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Evaluation of herbicide programs for the control of knotroot foxtail [*Setaria parviflora* (Poir.) Kerguélen] in bermudagrass pasture

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Research Article

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Glyphosate; hexazinone; indaziflam; metsulfuron-methyl; nicosulfuron; pendimethalin; Carolina horsenettle; *Solanum carolinense* L. SOLCA; knotroot foxtail; *Setaria parviflora* (Poir.) Kerguélen] SETGE; large crabgrass; *Digitaria sanguinalis* (L.) Scop. DIGSA; bermudagrass; *Cynodon dactylon* (L.) Pers. CYNDA

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Abstract

Knotroot foxtail has become more prevalent and problematic in pastures and hayfields in the southeastern United States. Gaps exist in our knowledge of which herbicide practices are best for managing this species in bermudagrass forage production. This study was conducted to determine the efficacy of various ways to control knotroot foxtail in bermudagrass with herbicide applications in autumn, postemergence (POST), with and without also applying a herbicide in preemergence (PRE), in spring. The study was a randomized complete block with a factorial arrangement of treatments and included a nontreated control for both fall and spring timings. Glyphosate at two rates (0.35 or 0.7 kg ae ha^{-1}), nicosulfuron (0.07 kg ai ha^{-1}) + metsulfuron (0.012 kg ai ha^{-1}), and hexazinone (1.3 kg ai ha^{-1}) were applied alone in the fall or followed by indaziflam (0.067 kg ai ha^{-1}) or pendimethalin (4.46 kg ai ha^{-1}) in the spring. Three harvests were conducted throughout the growing season to evaluate weed species (knotroot foxtail, large crabgrass, and horsenettle) and bermudagrass biomass as well as overall species composition. The combination of fall and spring treatments did not affect weed species or bermudagrass biomass. Therefore, treatment main effects were analyzed by fall or spring application timing. A spring application of either pendimethalin or indaziflam increased bermudagrass biomass compared with that of the nontreated control. However, neither PRE herbicide effectively reduced knotroot foxtail biomass compared with the nontreated control, although pendimethalin did reduce season-long knotroot foxtail composition. Spring PRE herbicides are an effective tool for forage producers, but further research is needed to identify effective herbicides and additional approaches for the control of knotroot foxtail.

Introduction

Knotroot foxtail is a problematic perennial weed of pastures, hayfields, and roadsides in the southeastern United States. It has similar morphological features as yellow foxtail [*Setaria pumila* (Poir.) Roem. & Shult.], including hairs on the leaf base and ligule, seed head size, and color around the base of shoots (Bryson and DeFelice 2009; Dyer et al. 2023). In addition to asexual propagation via rhizomes, knotroot foxtail can reproduce sexually by seed, from late summer through fall (Israel et al. 2014). The presence of knotroot foxtail can cause yield loss from competition with desirable forage species and may be injurious to livestock when ingested or cause oral ulcers (Israel et al. 2014). These factors can ultimately lead to grazing avoidance, further exacerbating annual and knotroot foxtail infestations in pastures. Successful propagation through multiple methods complicates knotroot foxtail management (McCullough 2016). Furthermore, controlling undesirable grasses in perennial bermudagrass pastures is challenging due to limited herbicide options, and potential damage to desirable forages resulting in diminished forage quality (James et al. 2009). Research investigating the mechanical and chemical management of knotroot foxtail in the southeastern United States is needed to address grower concerns around its management. Annual foxtail species are controlled with applications of preemergence (PRE) and postemergence (POST) herbicides; however, research using these methods for the control of perennial knotroot foxtail has not been conducted.

Effective, long-term management of knotroot foxtail will require the control of annual plants that germinate from seed and perennial plants that emerge from rhizomes. Therefore, multiple herbicide applications may be needed, including fall POST applications that target perennial plants, and spring PRE applications that target plants emerging from seed. Targeting both mechanisms of reproduction may provide effective knotroot foxtail control while promoting quality forage production.

Previous research has identified several POST herbicides that control rhizomatous weedy grasses, including glyphosate, hexazinone, and nicosulfuron + metsulfuron (Brecke 1981; Grichar and Foster 2019; Ivany 1975). Fall applications of systemic herbicides would translocate the active ingredient in the same direction of carbohydrate movement toward roots and rhizomes (Klingman and Ashton 1975; Linder et al. 1949; Wilson et al. 2006). Glyphosate controls johnsongrass [*Sorghum halepense* (L.) Pers.], a troublesome rhizomatous grass weed, when applied in the fall (Brown et al. 1988; Glenn et al. 1986). Hexazinone can be an effective herbicide for POST perennial grass weed control of smutgrass [*Sporolobus indicus* (L.) R. Br.] and fescue species (*Festuca* spp.) by entering the plant primarily through roots and shoots (Anonymous 2015b; Mislevy et al. 1999; Shaner 2014). Effective POST herbicides for the control of knotroot foxtail may reduce seed production and rhizome growth, thereby reducing weed infestation and limiting competition with desirable forage species. However, fall applications of herbicides that are more dependent on environmental conditions, soil type, and organic matter to perform well may not control plants that emerge the following spring.

Preemergent herbicides applied before seedling emergence are important tools for limiting the spread of weeds and to exhaust the presence of seeds within the soil profile. Atchison et al. (2001) observed that yellow foxtail seeds were capable of emerging up to 3 yr after dormancy; therefore, it is necessary to reduce the seedbank in order to reduce further infestation. Pendimethalin (1.4 to 4.46 kg ai ha^{-1}) is labeled for PRE control of annual foxtail species and other annual grasses (Anonymous 2015b). Pendimethalin may be applied sequentially to established bermudagrass, but it should be applied in spring before weed germination begins or after a forage harvest (Anonymous 2015a).

Indaziflam, a cellulose biosynthesis inhibitor, was recently labeled for use in bermudagrass hayfields and pastures (Anonymous 2020). Indaziflam has PRE activity with a long soil half-life (>150 d), providing extended residual activity throughout the growing season (Kaapro and Hall 2011). Dinitroaniline-resistant foxtail biotypes have been identified in Alberta, Manitoba, Saskatchewan, and North Dakota, demonstrating the potential for resistance to this herbicide family, but resistance is not widespread (Darmency et al 2011; Heap 2023). Incorporation of indaziflam into pasture management provides growers and producers with an additional herbicide mode of action, further promoting herbicide stewardship and reducing the possibility for the development of resistance. A comprehensive herbicide program to control emerging knotroot foxtail seedlings is important for pasture and hay producers in the southeastern United States. Therefore, the objective of our research is to determine the effect of fall-applied POST, and spring-applied PRE herbicides on knotroot foxtail control, forage yield, and weed species composition in bermudagrass pastures.

Materials and Methods

Studies were conducted from 2019 to 2021 in bermudagrass pastures located within Clarke and Oconee counties in northeastern Georgia. All bermudagrass stands were identified to have high (>60% visual coverage) infestations of knotroot foxtail. Two site-years were located in separate fields at the Athens Turfgrass Research and Education Center (ATREC) (33.905306°N, 83.373472°W) in Clarke County, consisting of a Pacolet Sandy Clay Loam (fine, kaolinitic, thermic Typic Kanhapludults) (USDA-NRCS 2021). A second site was identified in a producer's field in Clarke County (33.875528°N, 83.280556°W) with a Davidson Clay Loam (fine, kaolinitic, thermic Rhodic Kandiudults) (USDA-NRCS 2021). The final location was in Oconee County, at the J. Phil Campbell Research and Education Center (JPCREC) (33.886194°N, 83.492472°W) with a Cecil Sandy Loam (fine, kaolinitic, thermic Typic Kanhapludults) (USDA-NRCS 2021). Soil samples were collected before study establishment and analyzed by the University of Georgia Extension Agricultural and Environmental Services – Soil, Plant, and Water Laboratory in Clarke County. University of Georgia extension recommendations for coastal bermudagrass pastures were followed with a yield goal of 2,500 to 2,900 kg ha^{-1}. Amendments were applied using either a walk-behind rotary spreader (RS76; Shindaiwa, Lake Zurich, IL) or a three-point hitch tractor-mounted rotary cone spreader (FSP500; Land Pride, Salina, KS). Common weeds with consistent densities across study sites and locations included knotroot foxtail, large crabgrass, and horsenettle (*Solanum carolinense* L.).

The study was a randomized complete block design with four replications with a five by three factorial arrangement of treatments (four POST herbicide treatments, two PRE herbicide treatments, and a nontreated control at both fall and spring timings for comparison, for a total of 15 treatments). Treatment combinations and materials used in the experiment are summarized in Tables 1 and 2. Each site was mowed to a height of 13 cm with a rotary mower prior to trial initiation and allowed to begin to regrow before application. Fall POST herbicides were applied 1 mo before the first frost corresponding to mid-October at each study site (Table 1). In Year 1, treatments were applied to ATREC on October 11, 2019, and the on-farm location on October 22, 2019. In the second season, herbicides were applied on October 30, 2020, at ATREC at a new location on the site, and November 2, 2020, at JPCREC. Both locations in 2019 and 2020 received activating rainfall (≥6 mm) within 7 and 11 d of application, respectively. In spring, herbicides were applied in mid- to late February before foxtail emergence. Spring application dates were February 21, 2020, at ATREC and the on-farm location, and February 19, 2021, at ATREC and JPCREC (Table 1). Activating rainfall (≥6 mm) fell at both locations within 2 and 10 d in 2020 and 2021, respectively. All herbicides were applied with a CO_2-pressurized backpack sprayer using a four-nozzle boom with TeeJet 8003 VS nozzles (Spraying Systems Co., Glendale Heights, IL) calibrated to deliver 280 L ha^{-1} at a pressure of 152 kPa.

To maintain plots with uniformly high levels of knotroot foxtail infestation, plot sizes varied based on the year and trial location. In the 2019–2020 field season, plot sizes at ATREC and the on-farm location were 4 by 5 m and 2 by 5 m, respectively. In the 2020–2021 field season, plot sizes at ATREC and JPCREC were 2 by 5 m and 2.5 by 5 m, respectively. Between replications, a 2-m alleyway was maintained at a height of approximately 6 cm using a zero-turn mower (Z781KWI-60; Kubota, Grapevine, TX).

To determine the effect of herbicide treatments on weed and bermudagrass biomass, three separate biomass harvests were conducted. These harvests coincided with typical bermudagrass hay harvest timings in the area. Hay harvests occurred near June 1, July 1, and from mid-August to September. These harvest timings were determined by visual estimation of bermudagrass seed head emergence and based on recommendations that bermudagrass should be harvested at 4- to 5-wk intervals to obtain optimal forage quality (Hancock et al. 2017). At each harvest date, two 0.25-m^2

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Table 1. Herbicide treatments for the control of knotroot foxtail, horsenettle, and large crabgrass in bermudagrass pastures in the southeastern United States, by spring and fall application timing.

Treatment no.	Fall application[a]	Rate	Spring application[b]	Rate
		kg ai/ae ha^{-1}		kg ai ha^{-1}
1	Nontreated control		Nontreated control	
2	Glyphosate	0.35	Nontreated	
3	Glyphosate	0.70	Nontreated	
4	Nicosulfuron + metsulfuron	0.07 + 0.01	Nontreated	
5	Hexazinone	1.35	Nontreated	
6	Nontreated		Indaziflam	0.07
7	Glyphosate	0.35	Indaziflam	0.07
8	Glyphosate	0.70	Indaziflam	0.07
9	Nicosulfuron + metsulfuron	0.07 + 0.01	Indaziflam	0.07
10	Hexazinone	1.35	Indaziflam	0.07
11	Nontreated		Pendimethalin	4.46
12	Glyphosate	0.35	Pendimethalin	4.46
13	Glyphosate	0.70	Pendimethalin	4.46
14	Nicosulfuron + metsulfuron	0.07 + 0.01	Pendimethalin	4.46
15	Hexazinone	1.35	Pendimethalin	4.46

[a]Treatments including glyphosate and nicosulfuron + metsulfuron applied in autumn all included a nonionic surfactant at 0.25% v/v.
[b]Spring applications of indaziflam and pendimethalin included glyphosate at 0.70 kg ae ha^{-1}.

Table 2. Sources of materials and rates used in the experiments.

Herbicide	Trade name	Manufacturer[a]
Glyphosate	Roundup Weathermax	Bayer CropScience Inc.
Nicosulfuron, Metsulfuron	Pastora	Bayer CropScience Inc.
Hexazinone	Velpar L	Bayer CropScience Inc.
Indaziflam	Rezilon	Bayer CropScience Inc.
Pendimethalin	Prowl H_2O	BASF Corporation

[a]Manufacturer locations: Bayer CropScience, St. Louis, MO; BASF, Research Triangle Park, NC.

quadrats were randomly placed within each plot, and aboveground biomass was clipped at an approximately 2.5 cm height using ONE+ 18V cordless Battery Grass Shear hand shears (Ryobi USA, Anderson, SC). Hand-harvested biomass was immediately sorted by species to determine species composition. At each harvest, the biomass of bermudagrass, knotroot foxtail, large crabgrass, horsenettle, and all other species was separated and placed in labeled brown paper bags and placed in a forced-air dryer for 72 h at 60 C. Once dry, each species was weighed to determine the aboveground biomass.

Weather data were collected from the nearest weather station, which is part of the University of Georgia weather network (http://www.georgiaweather.net/) located 4.7 km from the ATREC site, 12.4 km from the on-farm location, and 0.3 km from the JPCREC location (Figure 1). Weather data were collected every 15 min from the site, and daily averages were used to determine rainfall in addition to soil and air temperatures following the fall and spring herbicide applications.

Statistical analysis of the data was performed using JMP Pro software (version 16.0.0; (SAS Institute Inc., Cary, NC). ANOVA was performed by harvest for biomass of each weed species and bermudagrass biomass using the MIXED procedure with treatment as a fixed effect and location and year as random effect. Data for harvest parameters, such as bermudagrass and weed biomass, were analyzed by both individual harvest dates and season-long biomass. Means were separated using Tukey's honestly significant difference (HSD) post hoc test at $\alpha \leq 0.05$.

Results and Discussion

Factorial combinations of fall POST applications and spring PRE herbicides were not statistically different; therefore, data were analyzed by the main effects of application timing (fall or spring treatments) (Table 1). The response variables evaluated were the biomass collected from the plots that included knotroot foxtail, bermudagrass, large crabgrass, and horsenettle, which are reported by harvest and overall seasonal responses.

Fall Treatments

Bermudagrass biomass and composition were the only response variables affected by fall POST treatments (Tables 3 and S1). Knotroot foxtail ($P = 0.14$), tall fescue ($P = 0.08$), horsenettle ($P = 0.59$), and large crabgrass ($P = 0.11$) were not affected by fall herbicide applications.

Total bermudagrass biomass at the end of the season was higher in response to nicosulfuron + metsulfuron (373 g m^{-2}) compared with the nontreated control (242 g m^{-2}), which was equivalent to a 54% increase in biomass (Table 4). No other differences in total bermudagrass biomass were observed between all other treatments when compared to either the nontreated control or the nicosulfuron + metsulfuron treatment. Han and Twidwell (2017) reported similar increases (209%) in bermudagrass composition the following season in response to fall applications of nicosulfuron + metsulfuron compared with the nontreated control.

Although fall herbicide treatments were unsuccessful, further investigation into the biology and ecology of knotroot foxtail may provide insight into more efficacious fall application timings. Our current research aimed to minimize bermudagrass injury during the onset of winter dormancy. Previous research noted that fall glyphosate applications do not damage bermudagrass as it goes dormant, but imazapic caused significant bermudagrass injury from fall applications (Han and Twidwell 2017). Although imazapic was not included in our study, hexazinone has been known to reduce bermudagrass yield (Wilder et al. 2008). Earlier applications may improve knotroot foxtail control by using the source/sink relationship of carbohydrate flow to rhizomes,

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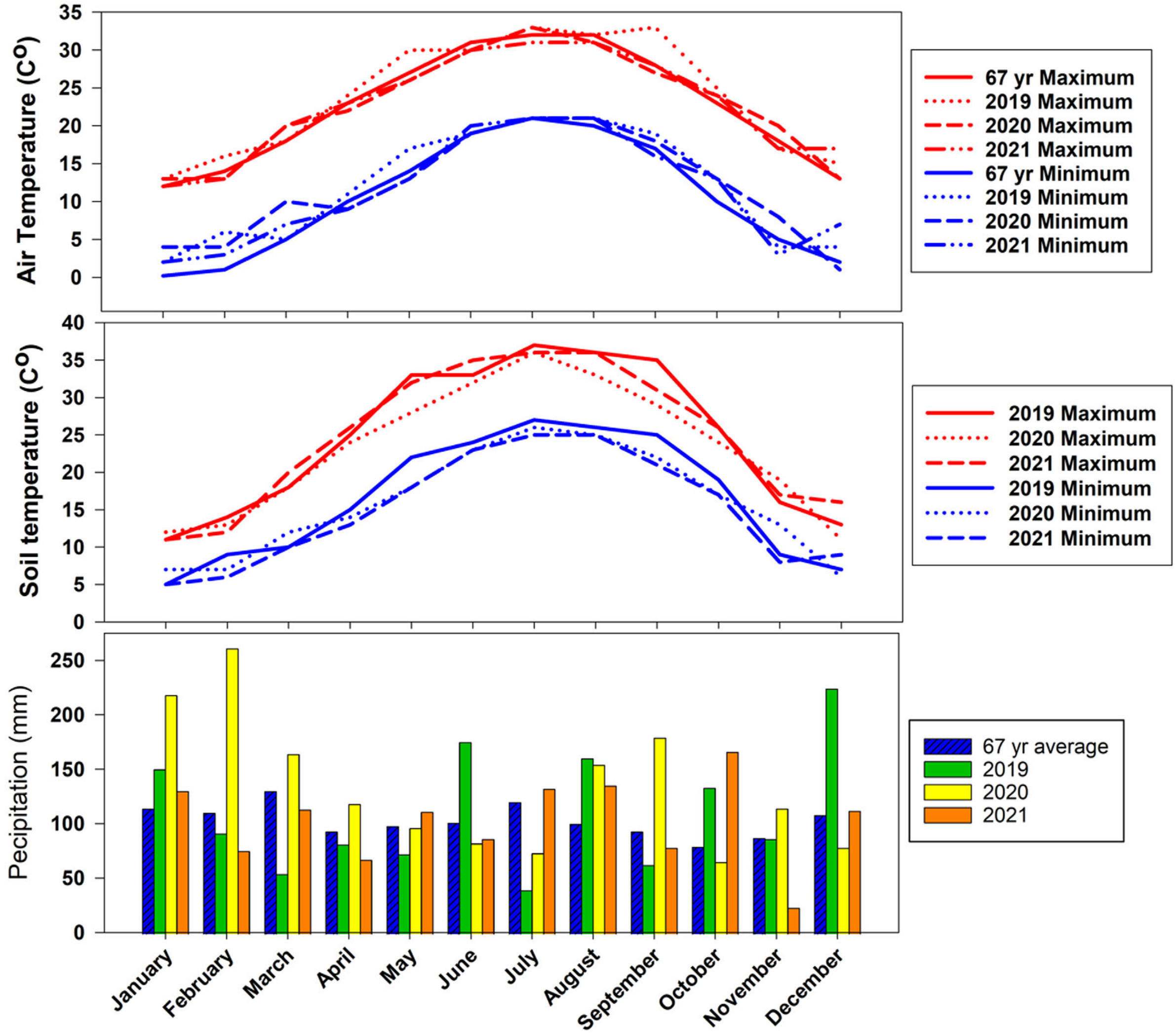

Figure 1. Maximum and minimum average air and soil temperatures and precipitation for the weather station closest to the research sites for the study duration, and the 67-yr average (1949 to 2016) for the location (33.888720°N, 83.420657°W). Historical data were not available for soil moisture at this location. Data were compiled from http://www.georgiaweather.net/.

Table 3. Bermudagrass biomass in response to fall herbicide treatments across all locations.

Herbicide[c,d]	Rate	Harvest[a,b] 1		Harvest 2		Harvest 3		Total	
		Biomass							
	kg ai/ae ha^{-1}	g m^{-2}							
Control	–	70	A	101	A	70	A	242	B
Glyphosate low dose	0.35	77	A	120	A	93	A	290	AB
Glyphosate high dose	0.70	99	A	105	A	75	A	279	AB
Nicosulfuron + Metsulfuron	0.07 + 0.01	111	A	153	A	109	A	373	A
Hexazinone	1.35	85	A	118	A	90	A	293	AB

[a]Harvest data combined across location and year (4 site-years). Harvests 1, 2, and 3 were conducted approximately June 15, July 15, and August 15, respectively.
[b]Means within a column followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Tukey's honestly significant difference test.
[c]Fall herbicides were applied on October 11, 2019, October 22, 2019, October 30, 2020, and November 2, 2020. Spring herbicides were applied on February 21, 2020, and February 19, 2021.
[d]All fall treatments, including nicosulfuron + metsulfuron, included a nonionic surfactant at 0.25% v/v.

but damage risk to desirable forage may exist. Furthermore, historically low rainfall occurrences in late summer and fall in the southeastern United States may affect herbicide uptake and efficacy (Kogan and Bayer 1996).

Spring Treatments

Bermudagrass, weed biomass, and species composition were significantly different at individual harvests and yearly harvest totals (Tables 4 and S1). Spring applications of either indaziflam or

Table 4. Bermudagrass and weed species biomass in response to spring herbicide treatments.

Species	Herbicide[c]	Harvest[a,b] 1		2		3		Total	
		Biomass							
		g m^{-2}							
Bermudagrass	Control	38	B	79	B	50	B	167	B
	Indaziflam	129	A	136	A	104	A	369	A
	Pendimethalin	97	A	142	A	108	A	347	A
Knotroot foxtail	Control	17	B	64	B	136	A	216	B
	Indaziflam	110	A	107	A	124	A	341	A
	Pendimethalin	36	B	67	AB	81	B	184	B
Horsenettle	Control	7	B	5	B	5	A	16	B
	Indaziflam	10	AB	4	B	7	A	21	AB
	Pendimethalin	14	A	7	A	7	A	28	A
Large crabgrass	Control	3	A	16	A	30	A	49	A
	Indaziflam	2	A	9	A	16	A	27	A
	Pendimethalin	1	A	6	A	21	A	28	A

[a]Harvest data were combined across location and year (4 site-years). Harvests 1, 2, and 3 were conducted approximately June 15, July 15, and August 15, respectively.
[b]Means within a column followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Tukey's honestly significant difference test.
[c]Spring applications of indaziflam and pendimethalin included glyphosate at 0.7 kg ai ha^{-1}, which included a nonionic surfactant at 0.25% v/v.

pendimethalin increased the biomass of bermudagrass forage when compared with the nontreated control. Variable effects on weed biomass and composition were also observed in response to spring PRE treatments.

Bermudagrass

Spring treatments positively affected bermudagrass biomass at each harvest. Bermudagrass biomass at each of the harvest timings and yearly totals were increased after pendimethalin and indaziflam were applied. The indaziflam treatment accounted for a 120% increase in bermudagrass biomass in yearly total harvest compared with the nontreated control biomass, while pendimethalin accounted for a 108% increase compared with that of the nontreated control (Table 4). Bermudagrass biomass at Harvest 1 was 124% and 110% greater than that of the nontreated control in response to PRE indaziflam and pendimethalin treatments, respectively (Table 4). Bermudagrass biomass was greatest at Harvest 2 compared to all other harvests. In previous research, bermudagrass biomass did not differ among indaziflam and pendimethalin treatments, and the nontreated control (Hurdle et al. 2020). However, Shay et al. (2022) reported an increase in bahiagrass forage yield following applications of indaziflam plus fertilizer.

Knotroot Foxtail

Indaziflam applied PRE resulted in a 647% and 167% greater knotroot foxtail biomass at Harvests 1 and 2, respectively, compared with the nontreated control (Table 4). At Harvest 3, knotroot foxtail biomass in response to indaziflam (136 g m^{-2}) was similar to that of the nontreated control (124 g m^{-2}) but greater than PRE-applied pendimethalin (81 g m^{-2}). Similarly, Wehtje et al. (2008) noted that PRE herbicides such as pendimethalin did not affect knotroot foxtail seed head production or completely control knotroot foxtail. Reductions in knotroot foxtail biomass production in response to pendimethalin would allow for desirable forage species to better compete with this weed. However, knotroot foxtail biomass totals for the season were greatest for the indaziflam treatment compared with totals for both the nontreated control and pendimethalin (Table 4). Other studies suggest that indaziflam does not negatively affect perennial grass growth (Clark et al. 2019, 2020; Courkamp et al. 2022; Hurdle et al. 2020; Sebastian et al. 2016, 2017). Although this may be beneficial for minimizing annual weed competition with bermudagrass forage, it could allow for the further release and spread of knotroot foxtail within bermudagrass pastures. Furthermore, other regional problematic perennial grass weeds such as johnsongrass, broomsedge (*Andropogon virginicus* L.), and vaseygrass (*Paspalum urvillei* Steud.) are not listed among species controlled by indaziflam (Anonymous 2020).

Indaziflam has a soil K_{oc} of less than 1,000 ml g^{-1} and is classified as moderately mobile to mobile in the soil compared to pendimethalin (which has a K_{oc} of 17,200 ml g^{-1}) (Shaner 2014), but leaching can occur when applications are followed by more than 30 cm of irrigation or rainfall (Jhala and Singh 2012). Pendimethalin may remain in contact with knotroot foxtail rhizomes within the soil profile since it exhibits low leaching potential (less than 10 cm in depth) (Alister et al. 2009; Chopra et al. 2010), and most knotroot foxtail rhizomes are shallow (≤2.5 cm in depth) (Dyer et al. 2023). In addition, forage systems containing high organic matter content near the soil surface may prevent the deeper movement of the aforementioned herbicides within the soil profile. Although indaziflam is listed as efficacious on knotroot foxtail, control may occur only on plants that emerge from seeds, not those that emerge from rhizomes. Indaziflam and pendimethalin applications also reduced the emergence of other annual weeds and limited interspecific competition with perennial knotroot foxtail, further exacerbating an increase in their biomass and reproduction. However, this trend was not observed in response to pendimethalin.

Horsenettle

Horsenettle total biomass was greater after pendimethalin treatments (73% more biomass) compared with biomass of the nontreated control (Table 4). Harvest 1 resulted in a 105% greater horsenettle biomass in response to pendimethalin than the nontreated control. Comparatively, at Harvest 2, pendimethalin and indaziflam treatments led to an increase of 55% and 73% more horsenettle biomass, respectively, than the nontreated control. No statistical differences were observed between treatments with

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respect to horsenettle biomass at Harvest 3. Pendimethalin is effective at controlling annual weeds and provides better control of grass species because it inhibits seedling root formation (Hess 1987; Vaughn 1986). Annual weed control using indaziflam and pendimethalin may have reduced interspecific competition for horsenettle, further allowing its proliferation and spread. Additionally, PRE herbicides such as pendimethalin are often ineffective in controlling horsenettle that emerges from vegetative structures due to the presence of a well-established root and rhizome system that contains an abundance of carbohydrate reserves. Furthermore, efficacy has been reported to be low for PRE control of horsenettle, which leads to reliance on POST herbicides to adequately reduce infestations (VanGessel 1999).

Large Crabgrass

No statistical differences were observed in large crabgrass biomass in response to spring treatments. Although it is not statistically different, the biomass of large crabgrass was numerically lower following indaziflam and pendimethalin treatments than that of the nontreated control (Table 4). This finding is contrary to previous findings from turfgrass and pasture research in which *Digitaria* spp., including large crabgrass, were controlled (Brosnan et al. 2011; Hurdle et al. 2020; Johnson 1994; Johnson and Carrow 1995; Schleicher et al. 1995). A lack of large crabgrass biomass reduction may benefit producers since crabgrass is often considered a valuable annual forage (Mitich 1988). Low populations of large crabgrass within our research sites may have made it difficult to accurately gauge the response of this weed to the treatments we investigated.

The need for effective herbicides for the control of invasive weeds such as knotroot foxtail in bermudagrass pastures is crucial for quality forage production in the southeastern United States. Further research is needed to explore additional herbicide options and control methods. An additional understanding of the biology and ecology of knotroot foxtail may aid in treatment efficacy and methodology. Research investigating knotroot foxtail rhizome formation and physiology, seed production, and seed viability and longevity within the soil seedbank may be warranted. The increase in prevalence of knotroot foxtail in pastures and hayfields throughout the southeastern United States may also require added insight into current production practices that enhance its persistence and initial routes of entry into production fields from roadsides and rights-of-way. Although our current research determined that a spring PRE pendimethalin application is effective for reducing knotroot foxtail biomass, there is a need for a more multifaceted approach for the long-term management of this species.

Practical Implications

Spring PRE herbicides were more beneficial for in-season weed control and therefore led to more bermudagrass biomass production compared to when fall POST herbicides were applied. Further research on when to apply fall herbicides based on weed biological shifts toward dormancy may be warranted. The current use of pendimethalin for the control of knotroot foxtail is effective; however, indaziflam applications may lead to the selection and proliferation of perennial knotroot foxtail plants through the reduction of interspecific competition. The use of a PRE herbicide increases overall bermudagrass forage production compared to no PRE application in the spring. However, pendimethalin and indaziflam alone were not effective in reducing knotroot foxtail biomass when compared to no herbicide application. It is important to note that herbicides are only one tool that producers can use to minimize the negative impacts of weed competition on forage production and quality. A dense healthy stand of forage is often the best defense against weed infestations. Conducting soil tests combined with proper fertility and lime applications is one of the most important steps to keeping pastures weed free. Spring PRE applications of indaziflam may also require careful consideration of fall forage planting dates and species selection since the long soil residual activity of this herbicide may result in diminished stands. Further investigation into efficacious POST herbicide options for the control of knotroot foxtail may help alleviate some of these challenges and concerns. Mechanical and cultural weed management techniques should also be evaluated alone and in combination with chemical measures to provide the best options for long-term knotroot foxtail control.

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Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/wet.2023.98

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