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Evaluation of chemical control and seasonal application options for smutgrass (*Sporobolus indicus*)

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Research Article

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Abstract

Smutgrass is a non-native perennial weed that is problematic because of its poor palatability to cattle and its difficulty to control once established. Limited literature exists to explain the effectiveness of herbicides other than hexazinone for smutgrass control and forage injury. This study aimed to evaluate seasonal applications of labeled herbicides used on forage for maximum smutgrass control. The second objective was to evaluate preemergent herbicides and hexazinone for their ability to control smutgrass germinating from seed. Hexazinone, nicosulfuron + metsulfuron-methyl, and glyphosate + imazapic were the most effective postemergence treatments, while quinclorac exhibited little activity on smutgrass. Common bermudagrass forage fully recovered from all treatments by 3 mo after treatment. Hexazinone, nicosulfuron + metsulfuron methyl, glyphosate, and imazapic were applied postemergence to smutgrass in spring, summer, and fall. Summer applications of hexazinone resulted in the greatest level of control, while spring treatments provided the least control. Applications of hexazinone or glyphosate resulted in the most effective smutgrass control. However, fall applications resulted in the least forage injury. Results of the study of preemergence herbicides indicate that treatments with indaziflam and hexazinone provide adequate control of germinating smutgrass seedlings in the greenhouse at 0.25×, 0.5×, and 0.75× of the lowest recommended labeled rate for seedling grass control. Indaziflam treatments prevented the emergence of any visible smutgrass seedling tissue, compared to hexazinone, which fully controlled the germinating seedlings by 21 d after treatment, whereas pendimethalin significantly reduced seedling numbers at the 0.5× and 0.75× rates.

Introduction

Smutgrass is a perennial, tuft-forming grassy weed that infests a significant portion of hectares in east Texas. Of the two varieties found within the United States, small smutgrass is the only smutgrass variety found in Texas (Shaw 2012; USDA-NRCS 2023). This problematic grass inhabits 54 counties, primarily in the southeast portion of the state (USDA-NRCS 2023).

Bermudagrass and bahiagrass are common forages in east Texas. Though bahiagrass out-competed small smutgrass at 4.5 and 5.5 pH with optimal growing conditions (Rana et al. 2017a), field conditions are rarely ideal for the forage. Bermudagrass production, however, is adversely affected by size and density of smutgrass. Bermudagrass forage quality has been shown to improve upon smutgrass removal (Smith et al. 1974).

Hexazinone (Velpar L VU; Bayer Environmental Science, Cary, NC) is currently recommended for postemergence control of smutgrass in perennial grass pastures. Research suggests that rates of 0.56, 0.84, 1.05, and 1.12 kg ha^{-1} have the potential to provide adequate control (Ferrell et al. 2006; Mislevy et al. 1999, 2002; Wilder et al. 2011), although lower application rates are highly variable (Wilder et al. 2011). Several environmental factors affect its efficacy. The label states to use lower rates on sand to sandy loam soils, and higher rates on clay loam to clay soils, and soil should be moist at the time of application (Anonymous 2019). Furthermore, Brooks (1980) reported that rainfall is the most significant factor that affects the performance of hexazinone as the roots take it up. This is supported by a report by Dias (2019), who concluded that a rate of 1.12 kg ha^{-1} should be recommended and that the highest hexazinone activity resulted when it was applied between mid-June and mid-August in Florida. This research demonstrates a different rainfall requirement than the Velpar L label, which indicates that 6.4 to 12.7 mm of rainfall within 2 wk is optimal for best performance

(Anonymous 2019). Further research is needed to learn how to best use this herbicide because the level of control is often variable. Thus, exploring other potential herbicide options for smutgrass control is warranted.

To prevent proliferation of smutgrass following postemergence control, a residual herbicide will be needed to control germinating seeds because they may remain viable for approximately 2 yr in soil (Currey et al. 1973). The effect of hexazinone on germinating seedlings is unknown; however, there is evidence that young smutgrass plants may be more susceptible to hexazinone than older plants (Wilder et al. 2011). Furthermore, the potential forage injury from a hexazinone application warrants the exploration of preemergent herbicide use.

Pendimethalin (Prowl H20; BASF Corporation, Research Triangle Park, NC) is a herbicide labeled for application to perennial pastures. This herbicide has been the common recommendation for the control of field sandbur (*Cenchrus spinifex*) (Nolte 2019), another problematic grassy weed. Indaziflam (Rezilon; Bayer Environmental Science) is a broad-spectrum preemergent herbicide used in a variety of perennial cropping systems to control both grass and broadleaf weeds that germinate from seed. Indaziflam has recently received federal registration for use in perennial pasture systems (Anonymous 2020) and has been shown to control weeds common to perennial pasture systems such as southern sandbur (*Cenchrus echinatus* L.) (Nolte et al. 2020), smooth crabgrass (*Digitaria ischaemum*), and annual bluegrass (*Poa annua*) (Brosnan and Breeden 2012). Furthermore, this herbicide has recently demonstrated the ability to help reduce smutgrass plant numbers when combined with a posteemergent herbicide.

A smutgrass infestation may have a negative effect on the quantity and quality of forages commonly used for livestock grazing (Ferrell et al. 2006). Thus, quality forage of these potentially productive acres is at risk for severe decline because of smutgrass infestations. Therefore, the objectives of this research were to 1) evaluate the efficacy of broadcast herbicides (hexazinone, nicosulfuron + metsulfuron methyl, glyphosate + imazapic) labeled for smutgrass control or suppression plus an herbicide (quinclorac) recently registered for use in forage and hay pastures; 2) evaluate the impact of herbicides (hexazinone, nicosulfuron + metsulfuron methyl, imazapic, and glyphosate) applied in three different seasons (spring, summer, and fall); and 3) evaluate preemergent herbicides and hexazinone in the greenhouse for their ability to control smutgrass germinating from seed.

Materials and Methods

Experiments 1 and 2

Experiment 1 was conducted near Richards, Texas (30.512417°N, 95.815667°W) in 2018 and repeated in 2019 at the same field site. Experiment 2 was conducted in 2019 at the Richards, Texas, location described above, and near Bellville, Texas (29.969167°N, 96.186250°W). At both locations, the pastures consisted of common bermudagrass, whereas approximately 60% of the forage included Pensacola bahiagrass at the Bellville location. For both experiments, the experimental design was a randomized complete block with three replications, including an untreated control in each replication. All herbicide treatments were applied with a backpack compressed air sprayer with TeeJet 8003 drift guard flat-fan nozzles (Spraying Systems Co., Glendale Heights, IL) calibrated to deliver 187 L ha^{-1}.

Visual smutgrass control was estimated using a scale of 0% as no control and 100% as total control, and forage injury as a combination of stunting and chlorosis using a scale of 0% as no injury and 100% as plant death. Data from both experiments were analyzed separately, and a similar procedure was used for both. All data were visually observed for normality and variance homogeneity and transformed as needed. Data were subject to ANOVA using R software (R Core Team 2019), and were analyzed for treatment by year interaction in Experiment 1, and treatment by location in Experiment 2. Means were separated using the *LSD.test* function under the AGRICOLAE package in R written by Hothorn et al. (2008).

Experiment 1. The objective of this experiment was to evaluate the efficacy of herbicide options labeled for the use of control or suppression of smutgrass. Herbicide treatments included hexazinone, nicosulfuron + metsulfuron methyl, nicosulfuron + metsulfuron methyl followed by nicosulfuron + metsulfuron methyl, imazapic + glyphosate, and quinclorac (Table 1). Hexazinone treatments were applied two separate times: once in the spring (A application) and once in the summer (B application), as separate plots. The low-rate follow-up treatment (C application) of nicosulfuron + metsulfuron methyl was made in late summer 1 mo after the initial high-rate treatment (B application). All other treatments were applied in the summer (B application). In 2018, visually estimated smutgrass groundcover within plots at the time of the A application averaged 33%, and 38% at the B and C applications, respectively. In 2019 the visual estimate of smutgrass groundcover within plots was 42% at the A application, and 44% at the B and C applications. Smutgrass height was not recorded in 2018 and ranged from 30.5 to 60.1 cm in all applications. Common bermudagrass height was not recorded in 2018, and ranged from 5 to 17.8 cm at all applications in 2019. Visual estimates of smutgrass control (Table 2) and bermudagrass injury (Table 3) were made using a 0% to 100% scale, with 0% being no injury and 100% complete mortality, at 5, 18, and 40 wk after the B application.

Experiment 2. The objective of this experiment was to evaluate labeled smutgrass control or suppression options across three seasons: spring (application A; made in April to May, 4 to 6 wk after spring green up occurred); summer (application B; made in June to July); and fall (application C; made in October, 4 wk before the average first frost date). All treatments were applied ahead of forecasted rain of 10 mm or greater within 7 d of the application. The experimental design was a randomized complete block with three replications, including an untreated control in each replication. Herbicide treatments included hexazinone, nicosulfuron + metsulfuron methyl, glyphosate, and imazapic (Table 4). A visual estimate of smutgrass groundcover within plots at the time of the A application was 35%, at the Richards location and 60% at the Bellville location. At B and C applications smutgrass groundcover was 41% at the Richards location and 60% at the Bellville location, and ranged from 30.5 to 60.1 cm in height at both locations and all application times. Common bermudagrass at the Richards location ranged from 5 to 17.8 cm in length, and both common bermudagrass and bahiagrass ranged from 7 to 15.3 cm in height at the Bellville site. All treatments were evaluated for bermudagrass injury 3 mo after treatment (MAT), and all treatments were evaluated for smutgrass control in spring 2020 after green up had occurred.

Experiment 3

An experiment was conducted to test the efficacy of hexazinone at 0.21, 0.42, and 0.63 kg ha^{-1}; pendimethalin at 0.53, 1.07, and

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Table 1. Herbicide application dates and rainfall amounts through 7 and 14 d after treatment in 2018 and 2019 for Experiment 1.[a,b]

Herbicide treatment	Rate	Treatment code	Application			Rainfall[c]	
			Year	Code	Date	7 DAA	14 DAA
	kg ha^{-1}					mm	
Hexazinone	0.84	A	2018	A	April 9	12	71
Hexazinone	0.84	B		B	May 23	0	1
Nicosulfuron + MSM	56.1, 15.8	B		C	July 3	5	41
Nicosulfuron + MSM	56.1, 15.8; 39.5, 10.5	B,C	2019	A	April 16	2	21
Imazapic + Glyphosate	0.21, 0.52	B		B	June 12	31	62
Quinclorac	0.42	B		C	July 30	13	13

[a]Abbreviations: DAA, days after application; MSM, metsulfuron methyl.
[b]Treatment and application codes: A, herbicides applied in April to May (4 to 6 wk after spring green up occurred); B, summer (herbicides applied in June to July); C, fall (herbicides applied in October, 4 wk before the average first frost date).
[c]Rainfall amounts are cumulative total rainfall received from the date of application up through 7 and 14 d after treatment.

Table 2. Control of smutgrass 5, 18, and 40 WAB, by herbicide treatment.[a,b]

Herbicide treatment	Rate	Application	Rating timing			
			2018	2019	Combined	
			5 WAB	5 WAB	18 WAB	40 WAB
	kg ha^{-1}		%			
Hexazinone	0.84	A	8 c	9 d	0 c	0 c
Hexazinone	0.84	B	23 b	68 b	6 bc	0 c
Nicosulfuron + MSM	56.1, 15.8	B	47 a	50 c	2 c	0 c
Nicosulfuron + MSM	56.1, 15.8; 39.5, 10.5	B,C	47 a	58 bc	12 b	10 b
Imazapic + Glyphosate	0.21, 0.52	B	62 a	83 a	65 a	52 a
Quinclorac	0.42	B	5 c	10 d	0 c	0 c

[a]Abbreviations: MSM, metsulfuron methyl; WAB, weeks after B application.
[b]Means within the same column followed by the same letters are not significantly different at the 5% probability level.

Table 3. Injury of common bermudagrass 5, 18, and 40 WAB, by herbicide treatment.[a,b]

Herbicide treatment	Rate	Application	Rating timing			
			2018		2019	
			5 WAB	10 WAB	5 WAB	10 WAB
	kg ha^{-1}		%			
Hexazinone	0.84	A	3 ab[b]	0 b	18 d	10 b
Hexazinone	0.84	B	0 b	0 b	67 a	22 a
Nicosulfuron + MSM	56.1, 15.8	B	0 b	0 b	37 c	12 b
Nicosulfuron + MSM	56.1, 15.8; 39.5, 10.5	B,C	0 b	0 b	45 bc	23 a
Imazapic + Glyphosate	0.21, 0.52	B	17 a	13 a	55 ab	28 a
Quinclorac	0.42	B	0 b	0 b	0 e	0 c

[a]Abbreviations: MSM, metsulfuron methyl; WAB, weeks after B application.
[b]Means within the same column followed by the same letters are not significantly different at the 5% probability level.

Table 4. Effect of treatment on control of smutgrass after spring, summer, and fall 2019 applications assessed at 2020 spring green up for Experiment 2.[a,b]

Herbicide treatment	Rate	Period applied					
		Spring		Summer		Fall	
		Richards	Bellville	Richards	Bellville	Richards	Bellville
	kg ha^{-1}	%					
Hexazinone	1.26	40 a	3	70 a	55 a	23 b	12 b
Nicosulfuron + MSM	56.1, 15.8	28 b	0	20 b	0 d	10 c	17 b
Glyphosate	0.52	0 c	0	10 c	37 b	52 a	15 b
Imazapic	0.21	0 c	0	12 c	15 c	57 a	25 a

[a]Abbreviation: MSM, metsulfuron methyl.
[b]Means within the same column followed by the same letters are not significantly different at the 5% probability level.

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1.6 kg ha^{-1}; and indaziflam at 18.25, 36.5, and 54.75 g ha ha^{-1} on smutgrass germinating from seed. Experiments were conducted in a greenhouse in a randomized complete block design with four replications and repeated over time. Each replication included an unsprayed control for comparison. A mixture of topsoil and sand in a 2:1 v/v ratio was sterilized and placed into 10-cm pots. All pots were subsurface irrigated before seeding. Twelve smutgrass seeds were placed on the soil surface following herbicide application to eliminate burying of any seed into soil (smutgrass seed will not germinate below the soil surface; Rana et al. 2017b). Natural light was supplemented with high-pressure sodium lights in the greenhouse for a 12/12-h day/night photoperiod. Greenhouse temperatures averaged 29/15 day/night. Herbicide treatments were applied using a single-nozzle track sprayer calibrated to deliver 140 L ha^{-1} from a TeeJet 8002 EVS flat-fan nozzle (Spraying Systems Co.) traveling 4.83 km h^{-1}.

All treatments were surface watered following application to activate the herbicide and then individually subsurface irrigated weekly. All pots were individually covered with clear plastic to retain soil moisture. The number of seedlings present per pot and visual estimates of percent chlorosis and percent stunting using a scale of 0% (no chlorosis or stunting) to 100% (complete plant death), were recorded every 7 d for 5 wk. All data were analyzed by ANOVA using R software (R Core Team 2019), and transformed as needed. The number of seedlings germinated in the treatments was compared against the untreated control using the *DunnettTest* function under the DescTools package in R written by Signorell et al. (2019). Chlorosis and stunting least square means were separated by Tukey's honestly significant difference test using the multcomp package in R written by Hothorn et al. (2008).

Results and Discussion

Experiments 1 and 2

Experiment 1. For Experiment 1, there was a significant ($P = 0.023$) treatment by year interaction for 5 wk after the B application (WAB); however, no significant ($P < 0.05$) interaction was observed for 18 and 40 WAB smutgrass control ratings. Consequently, data were analyzed separately by year for 5 WAB, and combined year for 18 and 40 WAB ratings. There were significant differences in smutgrass control between treatments at all rating timings. There was a significant treatment by year interaction for 5 WAB ($P < 0.0001$) and 10 ($P < 0.0001$) WAB injury ratings; therefore, data were analyzed separately by year, and separately by rating timings (5 WAB and 10 WAB).

The B application of hexazinone provided greater levels of control in 2019 (68%) than in 2018 (23%), whereas the A application provided the least control of any herbicide (8%; Table 2). Results of hexazinone treatments in this study confirm the findings of previous studies. For example, Wilder (2009) also observed relatively poor control of smutgrass when using a 0.81 kg ha^{-1} rate of hexazinone applied in the summer. Brecke (1981) observed variable control (90% and 79%) in separate locations when using a rate of 0.8 kg ha^{-1} hexazinone. Interestingly, Mislevy et al. (1999) found that a rate of 0.56 kg ha^{-1} provided 65% control in one year, but 89% control of smutgrass the next. These variable results could be from the result of rainfall after herbicide application. Research by Dias (2019) demonstrated in Florida that 10 to 75 mm of rainfall within 7 d following hexazinone treatment provided the best opportunity for giant smutgrass control. Also confirming findings by Wilder (2009), Dias (2019) concluded that a rate of 1.12 kg ha^{-1} hexazinone should be used to achieve the most consistent control.

Nicosulfuron + metsulfuron methyl, with and without follow-up applications provided similar results in both years (47% to 58%; Table 2), however, sequential applications resulted in a reduction in seed heads at 18 WAB. This treatment performed similar to other studies when applied on tufted grassy perennial weeds. Grichar and Foster (2019) observed no greater than 45% control with sequential applications to King Ranch bluestem (*Bothriochloa ischemum* var. *songarica*). Vasey's grass (*Paspalum urvillei*) incurred ground cover reductions when nicosulfuron + metsulfuron methyl was applied. Jeffries et al. (2017) concluded, however, that inputs across multiple years would be needed to achieve complete control.

At 5 WAB in both 2018 and 2019, imazapic + glyphosate treatments provided the greatest level of control at 62% and 83%, respectively (Table 2). Imazapic + glyphosate performed the best across all treatments in both years. Using this treatment to control downy brome, Morris et al. (2016) found that treatments reduced perennial grass cover in the first year after application, but it recovered in the following year. Others (Nyamai et al. 2011; Priest and Epstein 2011) have demonstrated the utility of this combination in assisting the establishment of native perennial grasses. Although it may be effective for use in controlling smutgrass, this premix herbicide combination is expensive, whereas glyphosate is significantly cheaper than imazapic. Experiment 2 included treatments of glyphosate and imazapic individually to observe their efficacy.

Quinclorac provided very little control (10%) over the entirety of the experiment. With proper timing it can provide control of annual grasses, however, it will not control plants that grow from rhizomes (Rector et al. 2018). On switchgrass, a perennial warm-season bunchgrass, quinclorac caused injury at establishment but plants recovered by 8 wk after treatment (Curran et al. 2011).

The results from our experiments in 2018 show similarities to those reported by Wilder et al. (2008), who showed that treatments with 0.25, 0.5, and 1.0 kg ha^{-1} of hexazinone applied to Tifton-85 hybrid bermudagrass had recovered to normal growth by 6 wk after treatment. Meyer and Baur (1979) observed a general increase in coastal bermudagrass ground cover when treatments with hexazinone at 1.1 kg ha^{-1} were applied. Our 2019 results exhibited significant injury from hexazinone when applied at the B application (Table 3), but they also demonstrate an increase in smutgrass control over 2018. As with the higher smutgrass control, this may be due to more rainfall (31 mm) within 7 d following the B application (Table 1). Lack of rainfall (1 mm) within 14 d and considerable cloud coverage 5 wk following the B application in 2018 probably led to a decrease in hexazinone activity compared with the 2019 B application. These conditions may explain the increase in bermudagrass injury to all treatments except quinclorac in 2019 compared with 2018.

Experiment 2. For Experiment 2, a significant ($P < 0.001$) treatment by location interaction was observed for spring, summer, and fall applications and data were therefore analyzed separately by location. For bermudagrass injury, there was a significant treatment by location interaction for 3 mo after the spring (A) application ($P < 0.001$) and 3 mo after the summer (B) application ($P = 0.0346$), therefore, data were analyzed by location. A significant difference in treatments was detected for bahiagrass injury.

Of the spring (A) applications, no treatment at the Richards location provided more than 40% control, and only hexazinone and nicosulfuron + metsulfuron methyl provided any control at

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Table 5. Herbicide application dates and rainfall amounts through 7 and 14 d after treatment at both locations for Experiment 2.[a]

	Application		Rainfall[b]	
Location	Code[c]	Date	7 DAA	14 DAA
			mm	
Richards	A	April 16	2	21
	B	June 12	31	62
	C	October 23	1	2
Bellville	A	May 17	1	6
	B	July 22	4	27
	C	October 23	276	308

[a]Abbreviation: DAA, days after application.
[b]Rainfall amounts are cumulative total rainfall received from the date of application up through 7 and 14 d after treatment.
[c]Application codes: A, herbicides applied in April to May (4 to 6 wk after spring green up occurred); B, summer (herbicides applied in June to July); C, fall (herbicides applied in October, 4 wk before the average first frost date).

the spring 2020 rating (Table 4). For summer (B) applications, hexazinone provided the greatest level control at both the Richards (70%) and Bellville (55%) locations. Smutgrass control from fall (C) applications was lower with hexazinone at both locations, and imazapic resulted in the greatest level of control of any treatment at the Richards (57%) and Bellville (25%) locations.

The forage in all treatments were fully recovered by the spring rating. No application injured bermudagrass by more than 17% (glyphosate) at the Richards site 3 mo after the spring (A) application, whereas imazapic injured bermudagrass the most (43%) at the Bellville location. No other treatments resulted in more than 12% injury. At 3 MAB, bermudagrass had recovered at the Richards location, while the nicosulfuron + metsulfuron methyl treatment resulted in 10% injury at the Bellville location. All treatments except hexazinone injured bahiagrass following the A and B applications, with nicosulfuron + metsulfuron methyl producing in the greatest amount of injury (90%) 3 mo after the A application, and glyphosate producing the greatest injury (68%) 3 mo after the B application.

The differences in hexazinone performance at various locations is not uncommon (Brecke 1981; Mislevy et al. 1999), as mentioned above, but this is not always the case (Dias 2019). The difference in smutgrass control by hexazinone for spring and summer results are similar to those reported by Mislevy et al. (1999), yet the difference is drastically different when comparing fall applications. Furthermore, the forage injury results reported here differ from those reported by Ferrell et al. (2006) that a general reduction in bahiagrass biomass occurred when hexazinone was applied to low and medium densities of smutgrass at 1.12 kg ha^{-1}. Most of these differences may be explained by total rainfall received 7 and 14 d after application (DAA) (Table 5).

Spring applications of hexazinone performed better at the Richards location, which received adequate rainfall (21 mm) for herbicide incorporation by 14 DAA, even though a lack of adequate rainfall (2 mm) was recorded 7 DAA (Table 5). This is significant because the spring application of 0.84 kg ha^{-1} hexazinone at the same location, which received the same rainfall, performed poorly in Experiment 1. This demonstrates an increase in efficacy and a reduction in variability when higher application rates are used. The 1.26 kg ha^{-1} application at the Bellville location performed poorly, partly because there was inadequate rainfall (6 mm) within 14 DAA. The summer treatment of hexazinone fared better, perhaps due to adequate rainfall occurring within 7 DAA (31 mm) at the Richards location, and 14 DAA (27 mm) at the Bellville location. Fall (C) applications of hexazinone performed as expected due to drought conditions that occurred for 8 wk prior to applications at the Bellville location. Furthermore, an excessive amount of rainfall following the application may have washed hexazinone through the soil profile. However, at the Richards location glyphosate and imazapic exhibited similar results (Table 4).

The results we recorded agree with the rainfall requirements that Dias (2019) deemed necessary for greater hexazinone activity on giant smutgrass, although results from our study demonstrate comparably lower overall performance, indicating that other factors may be at play. Many environmental factors affect herbicidal performance (Kudsk 2017; Kudsk and Kristensen 1992). Brooks (1980) noted that temperature can affect not just performance, but that higher temperatures promote an increase in water uptake (Kramer 1940), and therefore, hexazinone uptake. Overall, the results from our experiments support the concept that adequate rainfall that occurs within 14 d after application is important for achieving the greatest hexazinone activity possible, but this differs from 7 d after application that Dias (2019) reported. Furthermore, our results support the statement by Brooks (1980) that rainfall is the most significant factor that affects herbicide performance. This research also shows that using the rate of 1.26 kg ha^{-1} may lead to less variability in smutgrass control and demonstrates the need for experiments in controlled environments to ensure equal amounts of rainfall to evaluate application timing.

Experiment 3

Results of pendimethalin treatments were variable, but significant chlorosis and stunting occurred, and at the higher rates, seedling survival was reduced. No treatment of pendimethalin provided complete control; however, by 14 DAT fewer seedlings were observed at all rating times except for the 0.53 kg ha^{-1} rate (Table 6). Rates of 1.07 and 1.6 kg ha^{-1} caused the greatest initial stunting (>85%) of the pendimethalin treatments (Table 7). The most stunting and chlorosis were observed at 28 DAT for all pendimethalin rates, with the exception of stunting from the 0.53 kg ha^{-1} rate at 35 DAT (Tables 7 and 8).

The variability in control we observed when pendimethalin was applied to smutgrass was also reported by Dear et al. (2006) who observed moderate to severe injury and reduced shoot and root weights from perennial seedlings treated with 0.6 kg ha^{-1} pendimethalin. Although efficacy from rates of pendimethalin in this study was unsatisfactory, there does not appear to be a general trend of weed recovery between rating times from these treatments. Therefore, competition in a field setting from forages may not allow the injured seedling to recover or survive.

At 7 DAT, no herbicide treatment resulted in significantly fewer smutgrass seedlings than the control; however, by 14 DAT all treatments provided at least partial control (≤17% of control). Stunting was present at all observations up until total control, and chlorosis was present at all observations except for the 0.21 kg ha^{-1} rate at 7 DAT. The 0.63 kg ha^{-1} rate of hexazinone caused the least stunting, yet the quickest control. All treatments of hexazinone provided complete control by 21 DAT. Our results may help explain findings by Rana et al. (2015) that treatments of hexazinone reduced smutgrass stands following pasture renovation, as seedlings appear to be susceptible to hexazinone.

Treatments with indaziflam resulted in no germination at any rate. This is not surprising due to the action of indaziflam (Brabham et al. 2014) and the rates selected. The highest rate

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Table 6. Smutgrass seedling emergence at 7, 14, 21, 28, and 35 d after treatment, as influenced by herbicide treatment and reported as percent of the untreated control.[a,b]

		Smutgrass seedling emergence				
Herbicide treatment	Rate	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT
	ai ha^{-1}	% of untreated control				
Pendimethalin	0.53 kg	93	83	81	79	79
Pendimethalin	1.07 kg	100	67*	47*	24*	24*
Pendimethalin	1.6 kg	93	67*	56*	50*	44*
Indaziflam	18.25 g	0*	0*	0*	0*	0*
Indaziflam	36.5 g	0*	0*	0*	0*	0*
Indaziflam	54.75 g	0*	0*	0*	0*	0*
Hexazinone	0.21 kg	90	17*	0*	0*	0*
Hexazinone	0.42 kg	87	3*	0*	0*	0*
Hexazinone	0.63 kg	107	0*	0*	0*	0*

[a]Abbreviation: DAT, days after treatment.
[b]An asterisk (*) indicates a significant difference from the untreated control according to Dunnett's test ($\alpha = 0.05$).

Table 7. Stunting of emerged smutgrass seedlings at 7, 14, 21, 28, and 35 d after treatment, as influenced by herbicide treatment.[a,b,c]

		Stunting				
Herbicide treatment	Rate	7 DAT	14 DAT	21 DAT	28 DAT[d]	35 DAT[d]
	ai ha^{-1}	%				
Pendimethalin	0.53 kg	45 b	55 a	60 b	59	60
Pendimethalin	1.07 kg	89 a	84 a	78 a	56	54
Pendimethalin	1.6 kg	86 a	88 a	76 a	75	73
Hexazinone	0.21 kg	18 c	30 b	–	–	–
Hexazinone	0.42 kg	73 a	19 b	–	–	–
Hexazinone	0.63 kg	20 c	–	–	–	–

[a]Abbreviation: DAT, days after treatment.
[b]Means followed by the same letter within a column are not significantly different at $P > 0.05$.
[c]A dash (–) indicates that values are absent where no seedlings were observed.
[d]No significant differences were detected when subject to ANOVA at $P > 0.05$.

Table 8. Chlorosis of emerged smutgrass seedlings at 7, 14, 21, 28, and 35 d after treatment, as influenced by herbicide treatment.[a,b,c]

		Chlorosis				
Herbicide treatment	Rate	7 DAT	14 DAT[d]	21 DAT[d]	28 DAT[d]	35 DAT[d]
	ai ha^{-1}	%				
Pendimethalin	0.53 kg	4 b	24	50	68	60
Pendimethalin	1.07 kg	6 b	18	59	53	44
Pendimethalin	1.6 kg	0 b	43	55	68	55
Hexazinone	0.21 kg	0 b	39	–	–	–
Hexazinone	0.42 kg	66 a	20	–	–	–
Hexazinone	0.63 kg	6 b	–	–	–	–

[a]Abbreviation: DAT, days after treatment.
[b]Means followed by the same letter within a column are not significantly different at $P > 0.05$.
[c]A dash (–) indicates that values are absent where no seedlings were observed.
[d]No significant differences were detected when subject to ANOVA at $P > 0.05$.

selected for this study was the lowest recommended use rate by the current product label (Anonymous 2020). This could explain the lack of germination observed in these treatments, even at the lowest treatment rate. Field trials evaluating indaziflam, pendimethalin, and hexazinone will be a crucial part of future research, because all three herbicides have the potential for controlling germinating smutgrass seedlings.

Practical Implications

Our findings indicate that hexazinone at 1.26 kg ha^{-1} applied in the summer when rainfall was most likely, was the most preferable application for smutgrass control. This research supports advice on the Velpar L label that rainfall after application optimizes hexazinone performance. Improved efficacy of hexazinone applications will be reliant upon adequate soil moisture before treatment, as indicated by the herbicide label, and adequate rainfall (10 to 75 mm) within 14 d after application. Furthermore, these findings indicate that follow-up management techniques such as a repeat application are needed to improve smutgrass control the following growing season. Although glyphosate and imazapic provided moderate levels of control when applied in the fall, imazapic produced greater injury to the forage. Thus, future research should focus on evaluating multiple glyphosate rates in a search for a rate that provides adequate smutgrass control and transient forage injury. Regardless of the herbicide one chooses for

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postemergence smutgrass control, preemergent applications of hexazinone or indaziflam could be effective for reducing future seedling populations.

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