

Research Article

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Evaluating shifts in species distribution following herbicide and fertilizer applications for smutgrass (*Sporobolus indicus*) control in bahiagrass

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Abstract

Novel management strategies for controlling smutgrass have potential to influence sward dynamics in bahiagrass forage systems. This experiment evaluated population shifts in bahiagrass forage following implementation of integrated herbicide and fertilizer management plans for controlling smutgrass. Herbicide treatments included indaziflam applied PRE, hexazinone applied POST, a combination of PRE + POST herbicides, and a nonsprayed control. Fertilizer treatments included nitrogen, nitrogen + potassium, and an unfertilized control. The POST treatment reduced smutgrass coverage regardless of PRE or fertilizer application by the end of the first season and remained low for the 3-yr duration of the experiment ($P < 0.01$). All treatments, including nontreated controls, reduced smutgrass coverage during year 3 ($P < 0.05$), indicating that routine harvesting to remove the biomass reduced smutgrass coverage. Bahiagrass cover increased at the end of year 1 with POST treatment ($P < 0.01$), but only the POST + fertilizer treatment maintained greater bahiagrass coverage than the nontreated control by the end of year 3 ($P < 0.05$). Expenses associated with the POST + fertilizer treatment totaled US\$348 ha⁻¹ across the 3-yr experiment. Other smutgrass control options could include complete removal of biomass (hay production) and pasture renovation, which can cost 3-fold or greater more than POST + fertilizer treatment. Complete removal of biomass may reduce smutgrass coverage by removing mature seedheads, but at a much greater expense of US\$2,835 to US\$5,825 ha⁻¹, depending on herbicide and fertilizer inputs. Bahiagrass renovation is US\$826 ha⁻¹ in establishment costs alone. When pasture production expenses are included for two seasons postrenovation, the total increases to US\$1,120 ha⁻¹ across three seasons. The importance of hexazinone and fertilizer as components of smutgrass control in bahiagrass forage was confirmed in this study. Future research should focus on the biology of smutgrass and the role of a PRE treatment in a long-term, larger-scale forage system.

Introduction

Bahiagrass is one of the most predominant warm-season grasses grown in the southern coastal plains region of the southeastern United States. Although bahiagrass is considered a weed in many agricultural production systems, it is well suited for low-input grazing systems. Bahiagrass is more drought tolerant, better withstands insect pressure, requires lower fertility inputs, and better tolerates continuous grazing than other perennial forages (Hancock et al. 2010). However, weeds can be problematic, especially perennial weeds like smutgrass, which is nonnative and invasive (Sellers et al. 2023). Weed removal can complicate a management strategy that does not account for the possible introduction and shifts to other weedy species.

Smutgrass is a major pest in perennial grasslands throughout the Southeast, primarily in bahiagrass pastures and hayfields (Rana et al. 2012). The dense canopy and an aggressive upright growth of smutgrass can limit the vegetative potential of both bahiagrass and other opportunistic weeds (Rana et al. 2012). Extensive research has identified hexazinone as an effective management tool for controlling smutgrass in bahiagrass (Ferrell et al. 2006; Mislevy et al. 2002; Nolte 2017; Sellers and Ferrell 2011; Sellers et al. 2023; Shay et al. 2022; Wilder et al.

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2008). One of the challenges with hexazinone is timing the application to receive adequate precipitation. Lack of rainfall will result in reduced efficacy because the hexazinone is not moved into the root zone, whereas rainfall exceeding 76.3 mm could result in hexazinone moving beyond the root zone, which would also reduce effectiveness (Sellers and Ferrell 2011). It is also possible to increase competition from other weed species, especially during the first 30 d after application, when bahiagrass is recovering from initial hexazinone injury (Ferrell and Mullahey 2006).

A timely fertilizer application following hexazinone can accelerate bahiagrass recovery, giving it a competitive advantage over opportunistic weeds (Regmi et al. 2023; Sellers et al. 2023; Shay et al. 2022). Fertilizers are often the costliest input for low-input producers, although Rana et al. (2013) reported that the combination of hexazinone and fertilizer provided more effective smutgrass termination over singular applications of hexazinone. Unfortunately, weed seedbanks are dynamic in sod-based systems, and disturbances to the systems (i.e., smutgrass removal) can provoke the germination of weed seeds and a shift in species distribution. Hancock et al. (2010) described various aggressive summer annual grass species that can become problematic in bahiagrass, such as goosegrass [*Eleusine indica* (L.) Gaertn.] and crowfoot grass [*Dactyloctenium aegyptium* (L.) Willd.]. Hexazinone is the only selective, POST control option for these weeds in bahiagrass-dominant forage systems that is economical for producers to use. This reinforces the need for a fully integrated weed management plan that is both cost effective and resilient.

Furthermore, limited herbicide options may lead to herbicide resistance in weeds perennially treated with the same chemistries. The sustainability of long-term weed control programs will have to combat the potential challenge of herbicide resistance (Jabran et al. 2015). Thus including a PRE herbicide, along with other management tactics, can reduce the potential for resistance development by reducing off-target applications and preventing weed seed production. Sebastian et al. (2017) reported that indaziflam has a unique mode of action as a cellulose biosynthesis inhibitor. Indaziflam provides favorable control of annual and other early-germinating perennials through root and shoot growth inhibition (Sebastian et al. 2017).

Shay et al. (2022) found that including PRE (indaziflam) and POST (hexazinone) herbicides in addition to fertilization (nitrogen and potassium) improved the bahiagrass stand. Timely weed suppression removed competition, while fertilizer provided essential nutrients for optimum bahiagrass growth and recovery, allowing it to fill in the gaps left by controlled weeds. Combining herbicide and fertilizer was determined to be a more economical solution for producers looking to improve bahiagrass pasture when compared to complete bahiagrass field renovation (Shay et al. 2022).

Shay et al. (2022) presented the efficacy of the proposed smutgrass control efforts only in the year in which the herbicides were applied. No studies have addressed long-term sward responses to herbicide applications of hexazinone with indaziflam in bahiagrass forage systems. Disturbances to an agroecosystem following management implementation can provoke multitrophic biotic responses among varying species (Shennan 2008). Kemp and King (2001) observed that competitive interactions of plant species in pastures are modified by management practices and that these interactions increase in complexity as the number of species rises. This explains why other authors have expressed difficulty in improving bahiagrass vigor to increase competitiveness over other

weed species (Beaty et al. 1974; Silveira et al. 2017; Yarborough et al. 2017). Removing smutgrass from a bahiagrass system may shift ecological interactions. This change can promote the introduction of other opportunistic annual and perennial weed species, as buried seeds often take advantage of disturbed areas of bare soil and canopy gaps (Sanderson et al. 2014). The objective of this experiment was to evaluate population shifts in bahiagrass forage following the implementation of integrated herbicide and fertilizer management plans for controlling smutgrass.

Materials and Methods

Description of Research Site

This research was conducted at the University of Georgia Alapaha Beef Station in Alapaha, GA (31.58°N, 83.58°W; 81 m elevation), from April through October 2020 to 2023. The experimental sites were located in a previously established Tifton-9 and Pensacola bahiagrass pasture with a preexisting population of small smutgrass (location 1, average coverage = 42%, range in coverage = 20% to 80% in 2020; location 2, average coverage = 27%, range in coverage = 2% to 100% in 2021). The individual locations were initiated in consecutive years. The experimental areas were fenced off to exclude grazing. The research site was nearly level (<2% slope) and composed primarily of Alapaha loamy sand (loamy, siliceous, subactive, thermic Arenic Plinthic Paleaquults) and Rutledge loamy sand (sandy, siliceous, thermic Typic Humaquepts), with an average soil pH of 5.0 (USDA-SSS 2019).

Daily air temperatures and daily cumulative rainfall were collected throughout the experimental period from the University of Georgia Automated Environmental Monitoring Network (UG-CAES 2025). The maximum daily ambient temperatures often exceeded 25 C during the experimental period. Temperatures ranged from 26 C to 34 C each year, which was similar to the 100-yr average (NOAA 2024; UG-CAES 2025). Cumulative annual rainfall was highly variable in volume compared to the 100-year average of 715 mm for April to October (NOAA 2024). Cumulative rainfall amounts were 715, 1,103, 739, and 657 mm for April to October in 2020, 2021, 2022, and 2023, respectively (UG-CAES 2025).

Experimental Design and Treatments

The experiment was arranged in a randomized complete-block design with a 4 × 3 factorial arrangement and six replicates. Treatments included four herbicide (factor a) and three fertilizer (factor b) combinations, totaling 12 treatment combinations for a total of 72 plots. Each 2 × 5-m plot was surrounded by 1-m alleyways on all sides for distinction.

Herbicides were applied to plots only in the initial year for each location, as described in Shay et al. (2022). Herbicide treatment levels included unsprayed control, PRE, POST, and a combination of PRE + POST. Indaziflam (PRE; Anonymous 2020) was applied at 0.058 kg ai ha⁻¹ in the spring (Table 1). Hexazinone (POST; Anonymous 2015) was applied at 0.98 kg ai ha⁻¹ following harvest 4 (Table 1). The combination (PRE + POST) herbicide treatment received both indaziflam and hexazinone applications, as previously described. All herbicide treatments were applied using a tractor-mounted, 1.83-m boom sprayer with a shield and TeeJet® TP8003VS nozzles (TeeJet® Technologies, Glendale Heights, IL, USA) calibrated to deliver 205.7 L ha⁻¹. Rainfall timing and amount are critical for optimal activity of both indaziflam and

Table 1. Herbicide and fertilizer applications for the two trial locations in Alapaha, GA.

Treatment	Product	Rate	Application date		Date and amount of first precipitation after herbicide application	
			Location 1	Location 2	Location 1	Location 2
PRE	Indaziflam	0.058 kg ai ha ⁻¹	7 Apr 2020	15 Mar 2021	8 Apr 2020, 16 mm	18 Mar 2021, 13 mm
POST	Hexazinone	0.98 kg ai ha ⁻¹	7 Aug 2020	30 Aug 2021	10 Aug 2020, 15 mm	31 Aug 2021, 33 mm
Fertilizer (N and N + K)	Ammonium nitrate, 34% N	56 kg N ha ⁻¹	7 Apr 2020	23 Apr 2021	n/a	n/a
			12 Jul 2020	16 Jul 2021		
			23 Apr 2021	7 May 2022		
	Muriate of potash, 60% K ₂ O	56 kg K ₂ O ha ⁻¹	16 Jul 2021	7 Jul 2022	n/a	n/a
			7 May 2022	25 May 2023		
			7 Jul 2022	28 Jul 2023		

hexazinone. The date and amount of the first rainfall following each herbicide application are presented in Table 1.

Fertilizer treatment levels included unfertilized control, nitrogen only, and nitrogen plus potassium. Fertilizers were hand-applied each year following green-up and after the July harvest (Table 1). Fertilized plots received 56 kg N ha⁻¹ (applied as ammonium nitrate, 34% N) or 56 kg N ha⁻¹ (applied as ammonium nitrate, 34% N) + 56 kg K₂O ha⁻¹ (applied as muriate of potash; N + K). Fertilizer treatments were below the recommendations provided by the University of Georgia Feed and Environmental Water Laboratory in Athens but are typical of what most bahiagrass fields would receive in southern Georgia (Kissel and Sonon 2008).

Data Collection

Plot borders were mowed to 7.62 cm before each data collection. All plots were visually evaluated for bahiagrass, smutgrass, and other plant species ground cover to the nearest 5% every 4 to 6 wk from green-up (April/May) until winter dormancy (October). After this evaluation, all plots were harvested to 7.62 cm height with a Kubota ZD1211 mower with a 152.4-cm deck and a bagger attachment (Kubota Tractor Corporation, Grapevine, TX, USA) to remove plant material from the experimental areas because they were excluded from grazing. This mowing was consistent with the typical interval for rotational grazing.

Statistical Analysis

Data were subjected to an analysis of variance (ANOVA) in JMP Pro (version 16.0.0; SAS Institute, Cary, NC, USA). Data were analyzed using the MIXED procedure with treatment and time point (initiation and end of each year) as fixed effects and location (calendar year) as a random effect. Means within a year were separated using Fisher's protected least significant difference at $\alpha = 0.05$. Because of the large number of treatment combinations in this study, main effect means were compared by single degree of freedom contrasts to isolate the importance of each treatment component in reducing the smutgrass population. Finally, Dunnett's procedures ($\alpha = 0.05$) were conducted to evaluate if smutgrass and bahiagrass ground covers were comparable to that of the nontreated control (unsprayed and unfertilized) at initiation. All data were reported relative to the nontreated control at initiation instead of relative to the start of each season to capture the effects of applied treatments and biomass removal from the research area.

Economic Analysis

All fertilizer prices were collected from DTN in January 2024 (Quinn 2024). The DTN-sourced data considered in this analysis included national average fertilizer prices. All herbicide prices were collected locally in the southeastern United States. Because the fertilizer treatments were combined for the agronomic analysis, the costs of the N and N + K treatments were averaged to compute the fertilizer input cost. Fertilizer application cost was assumed to be US\$18.50 ha⁻¹ application⁻¹. Herbicide applications are assumed to be applied by the producer using an 8.3-m broadcast sprayer and a 56-kW tractor. The costs associated with each treatment were calculated by multiplying the quantities of inputs used by the market prices for the region (Table 2). All treatment costs are provided on a per-hectare basis. Because treatments were implemented over multiple years, total costs and per-year costs are estimated.

Bahiagrass hay production expenses were calculated under the hay production calculator of the University of Georgia 2024 Bahiagrass Forage Enterprise Budget (Secor et al. 2024; Table 2). This budget included market costs for lime, fertilizer, PRE and POST emergent fertilizer, fuel, repairs and maintenance, net wrap, operator labor, interest on operating capital, equipment fixed costs, and amortized establishment costs (Secor et al. 2024). These costs were applied to an ~40-ha bahiagrass farm that generated ~5,600 kg forage ha⁻¹ yr⁻¹ during five harvest events. Scenarios were analyzed with and without herbicide and fertilizer applications because hay production practices may vary.

Bahiagrass renovation expenses were calculated under the establishment calculator of the University of Georgia 2024 Bahiagrass Forage Enterprise Budget (Secor et al. 2024; Table 2). This budget included market costs for a preplant glyphosate burndown, 2,4-D application postplanting, 'TifQuik' bahiagrass seed, fertilizer and lime at planting and after first mowing, fuel, repairs and maintenance, operator labor, interest on operating capital, and equipment fixed costs (Secor et al. 2024). Bahiagrass pasture management expenses include 2 yr of fertilizer, fuel, repairs and maintenance, operator labor, interest on operating capital, and equipment fixed costs (Secor et al. 2024). These costs were applied to an ~40-ha bahiagrass farm that has an expected longevity of 10 yr.

Comparable bahiagrass forage budgets are rare in the Southeast for this time frame. Mississippi State University has a bahiagrass forage establishment budget using no-till planting (Maples et al. 2022). Its per-hectare cost projection is within ~10% of the University of Georgia's establishment cost. The maintenance budget from Mississippi State University includes bahiagrass, but

Table 2. Cost comparison of treatment inputs to various hay production and establishment scenarios^a.

Treatment components			Treatment expenses			Total expenses incurred over 3 yr
POST	PRE	Fertilizer	Product	Application	Total	
					US\$ ha ⁻¹	
None	None	None	—	—	—	—
		N and N + K	42	8	49	295
	Indaziflam	None	34	4	38	38
		N and N + K	76	11	87	332
Hexazinone	None	None	50	4	53	53
		N and N + K	91	11	102	348
	Indaziflam	None	84	7	91	91
		N and N + K	175	18	193	439
Hay production (with recommended herbicide and fertilizer) ^b						5,825
Hay production (no herbicide)						5,084
Hay production (no herbicide or fertilizer)						2,835
Bahagrass renovation						826
Bahagrass renovation + two grazing seasons						1,752

^aTreatment components included PRE (indaziflam, 0.28 kg ai ha⁻¹), POST (hexazinone, 4.82 kg ai ha⁻¹), and fertilizer (56 kg N ha⁻¹, applied as ammonium nitrate, 34% N; 56 kg N ha⁻¹ + 56 kg K₂O ha⁻¹, applied as muriate of potash).

^bBahagrass hay production, renovation, and grazing expenses were calculated with the University of Georgia 2024 bahagrass budget (Secor *et al.* 2024).

also includes other warm-season, perennial grasses (Maples *et al.* 2022). This makes these estimates less comparable. Last, although similar, these budgets do differ based on the timing of input cost collection and the exact practices used. In sum, the University of Georgia budgets represent plausible conditions facing many producers across the Southeast, though differences will certainly exist from one producer to another.

Results and Discussion

Changes in Ground Cover Percentage over Time

Because of the large number of treatment combinations evaluated in this study, pairwise comparisons of the main effects were not significant in determining the optimal treatment combinations for smutgrass control in bahagrass forage. Therefore contrasts were evaluated between the mean smutgrass ground cover at study initiation and the mean smutgrass cover at the end of each year for each respective effect.

Overall, herbicides effectively reduced smutgrass visible ground cover during the first year of this experiment and maintained reduced weed cover throughout all years ($P < 0.01$; Table 3). When examined individually, the PRE treatment was less effective than the POST treatment in the first season and did not reduce smutgrass cover below the level at initiation until the second season ($P < 0.01$; Table 3). The N and N + K fertilizer treatments were combined for the contrast analyses because ANOVA did not indicate differences among these two effects ($P = 0.51$; data not shown). The application of fertilizer also reduced smutgrass ground cover in all years of this evaluation ($P < 0.01$; Table 3). However, the impact of mowing (complete removal of biomass) was seen in the plots assigned to the nontreated control as smutgrass ground cover decreased over time ($P < 0.02$ in year 1; Table 3).

Smutgrass visible ground cover was compared directly to the nontreated control at study initiation. Even though there were no differences in smutgrass cover at study initiation ($P = 0.59$), Dunnett's procedure showed that N and N + K fertilization (with and without hexazinone) were lower in smutgrass cover at study initiation compared to the plots designated as the nontreated control ($P < 0.05$; Table 4). This difference is a consequence of how

Table 3. Effect of herbicide, fertilizer, and mowing on smutgrass visual ground cover^{a,b}.

Effect	Year	χ^2	P-value
Herbicide	1	571.04	<0.01 ^c
	2	957.04	<0.01
	3	800.17	<0.01
PRE	1	0.56	0.45
	2	37.86	<0.01
	3	92.62	<0.01
POST	1	178.17	<0.01
	2	217.85	<0.01
	3	178.17	<0.01
Fertilizer	1	21.46	<0.01
	2	104.91	<0.01
	3	133.34	<0.01
Mowing ^d	1	5.22	0.02
	2	59.62	<0.01
	3	145.96	<0.01

^aEach Effect × Year combination represents the smutgrass coverage at the last harvest of the year compared to the smutgrass coverage at the study initiation.

^bTreatments included PRE (indaziflam, 0.28 kg ai ha⁻¹), POST (hexazinone, 4.82 kg ai ha⁻¹), fertilizer (56 kg N ha⁻¹, applied as ammonium nitrate, 34% N; 56 kg N ha⁻¹ + 56 kg K₂O ha⁻¹, applied as muriate of potash).

^cSingle degree of freedom contrasts were conducted on the mean of smutgrass ground cover within the effect and the smutgrass cover at study initiation.

^dRefers to complete biomass removal from the experimental area using a mower with a bagger attachment. This consisted of clipping plots to 7.62 cm stubble height every 28 to 35 d.

error terms are partitioned among the two statistical procedures, which impacted the ability of the procedure to detect a difference among treatments at study initiation.

Regardless of the level of smutgrass coverage at study initiation, several interesting trends emerged throughout this experiment. After year 1, the POST herbicide reduced smutgrass coverage regardless of PRE or fertilizer applications ($P < 0.01$; Table 4). When no POST treatment was applied, the PRE treatment and fertilizer were both required to decrease smutgrass ground cover below that at study initiation ($P < 0.01$; Table 4). Smutgrass populations were variable at the start of year 2, but the trends at the end of year 2 followed those of year 1. At this time point, the POST herbicides maintained control of smutgrass ($P < 0.01$; Table 4), and the addition of fertilizer reduced smutgrass coverage

Table 4. Smutgrass visual ground cover in response to fertilizer and herbicide treatments^{a,b}.

Treatment components			Year 1		Year 2		Year 3	
POST	PRE	Fertilizer	Start	End	Start	End	Start	End
None	None	None	37	27	13**	26	19**	20**
		N and N + K	24*	31	18**	24*	19**	25*
		Indaziflam	33	35	27	27	24*	22*
Hexazinone	None	N and N + K	29	22**	25*	25*	19**	22**
		None	34	5**	10**	9**	10**	15**
		N and N + K	26*	2**	7**	5**	10**	10**
		Indaziflam	32	7**	5**	9**	17**	12**
		N and N + K	28	-1**	8**	8**	10**	14**
		None	34	5**	10**	9**	10**	15**

^aTreatment components included PRE (indaziflam, 0.28 kg ai ha⁻¹), POST (hexazinone, 4.82 kg ai ha⁻¹), fertilizer (56 kg N ha⁻¹, applied as ammonium nitrate, 34% N; 56 kg N ha⁻¹ + 56 kg K₂O ha⁻¹, applied as muriate of potash).

^bDifference from nontreated control at initiation at $\alpha = 0.05$ (*) and $\alpha = 0.01$ (**). Standard error of the mean = 5.6%.

regardless of PRE application ($P < 0.05$; Table 4). All treatments exhibited reduced smutgrass coverage during year 3 of the evaluation relative to the level at study initiation ($P < 0.05$; Table 4). This finding indicates that the complete removal of biomass by mowing had the unintended benefit of decreasing smutgrass coverage over time. The authors acknowledge that the lack of an unmown treatment is a pitfall in validating this result, but inferences from the surrounding pasture areas can be drawn. The experimental area was nested within larger grazing pastures at the Alapaha Beef Station. During the experimental period, these pastures were rotational grazed or clipped with a rotary mower every 4 to 6 wk, depending on forage availability. The smutgrass coverage in this pasture did not visibly decline during the experimental period and remained ~40% at the conclusion of this experiment.

Bahiagrass ground cover followed the same trend as smutgrass concentrations in that no differences were observed for the study initiation ($P = 0.62$; data not shown). Bahiagrass visible ground cover was also compared at multiple time points to the nontreated control at study initiation. Again, Dunnett's procedure did find greater bahiagrass at study initiation for the fertilized plots compared to the plots designated as the nontreated control ($P < 0.05$; Table 5). This was attributed to differences in error partitioning between the two analyses but did not impact the conclusions of this study at future time points.

Bahiagrass ground cover increased at the end of year 1 where a POST herbicide was used to reduce smutgrass coverage with or without PRE or fertilizer application ($P < 0.01$; Table 5). If the POST treatment was not applied, both PRE treatment and fertilizer were needed to increase bahiagrass ground cover above that at study initiation ($P < 0.05$; Table 5). Similar to the smutgrass populations, bahiagrass cover was variable at the start of year 2. At this time point, the POST herbicide remained effective in improving bahiagrass cover, but the treatment combination with fertilizer and/or PRE treatment was required ($P < 0.05$; Table 5). All plots treated with the POST treatment maintained improved bahiagrass coverage at the end of year 2 ($P < 0.01$; Table 5). All treatments were comparable at the start of year 3 and not different from study initiation ($P > 0.99$; Table 5). Only the POST + fertilizer treatment was able to maintain the greater bahiagrass coverage at the end of year 3 compared to all other herbicide and fertilizer combinations ($P < 0.05$; Table 5).

Hexazinone (POST) played a critical role in removing smutgrass from bahiagrass forage systems in the first year following application, as discussed in greater detail by Shay

et al. (2022). This effect was similar to the success of hexazinone applications reported throughout the literature (Ferrell et al. 2006; Mislevy et al. 2002; Nolte 2017; Sellers and Ferrell 2011; Sellers et al. 2023; Shay et al. 2022; Wilder et al. 2008). However, a knowledge gap related to long-term implications of sward dynamics following hexazinone application existed. Although smutgrass ground coverage increased in plots treated with hexazinone in year 3 of the evaluation, final ground coverage was still well below 50%, the threshold suggested for treatment by Sellers et al. (2023). Hexazinone may be applied below this threshold if producers want to prevent smutgrass encroachment; however, the economic impact of this herbicide application must be evaluated within the parameters of the respective farm (Sellers et al. 2023; Shay et al. 2022). Although fertilizer applications and the use of a PRE herbicide reduced smutgrass populations within the time frame of this evaluation, they are still not considered a suitable alternative to hexazinone (POST). These components are important to improving the total forage system, but that is beyond the scope of this study.

Although herbicide applications in this study proved efficacious for controlling smutgrass, frequent mowing also reduced smutgrass coverage in this study. Previous literature has shown that mowing or clipping pastures is not effective in controlling smutgrass in bahiagrass pastures and can rapidly increase seed disbursement (Currey et al. 1973; Mislevy et al. 2002). Mowing can decrease the diameter of the smutgrass plants but will increase the number of plants through seed disbursement (Mislevy et al. 1999). Although mowing may slow the spread of smutgrass, complete termination and removal are highly unlikely (Mislevy et al. 1999). Grazing has also been ineffective at reducing smutgrass populations because the seeds can cling to the coats of the grazing animals. Smutgrass becomes sticky when the pericarp has been loosened by moisture, allowing for adhesion to animal hair (Andrews 1995). Mowing or frequent grazing events may make the smutgrass more palatable to the grazing animals, but this does not result in long-term control (Sellers 2022).

Complete biomass removal through hay production has not been reported in previous literature. Although it was not a planned treatment effect in this current evaluation, biomass removal from the research area did decrease smutgrass ground coverage over the 3 yr of the experiment. It appears that smutgrass is less tolerant than bahiagrass to frequent, complete defoliation events that simulate a hay harvest (Gates et al. 2004). These events would have greatly reduced the photosynthetic capability of the smutgrass so that regrowth would have relied heavily on carbohydrate removal from the plant roots and rhizomes. This frequent reliance on belowground carbohydrate stores over time appears to have

Table 5. Bahiagrass visual ground cover in response to fertilizer and herbicide treatments^{a,b}.

Treatment components			Year 1		Year 2		Year 3	
POST	PRE	Fertilizer	Start	End	Start	End	Start	End
None	None	None	67	76	68	73	67	73
		N and N + K	79*	71	61	76	64	68
	Indaziflam	None	71	68	61	73	62	70
Hexazinone	None	N and N + K	73	81*	63	75	65	71
		None	69	92**	73	88**	73	78
	N and N + K	78	101**	79*	95**	70	82*	
	Indaziflam	None	71	93**	86**	90**	68	81
		N and N + K	76	103**	83**	92**	73	78

^aTreatment components included PRE (indaziflam, 0.28 kg ai ha⁻¹), POST (hexazinone, 4.82 kg ai ha⁻¹), fertilizer (56 kg N ha⁻¹, applied as ammonium nitrate, 34% N; 56 kg N ha⁻¹ + 56 kg K₂O ha⁻¹, applied as muriate of potash).

^bDifference from nontreated control at initiation at $\alpha = 0.05$ (*) and $\alpha = 0.01$ (**). Standard error of the mean = 7.5%.

decreased the competitiveness of the smutgrass concerning the bahiagrass.

More research is needed to confirm the relationship between mowing frequency and carbohydrate stores in smutgrass; however, harvesting hay from bahiagrass may not be economically viable. Bahiagrass accumulates more forage near the soil surface, rather than evenly throughout the sward (Johnson 1990). As much as 58% of the accumulated forage is found within 5 cm of the soil surface, too low to be effectively harvested for a hay crop (Beaty et al. 1968). Nitrogen fertilization can shift the distribution of aboveground biomass above this zone so that more accumulated forage is captured in the harvest event (Gates et al. 2004); however, the economic benefit of the harvested material may not offset the expenses associated with hay production.

When the smutgrass was removed from the plots, there was a risk of shifting weed populations and introducing opportunistic annual and perennial weeds. Forage systems are highly complex, including a substantial mix of buried seed, favoring this shift in abundance and distribution once vegetation and soil are disturbed (Sanderson et al. 2014). However, these other opportunistic weeds never composed more than 5% of the canopy on average during this evaluation and were thus excluded from statistical analyses. When present, these species most often included yellow nutsedge (*Cyperus esculentus* L.), globe sedge [*Cyperus globulosus* Aubl. var. *robustus* (Boeckeler) Shinnors], green kyllinga (*Kyllinga brevifolia* Rottb.), common rush (*Juncus effusus* L.), Elliot's lovegrass (*Eragrostis elliottii* S. Watson), wandering cudweed (*Gnaphalium pensylvanicum* Willd.), vaseygrass (*Paspalum urvillei* Steud.), and dallisgrass (*Paspalum dilatatum* Poir.).

The use of hexazinone for controlling other weeds outside of smutgrass is an indirect benefit, but producers may still require other herbicides to control broadleaf species (Hancock et al. 2010). Ideally, a PRE herbicide would be used to reduce the need for additional POST control options. Kaapro and Hall (2012) highlighted that the chemical and physical characteristics of indaziflam make it an effective option for many annual weed species, especially grass weeds that are challenging to control selectively in bahiagrass. Combinations of indaziflam and hexazinone did not increase the presence of other weed species in the present research. Further research may be necessary to document the long-term implications of hexazinone use in combination with indaziflam and fertilizer on other weeds' abundance and distribution exclusive of complete biomass removal. The application of fertilizer more than likely benefits all weeds present; however, the aggressive nature of bahiagrass and its extensive root system supported better nutrient utilization. As a

result, fertilizer provided a boost for bahiagrass from the limited initial injury of hexazinone and gave it a competitive advantage over weedy species to result in the greatest bahiagrass coverage by the conclusion of the experiment.

Economic Implications of Smutgrass Control Options

The treatment costs summed across the three seasons are presented in Table 2. These varied greatly from US\$38 ha⁻¹ for PRE alone to US\$439 ha⁻¹ for PRE + POST + fertilizer. Fertilizer was a much greater input cost (US\$295 ha⁻¹) compared to either herbicide option (US\$38 ha⁻¹ for PRE and US\$53 ha⁻¹ for POST). It may be tempting for producers to use only the POST treatment to control smutgrass, but bahiagrass can decline over time with the absence of fertilizer (Sollenberger 2019). Again, the POST + fertilizer treatment was the only treatment able to maintain the greater bahiagrass coverage at the end of year 3 compared to all other herbicide and fertilizer combinations ($P < 0.05$; Table 5). This treatment totaled US\$348 ha⁻¹ across the 3-yr experiment.

Producers may be hesitant to make this investment in their farms, especially during periods of increased input costs. It may be argued that harvesting hay from a bahiagrass field infested with smutgrass could be as effective as herbicide and fertilizer applications in controlling smutgrass over time. However, hay production comes at a much greater expense. When the hay production expenses are totaled for 3 yr, producers would expend US\$2,835 ha⁻¹ in equipment, labor, and operating costs. When fertilizer is added to the system, total production expenses would increase to US\$5,085 ha⁻¹ (annually, 225 kg N ha⁻¹, 90 kg P₂O₅ ha⁻¹, and 112 kg K₂O ha⁻¹). If a producer wanted to include a basic herbicide plan, the expense would reach US\$5,825.00 ha⁻¹ (two applications of indaziflam and one application of 2,4-D). Hay production expenses cannot be justified with the low production potential of bahiagrass.

If smutgrass is not controlled, then renovation of the bahiagrass stand may be required. Based on the University of Georgia 2024 Bahiagrass Forage Enterprise Budget, it would cost US\$826 ha⁻¹ to establish a new stand of 'TifQuik' bahiagrass. This does not include time out of production to allow for successful establishment, which could increase production costs if the producer were required to purchase supplemental hay or feed. Ideally, this new stand would be established well enough to support grazing after 1 yr of establishment. If 2 yr of pasture production expenses (US\$463 ha⁻¹ yr⁻¹) were to be added to the cost of establishment, then this option would cost a producer a total of US\$1,752 ha⁻¹ across three seasons. Although this option is less expensive than bahiagrass hay

production, it is still triple the expense of the suggested POST + fertilizer treatment.

Practical Implications

The importance of hexazinone in smutgrass control in bahiagrass forage was confirmed in this study. Fertilizer helped the bahiagrass recover from the limited initial injury of hexazinone and gave it a competitive advantage over weedy species, resulting in the greatest bahiagrass coverage by the conclusion of the experiment. It appears that smutgrass is less tolerant than bahiagrass to frequent complete defoliation events that simulate a hay harvest, but more research is needed to confirm this hypothesis. Unfortunately, hay harvesting is not agronomical or economically effective for bahiagrass stands. Future research should focus on the biology of smutgrass and the role of the PRE treatment in a long-term, larger-scale forage system.

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