed suppression without being in direct competition with maturing little bluestem (J. Seymour,

personal communication, 16 March 2017). Unfortunately, our methods could not parse the effects of interspecific competition among little bluestem, sideoats grama, and crabgrass.

5 | CONCLUSIONS

There are more than several knowledge gaps pertaining to the establishment of NWSG golf course roughs. Foremost, there are other NWSG species suitable for golf course rough other than the two discussed here. However, characteristics such as playability and aesthetics of those candidate species are only part of the criteria.

Understanding cultural and chemical weed control strategies for individual and composite blends of NWSG species is necessary in order to fully leverage the potential of NWSG species. Future research should also evaluate the rates and timings of preemergence and postemergence herbicides for the management of various NWSG golf course roughs, differential species response, and establishment methods. Furthermore, there is little known about herbicide mixtures with imazapic. Research to explore herbicide combinations with imazapic would allow control of a broader range of weed species (including broad-leaved and grassy weeds other than smooth crabgrass) with decreased disturbance of these often-sensitive ecosystems.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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