This is a “preproof” accepted article for Weed Science. This version may be subject to change in the production process, *and does not include access to supplementary material*.
DOI: 10.1017/wet.2024.99

Short title: Species shifts after smutgrass

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

Nicholas J. Shay[1], Lisa L. Baxter[2], Nicholas T. Basinger[3], William G. Secor[4], Justin C. Burt[5], Guy A. Hancock[6], Brian M. Schwartz[7], and Jason Belcher[8]

[1]Graduate Student (ORCID 0000-0002-6638-580X), Crop and Soil Sciences Department, University of Georgia, Tifton, GA, USA; [2]State Forage Extension Specialist (ORCID 0000-0001-8488-7849), Department of Crop and Soil Sciences, University of Georgia, Tifton, GA; [3]Associate Professor (ORCID 0000-0002-7317-5835), Department of Crop and Soil Sciences, University of Georgia, Athens, GA; [4]Assistant Professor (ORCID 0000-0002-6968-6923), Department of Agricultural and Applied Economics, University of Georgia, Athens, GA 30602; [5]Post-Doctoral Research Associate (ORCID 0000-0001-7374-6581), Department of Crop and Soil Sciences, University of Georgia, Tifton, GA; [6]Public Service Assistant (ORCID 0009-0004-9270-1046), Department of Agricultural and Applied Economics, University of Georgia, Tifton, GA 31793; [7]Professor (ORCID 0000-0001-8734-6474), Department of Crop and Soil Sciences, University of Georgia, Tifton, GA; [8]North America Vegetation Management Product Manager, Envu, Auburn, AL.

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 preemergence (PRE), hexazinone applied postemergence (POST), a combination of PRE + POST herbicides, and a nonsprayed control. Fertilizer treatments included nitrogen (N), nitrogen + potassium (N+K), and an unfertilized control. The POST reduced smutgrass coverage regardless of PRE or fertilizer application by the end of the first season and remained low for the three-year 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 ($P < 0.01$) 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 \$348 ha^{-1} across the three-year experiment. Other smutgrass control options could include complete removal of biomass (hay production) and pasture renovation, which can cost threefold 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 \$2,835 to \$5,825 ha^{-1} depending on herbicide and fertilizer inputs. Bahiagrass renovation is \$826 ha^{-1} in establishment costs alone. When pasture production expenses are included for two seasons post-renovation, the total increases to \$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 in a long-term, larger-scale forage system.

Nomenclature:

Hexazinone; indaziflam; bahiagrass, *Paspalum notatum* Alain ex Fluggé; smutgrass, *Sporobolus indicus* (L.) R. Br.

Keywords: Integrated weed management; forages; pasture

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

Introduction

Bahiagrass is one of the most predominant warm-season grasses grown in the southern Coastal Plains Region in 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 such as smutgrass, which is non-native 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 the use of 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. 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 rootzone, while rainfall exceeding 76.3 mm could result in hexazinone moving beyond the rootzone, which also would reduce effectiveness (Sellers and Ferrell 2011). It is also possible to increase competition from other weed species, especially during the first 30 days 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. (2015) reported that the combination of hexazinone and fertilizer provided more effective smutgrass termination over singular applications of hexazinone. Unfortunately, weed seed banks 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 the species distribution. Hancock et al. (2010) described various aggressive summer annual grass species that can become problematic in bahiagrass like goosegrass (*Eleusine indica*) and crowfoot grass (*Dactyloctenium* *aegyptium*). Hexazinone is the only selective, postemergence control option for these weeds in bahiagrass-dominant forage systems that are economical for producers to use. This reinforces the need to have a fully integrated weed management plan that is both cost-effective and resilient.

Furthermore, the 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, the inclusion of 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 a complete bahiagrass field renovation (Shay et al. 2022).

Shay et al. (2022) only presented the efficacy of the proposed smutgrass control efforts in 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 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°35’ N, 83°35’ W; 81 m elevation) from April through October 2020-2023. The experimental sites were located in a previously established Tifton-9 and Pensacola bahiagrass pasture with a pre-existing population of small smutgrass (location 1: average coverage = 42%; range in coverage = 20-80% in 2020; location 2: average coverage = 27%; range in coverage = 2-100% in 2021). Each location was initiated in consecutive years. The experimental areas were fenced off to exclude grazing. The research site is nearly level (< 2 % slope) and primarily composed 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 Soil Survey Staff 2021).

Daily air temperatures and daily cumulative rainfall were collected throughout the experimental period from the University of Georgia Automated Environmental Monitoring Network (UGA-AEMN 2024). 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-year average (UGA-AMEN 2024; NOAA 2024). 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 mm, 1,103 mm, 739 mm, and 657 mm for April to October in 2020, 2021, 2022, and 2023, respectively (UGA-AMEN 2024).

Experimental Design and Treatments.

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

Herbicides were only applied to plots 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 shield and TeeJet TP8003VS nozzles (TeeJet Technologies Inc., Glendale Heights, IL) calibrated to deliver 205.7 L ha^{-1}. Rainfall timing and amount are critical for optimal activity of both indaziflam and 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 (N), and nitrogen plus potassium (N+K). 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, GA, but are typical of what most bahiagrass fields would receive in South 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 groundcover to the nearest 5% every 4-6 weeks 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 bagger attachment (Kubota Tractor Corporation, Grapevine, TX) to remove plant material from the experimental areas since 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 Software (version 16.0.0; SAS Institute Inc., Cary, NC). Data were analyzed using the MIXED procedure with treatment and timepoint (initiation and end of each year) as fixed effects and location (calendar year) as a random effect. Means within year were separated using Fisher’s protected least significant difference (LSD) at $\alpha = 0.05$. Because of the large number of treatment combinations

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

in this study, main effect means were compared by a 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 cover were comparable to those of the nontreated control (unsprayed and unfertilized) at initiation. All data were reported relative to the nontreated control at initiation instead of 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 USA. Because the fertilizer treatments were combined for the agronomic analysis, the cost of the N and the N+K treatments were averaged to compute the fertilizer input costs. Fertilizer application cost was assumed to be \$18.50 ha^{-1} $application^{-1}$. Herbicide applications are assumed to be applied by the producer using an 8.3-m broadcast sprayer and 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 in 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 a ~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 since hay production practices may vary.

Bahiagrass renovation expenses were calculated under the establishment calculator in the University of Georgia 2024 Bahiagrass Forage Enterprise Budget (Secor et al. 2024; Table 2). This budget included: market costs for a pre-plant glyphosate burndown, 2,4-D application post-planting, 'TifQuik' bahiagrass seed, fertilizer and lime at planting and after first mowing, fuel,

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

repairs and maintenance, operator labor, interest on operating capital, and equipment fixed costs (Secor et al. 2024). Bahiagrass pasture management expenses include two years 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 a ~40 ha bahiagrass farm that has an expected longevity of 10 years.

Comparable bahiagrass forage budgets are rare in the Southeast for this timeframe. Mississippi State University has a bahiagrass forage establishment budget using no-till planting (Mississippi State University, 2023). Their per-hectare cost projection is within approximately 10 percent of the University of Georgia's establishment cost. The maintenance budget from Mississippi State University includes bahiagrass, but also includes other warm-season, perennial grasses. This makes these estimates less comparable. Lastly, while 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 groundcover 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 bahiagrass forage. Therefore, contrasts were evaluated between the mean smutgrass ground cover at study initiation to the mean smutgrass cover at the end of each year for each respective effect.

Overall, herbicides effectively reduced smutgrass visible ground cover the first year of this experiment and maintained reduced weed cover throughout all years (Table 3; $P < 0.01$). When examined individually, the PRE was less effective than the POST in the first season and did not reduce the smutgrass cover below the level at initiation until the second season (Table 3; $P < 0.01$). The N and N+K fertilizer treatments were combined for the contrast analyses since ANOVA did not indicate differences among these two affects ($P = 0.51$; data not shown). The application of fertilizer also reduced smutgrass ground cover in all years of this evaluation (Table 3; $P < 0.01$). 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 (Table 3; $P < 0.02$ in year 1).

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 (Table 4, $P < 0.05$). This difference is a consequence of how error terms are partitioned among the two statistical procedures which impacted the ability of the procedure to detect a difference among treatments at the 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 (Table 4, $P < 0.01$). When no POST was applied, the PRE and fertilizer were both required to decrease smutgrass ground cover below that at study initiation (Table 4, $P < 0.01$). Smutgrass populations were variable at the start of year 2 but the trends at the end of year 2 followed that of year 1. At this time point, the POST herbicides maintained control of smutgrass (Table 4, $P < 0.01$), and the addition of fertilizer reduced smutgrass coverage regardless of PRE application (Table 4, $P < 0.05$). All treatments exhibited reduced smutgrass coverage during year 3 of the evaluation relative to the level at study initiation (Table 4, $P < 0.05$). This finding indicates that the complete removal of biomass by mowing had the unintended benefit of decreasing smutgrass coverage over time. The authors acknowledge 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 4-6 weeks depending on forage availability. The smutgrass coverage in this pasture did not visibly decline during the experimental period and remained approximately 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 (Table 5, $P < 0.05$).

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

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 applications (Table 5, $P < 0.01$). If the POST was not applied, both PRE and fertilizer were needed to increase the bahiagrass ground cover above that at study initiation (Table 5, $P < 0.05$). 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 the improvement of bahiagrass cover but the treatment combination with fertilizer and/or PRE was required (Table 5, $P < 0.05$). All plots treated with the POST maintained improved bahiagrass coverage at the end of year 2 (Table 5, $P < 0.01$). All treatments were comparable at the start of year 3 and not different from the study initiation (Table 5, $P > 0.99$). 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 (Table 5, $P < 0.05$).

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 the smutgrass ground coverage increased in plots treated with hexazinone in year 3 of evaluation, final ground coverage was still well below the 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 (Seller et al. 2020; 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 improve the total forage system but that is beyond the scope of this study.

Although herbicide applications in this study proved efficacious for the control of smutgrass, frequent mowing also reduced smutgrass coverage in this study. Previous literature

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

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, the consequences of biomass removal from the research area did decrease smutgrass ground coverage over the three years 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 relied heavily on carbohydrate removal from the plant roots and rhizomes. This frequent reliance on below-ground carbohydrate stores over time appears to have decreased the competitiveness of the smutgrass concerning the bahiagrass.

More research would be 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 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 the introduction of opportunistic annual and perennial weeds. Forage systems are highly complex including a substantial mix of buried seed favoring this shift in abundance

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

and distribution once vegetation and soil are disturbed (Sanderson et al. 2014). However, these other opportunistic weeds never comprised 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*), green kyllinga (*Kyllinga brevifolia*), common rush (*Juncus effusus*), Elliot's lovegrass (*Eragrostis elliottii*), wandering cudweed (*Gnaphalium penysylvanicum* Willd.), vaseygrass (*Paspalum urvillei*), and dallisgrass (*Paspalum dilatatum*).

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 (2011) 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 in combination with indaziflam and fertilizer on other weed 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 \$38 ha^{-1} for PRE alone to \$439 ha^{-1} for PRE + POST + Fertilizer. Fertilizer was a much greater input cost (\$295 ha^{-1}) compared to either herbicide option (\$38 ha^{-1} for PRE and \$53 ha^{-1} for POST). It may be tempting for producers to use only the POST to control smutgrass, but bahiagrass can decline over time with the absence of fertilizer (Sollenberger 2019). Again, only 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

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

combinations (Table 5, $P < 0.05$). This treatment totaled \$348 ha^{-1} across the three-year 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 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 three years, producers would expend \$2,835 ha^{-1} in equipment, labor, and operating costs. When fertilizer is added to the system, total production expenses increase to \$5,085 ha^{-1} (annually: 225 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, and 112 kg K_2O ha^{-1}). If a producer wanted to include a basic herbicide plan, the expense reaches \$5,825.00 (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 \$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 these production costs if the producer must purchase supplemental hay or feed. Ideally, this new stand will be established well enough to support grazing after one year of establishment. If two years of pasture production expenses (\$463 ha^{-1} yr^{-1}) are added to the cost of establishment, then this option would cost a producer a total of \$1,752 ha^{-1} across three seasons. While 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 theory. 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 in a long-term, larger-scale forage system.

Acknowledgments

The authors would like to thank Deigo Reyes and Dixie Webb for technical assistance with this research effort.

Funding

Funding for this research was provided by the Georgia Beef Cattle Commodity Commission.

Competing Interests

The authors declare none.

References

Anonymous (2015) Velpar® L product label. Publication No. 7511-1117. Research Triangle Park, NC: Bayer CropScience. 25 p

Anonymous (2020) Rezilon® product label. Publication No. 86279134B. Research Triangle Park, NC: Bayer CropScience. 33 p

Beaty ER, McCreery RA, Powell JD (1960) Response of Pensacola bahiagrass to nitrogen fertilization. J Agron 52:453–455

Beaty ER, Smith YC, Powell JD (1974) Response of Pensacola bahiagrass to irrigation and time of N fertilization. J Range Manag 27:394–396

Chambliss CG, Sollenberger LE (1991) Bahiagrass: The foundation of cow–calf nutrition in Florida. Pages 74–80 in Proceedings of the 40th Annual Beef Cattle Short Course. Gainesville, FL: IFAS, University of Florida

Chemical Warehouse (2022) Herbicide costs. https://chemicalwarehouse.com/. Accessed: May 13, 2024

Coffman CB, Frank JR, Potts WE (1993) Crop responses to hexazinone, imazapyr, tebuthiuron, and triclopyr. Weed Technol 7:140–145

Dias JLC, Sellers BA, Ferrell JA, Silveira ML, Vendramini JM (2018) Herbage responses to dogfennel cover and limited nitrogen fertilization in bahiagrass pastures. J Agron 110:2507–2512

Ferrell JA, Mullahey JJ (2006) Effect of mowing and hexazinone application on giant smutgrass (*Sporobolus indicus* var. *pyramidalis*) control. Weed Technol 20:90–94

Ferrell JA, Mullahey JJ, Dusky JA, Roka FM (2006) Competition of giant smutgrass (*Sporobolus indicus*) in a bahiagrass pasture. Weed Sci 54:100–105

Hancock DW, Lacy RC, Stewart L, Tubbs RS, Kichler JM, Green TW, Hicks R (2010) The management and use of bahiagrass. University of Georgia. Bulletin 1362. extension.uga.edu/publications. Accessed: May 1, 2022

Hurdle NL, Grey TL, McCullough PE, Shilling D, Belcher J (2020) Bermudagrass tolerance of indaziflam PRE applications in forage production. Weed Technol 34:125–128

Kemp DR, King WM (2001) Plant competition in pastures–implications for management. Pages 85–102 in Tow PG, Lazenby A, eds, Competition and Succession in Pastures. Wallingford, UK: CABI Publishing

Kissel DE, Sonon LS (2008) Soil test handbook for Georgia (Bulletin 62). Athens, GA: University of Georgia Extension

Lacy RC, Morgan RN, Russell LA (2016) Tifton 85 Bermuda Grass Hay Budget. University of Georgia: Extension Ag Economics and Crop & Soil Science Departments. https://agecon.uga.edu/extension/budgets.html. Accessed: May 13, 2024

Littell R, Milliken G, Stroup W, Wolfinger R, Schabenberger O (2006) SAS for Mixed Models, 2nd Edn. Cary, NC: SAS Institute Inc.

McCaleb JE, Hodges EM, Kirk WG (1963) Smutgrass control. University of Florida IFAS Extension, Ona, FL. Circular S-149. 10 p.

Mislevy P, Martin FG, Hall DW (2002) West Indian dropseed/giant smutgrass (*Sporobolus indicus* var. *pyramidalis*) control in bahiagrass (*Paspalum notatum*) pastures. Weed Technol 16:707–711

Mislevy P, Shilling DG, Martin FG, Hatch SL (1999) Smutgrass (*Sporobolus indicus*) control in bahiagrass (*Paspalum notatum*) pastures. Weed Technol 13:571–575

Moore JE, Undersander DJ (2002) Relative forage quality: an alternative to relative feed value and quality index. Pages 16–28 in Proceedings of the 13th Annual Florida Ruminant Nutrition Symposium, January 2002, Gainesville, FL.

NOAA (2024) National Centers for Environmental information, Climate at a Glance: County Time Series https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/county/time-series Accessed May 15, 2024

Nolte S (2017) Smutgrass management in bermudagrass and bahiagrass pastures. Texas A&M AgriLife Extension Service, College Station, TX: Bulletin SCS-2017-18. http://publications.tamu.edu. Accessed: May 1, 2022

Quinn R (2024) DTN retail fertilizer trends. https://www.dtnpf.com/agriculture/web/ag/crops/article/2024/01/30/six-fertilizers-lead-prices-lower Accessed: 15 May 2024

Rana N, Sellers B, Ferrell J, MacDonald G, Silveira M, Vendramini J (2013) Impact of soil pH on bahiagrass competition with giant smutgrass (*Sporobolus indicus* var. *pyramidalis*) and small smutgrass (*Sporobolus indicus* var. *indicus*). Weed Sci 61:109–116

Rana N, Wilder B, Sellers B, Ferrell J, MacDonald G (2012) Effects of environmental factors on seed germination and emergence of smutgrass (*Sporobolus indicus*) varieties. Weed Sci 60:558–563

Regmi S, Devkota P, Sellers BA, Dubeux Jr. J, Sales CA R, Mathew S, Daramola OS (2023) Bahiagrass Response and Smutgrass Control with Hexazinone Co-applied with Liquid Urea Ammonium Nitrate. In: Proceedings of the 76th Annual Southern Weed Science Society Annual Meeting. pg 95. https://www.swss.ws/wp-content/uploads/2023_SWSS_Proceedings_Final-002.pdf

Secor W, Baxter L, Hancock G (2024) Bahiagrass Forage Enterprise Budget. University of Georgia Extension and Department of Agricultural and Applied Economics. https://agecon.uga.edu/extension/budgets.html Accessed: 13 May 2024.

Sellers BA, Ferrell JA (2011) The impact of mowing smutgrass control. The Florida Cattlemen and Livestock Journal. https://rcrec-ona.ifas.ufl.edu/media/rcrec-onaifasufledu/pdf/or6-2012.pdf. Accessed: 13 May 2024.

Sellers BA, Rana N, Dias JLC, Devkota P (2023) Smutgrass control in perennial grass pastures. University of Florida IFAS Extension: Bulletin SS-AGR-18/ AA261, Ona, FL.

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

Shay NJ, Baxter LL, Basinger NT, Schwartz BM, Belcher J (2022) Smutgrass (*Sporobolus indicus*) control in bahiagrass is improved with applications of herbicide and fertilizer. Weed Technol 36:700-707

Silveira ML, Vendramini JM, Sellers BA (2017) Nitrogen fertilizer source effects on bahiagrass responses. Crops Soils 50:4–9

Sollenberger LE (2019) Finding a solution to declining bahiagrass pastures. Hay & Forage Grower. https://hayandforage.com/article-2364-finding-a-solution-to-declining-bahiagrass-pastures.html. Accessed: May 15, 2024

USDA Soil Survey Staff. (2019). Web soil survey. United States Department of Agricultural and Natural Resource Conservation Service. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx Accessed: May 2, 2019

Vengris J, Drake M, Colby W, Bart J (1953) Chemical composition of weeds and accompanying crop plants. J Agron 45:213–218

Wallau M, Vendramini J, Dubeux J, Blount A (2010) Bahiagrass (*Paspalum notatum* Flueggé): overview and pasture management. University of Florida, IFAS Extension: Bulletin SS-AGR-332, Ona, FL. https://edis.ifas.ufl.edu/ag342. Accessed: May 1, 2022

Wilder B, Ferrell JA, Sellers BA, MacDonald GE (2008) Influence of hexazinone on 'Tifton 85' bermudagrass growth and forage quality. Weed Technol 22:499–501

Yarborough JK, Vendramini JM, Silveira ML, Sollenberger LE, Leon, RG, Sanchez JM, Filho CS (2017) Impact of potassium and nitrogen fertilization on bahiagrass herbage accumulation and nutrient concentration. J Agron 109:1099–1105

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

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}	Apr 7, 2020	Mar 15, 2021	April 8, 2020 16 mm	Mar 18, 2021 13 mm
POST	Hexazinone	0.98 kg ai ha^{-1}	Aug 7, 2020	Aug 30, 2021	Aug 10, 2020 15 mm	Aug 31, 2021 33 mm
Fertilizer (N and N+K)	ammonium nitrate, 34% N	56 kg N ha^{-1}	April 7, 2020 July 12, 2020 April 23, 2021	April 23, 2021 July 16, 2021 May 7, 2022	n/a	n/a
	muriate of potash, 60% K_2O	56 kg K2O ha^{-1}	July 16, 2021 May 7, 2022 July 7, 2022	July 7, 2022 May 25, 2023 July 28, 2023		

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

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

Treatment components[a]			Treatment expenses			Total expenses incurred over 3-years
Post	Pre	Fertilizer	Product	Application	Total	
			---$ 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
Bahiagrass renovation						$826
Bahiagrass renovation + two grazing seasons						$1,752

[a] Treatment components included PRE (preemergence, indaziflam, 0.28 kg ai ha^{-1}), POST (postemergence, 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 K_2O ha^{-1} applied as muriate of potash).

[b] Bahiagrass hay production, renovation, and grazing expenses calculated with the University of Georgia 2024 bahiagrass budget (Secor et al. 2024).

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

Table 3. Effect of herbicide, fertilizer, and mowing on smutgrass visual ground cover. Each effect x year combination represents the smutgrass coverage at the last harvest of the year compared to the smutgrass coverage at the study initiation.

Effect[a]	Year	ChiSq	P-value
Herbicide	1	571.04	<0.01 [b]
	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[c]	1	5.22	0.02
	2	59.62	<0.01
	3	145.96	<0.01

[a] Treatments included PRE (preemergence, indaziflam, 0.28 kg ai ha^{-1}), POST (postemergence, 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).

[b] Single degree of freedom contrasts were conducted on the mean of smutgrass ground cover within the effect and the smutgrass cover at study initiation.

[c] Mowing refers to complete biomass removal from the experimental area using a mower with bagger attachment. This consisted of clipping plots to 7.62 cm stubble height and every 28-35 days.

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

Table 4. Smutgrass visual ground cover in response to fertilizer and herbicide treatments.

Treatment components[a]			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	None	33	35	27	27	24*	22*
		N and N+K	29	22**	25*	25*	19**	22**
Hexazinone	None	None	34	5**	10**	9**	10**	15**
		N and N+K	26*	2**	7**	5**	10**	10**
	Indaziflam	None	32	7**	5**	9**	17**	12**
		N and N+K	28	-1**	8**	8**	10**	14**

[a] Treatment components included PRE (preemergence, indaziflam, 0.28 kg ai ha^{-1}), POST (postemergence, 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 K_2O ha^{-1} applied as muriate of potash).

[b] Difference from nontreated control at initiation at alpha 0.05 (*) and 0.01 (**). Note: standard error of the mean (SEM) = 5.6%

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press

Table 5. Bahiagrass visual ground cover in response to fertilizer and herbicide treatment.

Treatment components[a]			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
		N and N+K	73	81*	63	75	65	71
Hexazinone	None	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

[a] Treatment components included PRE (preemergence, indaziflam, 0.28 kg ai ha^{-1}), POST (postemergence, 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 K_2O ha^{-1} applied as muriate of potash).

[b] Difference from nontreated control at initiation at alpha 0.05(*) and 0.01 (**). Note: standard error of the mean (SEM) = 7.5%

https://doi.org/10.1017/wet.2024.99 Published online by Cambridge University Press