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Assessing herbicides for Japanese stiltgrass (*Microstegium vimineum*) control in cool-season turfgrass

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Abstract

Japanese stiltgrass is one of the most troublesome invasive weed species in the eastern United States. Strategies for controlling the weed in managed lawns are limited because most previous research was conducted in forest understories or on golf course natural areas. Eight field experiments were conducted in Virginia from 2014 to 2019 to evaluate the response of Kentucky bluegrass, tall fescue, and Japanese stiltgrass to selective herbicides traditionally marketed for use on cool-season turfgrass. Only treatments that contained mesotrione caused transient injury to tall fescue of 15% to 25% at 2 wk after treatment (WAT). When fenoxaprop was applied at a rate of 35 g ha^{-1} or higher, at 8 WAT Japanese stiltgrass was controlled by ≥90%, relative cover was reduced to <15% compared with a nontreated control, and shoot density was reduced to ≤6 shoots m^{-2}. Sequential applications of topramezone at 27 g ha^{-1} at 3-wk intervals, or a single application of topramezone at 54 g ha^{-1} alone or with triclopyr, resulted in ≥80% control of Japanese stiltgrass and a reduction in relative weed cover and shoot density to ≤22% and <35 shoots m^{-2}, respectively. Fenoxaprop applied at 0.25× of the labeled rate and herbicide combinations that contained topramezone selectively controlled Japanese stiltgrass without injuring tall fescue. Fluazifop applied at 53 g ha^{-1} resulted in 25% injury to Kentucky bluegrass and digitally assessed turf cover was reduced by 20% at 4 WAT, but turfgrass recovered by 6 WAT. Reduced rates of fluazifop provided 85% control of Japanese stiltgrass, and a reduction in weed shoot density to <20 shoots m^{-2}, and relative cover to <20% at 8 WAT. Kentucky bluegrass did not appear to be injured with premixed applications of dicamba, fenoxaprop, and fluroxypyr, but Japanese stiltgrass was controlled by ≥92%, the relative weed cover was reduced to ≤7%, and shoot density was reduced to ≤5 shoots m^{-2} at 8 WAT. Our research provides herbicide options for turf managers for controlling Japanese stiltgrass in lawns of Kentucky bluegrass and tall fescue.

Introduction

Japanese stiltgrass is characterized as an annual, C_4 invasive grassy weed species that has colonized areas from New York to Puerto Rico (Barden 1987; Fairbrothers and Gray 1972). Japanese stiltgrass has the adaptability to invade disturbed and undisturbed areas, including riverbanks, wetlands, woodlands, roadside ditches, utility corridors, and landscape bedding and turfgrass (Derr 1999; Fairbrothers and Gray 1972; Redman 1995; Swearingen and Adams 2008). One of the main reasons that Japanese stiltgrass has gained such broad invasion success is derived from its ability to grow under full sun to almost full shade (Horton and Neufeld 1998). The ability of Japanese stiltgrass to tolerate shade distinguishes it from most other C_4 grasses such as smooth crabgrass [*Digitaria ischaemum* (Schreb.) ex Muhl.] (Brown 1977; Winter et al. 1982).

Winter et al. (1982) demonstrated that Japanese stiltgrass can maintain dry matter production at 18% of full sun and grow in ways that are equivalent to plants maintained under full sun. Japanese stiltgrass can grow and produce viable seeds even with just 2% to 8% of full sunlight (Cheplick 2005). Japanese stiltgrass exhibits phenotypic plasticity, can grow without sufficient nutrients under challenging environmental conditions, and inhibits the growth of native species (Swearingen and Adams 2008; Ziska et al. 2015). Japanese stiltgrass can also form large, sprawling mats that can grow from 0.6 to 1.0 m tall, which can shade out other native plants and produce up to 1,000 seeds per plant (Swearingen and Adams 2008; Miller and Matlack 2010). These traits allow Japanese stiltgrass to outcompete most understory native species, making it a serious threat to native plant communities and ecosystem function (Culpepper et al. 2018; Miller 2003).

Japanese stiltgrass management is challenging due to the plant's ability to spread rapidly and produce seeds that can remain viable for up to 5 yr (Swearingen and Adams 2008; Tu 2000).

Table 1. Field study information.

Study	Species assessed	Location	Latitude and longitude	Herbicide application
Postemergence herbicides for Japanese stiltgrass control in tall fescue[a]	Japanese stiltgrass and tall fescue	Newport, VA	37.29°N, 80.51°W	August 15, 2014
	Japanese stiltgrass and tall fescue	Blacksburg, VA	37.21°N, 80.41°W	July 15, 2015
	Tall fescue	Blacksburg, VA	37.22°N, 80.41°W	August 28, 2017
	Tall fescue	Blacksburg, VA	37.23°N, 80.44°W	August 15, 2019
Fenoxaprop combinations and fluazifop for Japanese stiltgrass control in Kentucky bluegrass	Japanese stiltgrass	Blacksburg, VA	37.23°N, 80.43°W	July 15, 2015
	Japanese stiltgrass	Newport, VA	37.29°N, 80.50°W	August 25, 2017
	Kentucky bluegrass	Blacksburg, VA	37.23°N, 80.43°W	July 15, 2015
	Kentucky bluegrass	Blacksburg, VA	37.22°N, 80.41°W	August 25, 2017

[a]Selected herbicides were applied sequentially at a 3-wk interval during the study.

Japanese stiltgrass can be controlled via manual or mechanical measures, but herbicides are recommended for controlling large infestations (Shelton 2012; Tu 2000). Previous researchers have assessed several preemergence and postemergence herbicides for their ability to control Japanese stiltgrass in forest environments (Flory 2010; Gover et al. 2003; Judge et al. 2005a; Ward and Mervosh 2012), but only a few extension publications (e.g., Nitzsche and Rector 2023) have reported selective Japanese stiltgrass control in cool-season turfgrass despite increasing infestations.

Judge et al. (2005b) demonstrated that preemergence herbicides labeled for control of large crabgrass [*D. sanguinalis* (L.) Scop.] in cool-season turfgrass may also be able to control Japanese stiltgrass. Those preemergence herbicides included dithiopyr, prodiamine, trifluralin, oxadiazon, isoxaben, and pendimethalin. Selective and nonselective herbicides applied postemergence have also been effective in controlling Japanese stiltgrass. They include sethoxydim, clethodim, imazapic, fenoxaprop, MSMA, fluazifop, glyphosate, and glufosinate (Gover et al. 2003, Judge et al. 2005b, Weaver et al. 2020), but only fenoxaprop and fluazifop are registered for selective weed control in cool-season turfgrass lawns (Anonymous 2022a). In order to expand the number of options available for Japanese stiltgrass control in managed cool-season turf, more information is needed on its response to traditional postemergence lawn herbicides such as topramezone, mesotrione, quinclorac, and combinations of topramezone + triclopyr and mesotrione + triclopyr. We hypothesized that herbicide combinations that contained topramezone, mesotrione, or quinclorac will control Japanese stiltgrass to an equal or greater extent than fenoxaprop and fluazifop. Thus the objectives of this study were to assess the effectiveness of various herbicides in controlling Japanese stiltgrass that grows in tall fescue lawns, and to assess the ability of selective herbicides to control Japanese stiltgrass in Kentucky bluegrass.

Materials and Methods

Initial Screen of Postemergence Herbicides

Four field experiments were conducted from 2014 to 2019 to evaluate the tolerance of tall fescue to multiple postemergence herbicides and their efficacy in controlling Japanese stiltgrass in lawns (Table 1). The study consisted of a randomized complete block design with three replications and four temporal runs across two locations. The response of tall fescue to herbicide treatments was assessed in all four studies, whereas Japanese stiltgrass control was evaluated in two of the studies (Table 1). Each plot measured 1.8 m by 1.8 m. A comprehensive list of treatments, including common names, product names, manufacturer information, and application rates, is provided in Table 2. All herbicides were applied with a CO_2-pressurized hooded boom sprayer equipped with two TTI11003 flat-fan nozzles (TeeJet Technologies, Glendale Heights, IL), spaced 36 cm apart, calibrated to deliver 281 L ha^{-1} of spray solution at 4.8 km h^{-1}. Japanese stiltgrass was at the 4- to 6-tiller stage at the time of herbicide application. The experiment sites were mowed regularly at 1-wk intervals to a height of 6.4 cm throughout the study period.

Table 2. Herbicide common names, trade names, manufacturer, and rates used in field experiments to assess tall fescue tolerance and Japanese stiltgrass control.

Common name	Product name	Manufacturer[d]	Rate
			g ae or ai ha^{-1}
Fenoxaprop	Acclaim® Extra	Bayer	35
Fenoxaprop	Acclaim® Extra	Bayer	70
Fenoxaprop	Acclaim® Extra	Bayer	140
Mesotrione[a,c]	Tenacity®	Syngenta	140
Mesotrione[a]	Tenacity®	Syngenta	280
Mesotrione + triclopyr[a]	Tenacity®; Turflon® Ester Ultra	Syngenta; Dow	280 + 1,120
Quinclorac[b,c]	Drive® XLR8	BASF	660
Quinclorac[b]	Drive® XLR8	BASF	1,120
Topramezone[b,c]	Pylex™	BASF	27
Topramezone[b]	Pylex™	BASF	54
Topramezone + triclopyr[b]	Pylex™; Turflon® Ester Ultra	BASF; Dow	54 + 1,120
Triclopyr	Turflon® Ester Ultra	Dow	1,120

[a]Nonionic surfactant at 2.5 mL L^{-1}.
[b]Methylated seed oil at 5 mL L^{-1}.
[c]Applied sequentially at a 3-wk intervals.
[d]Manufacturer locations: BASF Corp., Research Triangle Park, NC; Bayer Environmental Science, Cary, NC; Dow Agrosciences LLC, Indianapolis, IN; Syngenta Crop Protection, LLC, Greensboro, NC

Tall fescue and Japanese stiltgrass cover, control, and injury were visually assessed on a scale of 0% to 100%, with 0% being no control, no cover, or no injury and 100% being complete plant death or complete cover. Data were assessed at 0, 1, 2, 4, 6, and 8 wk after initial treatment (WAIT). Japanese stiltgrass counts were taken in each plot at 8 WAIT using a 1-m^2 quadrant. Visual cover of tall fescue or Japanese stiltgrass was converted to relative cover based on the percent cover of a nontreated control plot within each replication. All response variables were subjected to ANOVA using the GLM procedure with SAS software (v. 9.3; SAS Institute, Cary, NC). Treatment was considered as a fixed effect, while experimental run and block were treated as random effects. The mean square of the treatment effect was tested for all assessed parameters using the mean square associated with the experimental run (McIntosh 1983). Means were separated using Fisher's protected LSD ($\alpha = 0.05$). Means were presented separately by experimental run if the treatment-by-experimental run interactions were significant; otherwise, means were pooled over experimental runs.

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Table 3. Herbicide common names, trade names, manufacturer, and rates used in field experiments to assess the response of Kentucky bluegrass and Japanese stiltgrass.

Common name	Product name	Manufacturer[c]	Rate
			g ae or ai ha^{-1}
Dicamba + fenoxaprop + fluroxypyr	Last Call™	Nufarm	421
Dicamba + fenoxaprop + fluroxypyr[a]	Last Call™	Nufarm	421
Fluazifop[a]	Ornamec®	PBI Gordan	53
Fluazifop[a]	Ornamec®	PBI Gordan	105
Quinclorac[b]	Drive® 75 DF	BASF	840

[a]Nonionic surfactant at 2.5 mL L^{-1}.
[b]Methylated seed oil at at 5 mL L^{-1}.
[c]Manufacturer locations: BASF Corp., Research Triangle Park, NC; Nufarm Americas, Inc., Alsip, IL; PBI Gordan Corp., Kansas City, MO;

Assessing Fenoxaprop Combinations and Fluazifop

Four field experiments were conducted in 2015 and 2017 to assess Japanese stiltgrass control and Kentucky bluegrass tolerance after selective herbicide treatments (Table 1). The experiment was a randomized, complete block design with three replications and two temporal runs for each species. Treatments included a nontreated control, a premix of fenoxaprop + fluroxypyr + dicamba at 421 g ha^{-1} (with or without a nonionic surfactant), fluazifop at 53 g ha^{-1} with a nonionic surfactant, fluazifop at 105 g ha^{-1} with a nonionic surfactant, and quinclorac at 840 g ha^{-1} with methylated seed oil. A detailed list of herbicide common names, trade names, manufacturer names and locations, and rates evaluated in the study is provided in Table 3. Herbicide application method, site maintenance, and data collection were the same as the previous study except that digital photographic images were also taken to quantify turf cover using TurfAnalyzer (Green Research Services, Fayetteville, AR) to detect the green pixels in each image. Turf cover was converted to relative cover based on the percent green cover in the nontreated plot within each replication. Data were analyzed as described above because the experimental design and response variables are similar for both studies. Means were separated using Fisher's protected LSD ($\alpha = 0.05$).

Results and Discussion

Initial Screen of Postemergence Herbicides

The main effect of treatment was visual injury to tall fescue, and it was highly significant ($P < 0.0001$) and not dependent on trial ($P > 0.05$), leading to the pooling of data across all four experimental runs (data not shown). Only treatments that contained mesotrione caused injury to tall fescue, with injury levels between 15% and 25% at 2 WAIT. Those treatments, however, did not affect the relative turf cover (data not shown). Transient injury to tall fescue from mesotrione has been noted in other studies (Goddard et al. 2010; Willis et al. 2006), whereas the plant exhibited no injury from triclopyr (Dernoeden et al. 2008). Fenoxaprop did not alter tall fescue color or density beyond commercially acceptable levels (McCarty et al. 1989) and was generally safe to turf even with frequent applications (Johnson and Carrow 1995). Finally, in other previous reports, topramezone and quinclorac treatments resulted in less than 7% injury to tall fescue without affecting turf quality (Brewer et al. 2017; Patton et al. 2021).

The herbicide treatment-by-experimental run interaction was significant for Japanese stiltgrass control ($P < 0.0001$), relative weed cover ($P = 0.0032$), and weed shoot density ($P < 0.0001$) at 8 WAIT (Table 4). In nontreated control plots, Japanese stiltgrass density was 224 and 314 shoots m^{-2} at the Newport and Blacksburg locations, respectively (Table 4). Japanese stiltgrass was controlled by ≥90% with fenoxaprop, regardless of rate, cover was reduced to <15% and shoots to ≤6 m^{-2} at both study sites (Table 4). These results align with those reported in previous research in forest ecosystems, where even reduced rates of fenoxaprop were found to be as effective as the labeled rate for controlling Japanese stiltgrass (Peskin et al. 2005; Ward and Mervosh 2012). Topramezone, applied at 27 or 54 g ha^{-1} (alone or with triclopyr), provided ≥80% control of Japanese stiltgrass, and relative weed cover and shoot density were reduced to ≤22% and 35 shoots m^{-2}, respectively (Table 4). Although triclopyr did not improve the performance of topramezone in its ability to control Japanese stiltgrass (Table 4), applications of both triclopyr and metribuzin led to sustained or enhanced topramezone performance in goosegrass [*Eleusine indica* (L.) Gaertn.] control (Brewer et al. 2022; Cox et al. 2017) Topramezone is specifically labeled for Japanese stiltgrass control in cool-season turf and recommended for selective management of troublesome weeds (Anonymous 2022b; Cox et al. 2017; Landschoot et al. 2023; Peppers et al. 2023). Treatments with mesotrione, quinclorac, and triclopyr applied individually resulted in decreased Japanese stiltgrass relative cover and shoot density, but weed control was <68% (Table 4). Other studies have similarly reported poor control of Japanese stiltgrass following applications of quinclorac on golf course naturalized areas and triclopyr on cool-season grass forages (Flessner et al. 2019; Weaver et al. 2020). Overall, these data suggest that fenoxaprop and treatments with topramezone were able to effectively and selectively control Japanese stiltgrass in tall fescue lawns without causing significant turfgrass injury.

Assessing Fenoxaprop Combinations and Fluazifop

The main effect of treatment was significant for both Kentucky bluegrass injury ($P = 0.0004$) and relative turfgrass cover ($P = 0.039$) at 4 wk after treatment (WAT), but these response variables were not dependent ($P > 0.05$) on the experimental run (Table 5). Treatments containing fluazifop resulted in ≥25% injury to Kentucky bluegrass and a reduction of ≥20% in digitally assessed relative turf cover at 4 WAT (Table 5). Fluazifop resulted in 25% to 46% Kentucky bluegrass injury, similar to previous reports (Warren et al. 1989).

In contrast, Kentucky bluegrass was highly tolerant to applications of dicamba + fenoxaprop + fluroxypyr (regardless of surfactant) or quinclorac; injury measured ≤3% (Table 5). Quinclorac, when applied at 840 g ha^{-1}, did not cause injury to newly established Kentucky bluegrass (Reicher et al. 1999). Previous research also confirmed that tank mixing fenoxaprop with fluroxypyr does not compromise the efficacy of fenoxaprop against smooth crabgrass, nor does it cause injury to cool-season turfgrass (McCullough et al. 2009).

The main effect of treatment was significant for Japanese stiltgrass control ($P = 0.0002$), relative weed cover ($P = 0.0003$), and weed shoot density ($P < 0.0001$) at 8 WAT, with these response variables showing no dependence on the experimental run; therefore, data were pooled over runs (Table 5). At 8 WAT, Japanese stiltgrass was controlled by ≥92%, relative cover was reduced to ≤7%, and shoot density was <5 shoots m^{-2} when the

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Table 4. Effect of herbicide treatments on Japanese stiltgrass control, relative cover, and shoot density at 8 wk after initial treatment.[a]

Treatment	Rate	Japanese stiltgrass control		Japanese stiltgrass relative cover		Japanese stiltgrass shoot density	
		Newport	Blacksburg	Newport	Blacksburg	Newport	Blacksburg
	g ae or ai ha^{-1}	———— % ————		———— % ————		——— no m^{-2} ———	
Nontreated		–	–	–	–	224 a	314 a
Fenoxaprop	35	90 bc	97 a	14 cd	5 c	6 f	5 c
Fenoxaprop	70	95 ab	98 a	7 de	3 c	2 f	2 c
Fenoxaprop	140	100 a	99 a	0 de	1 c	0 f	1 c
Mesotrione[b,d]	140	31 h	13 e	53 a	82 a	130 b	293 a
Mesotrione[b]	280	40 g	24 e	51 a	74 a	122 bc	265 a
Mesotrione + triclopyr	280 + 1,120	75 d	62 b	32 abc	46 b	81 d	162 b
Quinclorac[c,d]	660	62 e	55 bc	32 abc	46 b	87 cd	160 b
Quinclorac[c]	1,120	50 f	35 d	42 ab	80 a	105 bcd	250 a
Topramezone[c,d]	27	87 cd	94 a	22 bcd	4 c	29 f	7 c
Topramezone[c]	54	80 d	91 a	21 bcd	11 c	34 ef	10 c
Topramezone + triclopyr[c]	54 + 1,120	87 cd	97 a	21 bcd	3 c	26 f	3 c
Triclopyr	1,120	67 e	43 cd	36 ab	63 ab	69 de	173 b
P-value		<0.0001		0.0032		<0.0001	

[a]Means followed by a different letter within the same column are different based on Fisher's protected LSD ($\alpha = 0.05$).
[b]Nonionic surfactant at 2.5 mL L^{-1}.
[c]Methylated seed oil at 5 mL L^{-1}.
[d]Applied sequentially at 3-wk intervals.

Table 5. Effect of herbicide treatments on Kentucky bluegrass injury and relative cover compared to nontreated control at 4 WAT and Japanese stiltgrass control, relative weed cover, and shoot density at 8 WAT.[a,b]

Treatment	Turf injury 4 WAT	Relative turf cover 4 WAT	Japanese stiltgrass control 8 WAT	Japanese stiltgrass relative cover 8 WAT	Japanese stiltgrass shoot density 8 WAT
	%	%	%	%	no m^{-2}
Nontreated	–	–	–	–	228 a
Dicamba + fenoxaprop + fluroxypyr	2 c	105 a	97 a	2 c	2 c
Dicamba + fenoxaprop + fluroxypyr[c]	1 c	101 a	92 ab	7 c	5 c
Fluazifop[c,d]	25 b	80 b	85 b	17 b	19 c
Fluazifop[c,e]	46 a	75 b	87 b	9 bc	7 c
Quinclorac[f]	3 c	104 a	42 c	65 a	108 b
P-value	0.0004	0.039	0.0002	0.0003	<0.0001

[a]Abbreviation: WAT, weeks after treatment.
[b]Means followed by the same letter within each column are not different based on Fisher's protected LSD ($\alpha = 0.05$).
[c]Nonionic surfactant at 2.5 mL L^{-1}.
[d]Fluazifop was applied at 53 g ha^{-1}.
[e]Fluazifop was applied at 105 g ha^{-1}.
[f]Methylated seed oil at 5 mL L^{-1}.

combination of dicamba + fenoxaprop + fluroxypyr was applied, both with and without a nonionic surfactant (Table 5). In other studies, when fenoxaprop was applied alone, Japanese stiltgrass was controlled by 93% and weed cover was reduced by 89% (Judge et al. 2005a, 2005b). A commercial premix of dicamba, fenoxaprop, and fluroxypyr is marketed for controlling Japanese stiltgrass and other problematic weeds in Kentucky bluegrass turf (Anonymous 2017). Although the current study shows that dicamba and fluroxypyr do not reduce the performance of fenoxaprop in its ability to control Japanese stiltgrass, in other studies (Cox and Askew 2014), mixtures with other herbicides such as 2,4-D and mecoprop have antagonized graminicides for annual grass control.

Fluazifop treatments were also highly effective, controlling Japanese stiltgrass by ≥85% across various application rates, while reducing relative cover and weed shoot density to ≤17% and <20 shoots m^{-2}, respectively, at 8 WAT (Table 5). Similar results were observed by Judge et al. (2005b), who reported 97% control of Japanese stiltgrass 8 wk after treatment with fluazifop. In the studies reported here, treatments were applied in July or August when Japanese stiltgrass was relatively mature and chances of subsequent germination were relatively low. Herbicides applied earlier in the season may not perform as well due to subsequent seedling emergence as has been demonstrated with Japanese stiltgrass (Judge et al. 2005b) and other grassy weeds (Askew et al. 2000). Quinclorac reduced Japanese stiltgrass relative cover by only 35% and shoot density to only 108 shoots m^{-2}, indicating it is not effective in controlling this weed (Table 5). Fluazifop at 53 g ha^{-1} injured Kentucky bluegrass by 25% at 4 WAT, but even a low injury would not be considered completely safe by turfgrass managers. Additionally, this response is very different from the minimal injury to Kentucky bluegrass observed after dicamba + fenoxaprop + fluroxypyr treatments.

Practical Implications

This research provides information that will aid turf managers to selectively control Japanese stiltgrass in cool-season turfgrasses. Fenoxaprop selectively controls Japanese stiltgrass even at 35 g ha^{-1} and reduces the overall cost of managing this problematic weed in tall fescue. Topramezone-based herbicides also effectively control

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Japanese stiltgrass without compromising tall fescue safety. Fluazifop at 53 g ha^{-1} resulted in transient injury to Kentucky bluegrass but it effectively controlled Japanese stiltgrass. Reduced rates of fluazifop could be applied for selectively managing Japanese stiltgrass in Kentucky bluegrass if land and turf managers are willing to tolerate transient turf injury up to 4 wk after herbicide application. Dicamba, fenoxaprop, and fluroxypyr premix controlled Japanese stiltgrass by >90% without compromising Kentucky bluegrass safety. Although our study did not evaluate the tolerance of tall fescue to the dicamba, fenoxaprop, and fluroxypyr premix, this product is labeled for use on tall fescue and other cool-season turfgrass species.

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Competing Interests. The authors declare they have no competing interests.

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