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Effectiveness of integrating mowing and systemic herbicides applied with a weed wiper for *Sporobolus indicus* var. *pyramidalis* management in Florida

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Research Article

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Abstract

Giant smutgrass [*Sporobolus indicus* (L.) R. Br. var. *pyramidalis* (P. Beauv.) Veldkamp] is an invasive species in grasslands, and herbicide application has been the most efficient management method to suppress this weed. Experiments were conducted in 2017 and 2018 to determine the effects of wiping glyphosate and hexazinone on *S. indicus* var. *pyramidalis*. A dose–response experiment using a handheld weed wiper was established with 20 treatments comprising two herbicides (glyphosate and hexazinone), uni- and bidirectional wiping methods, and 5 herbicide concentrations (6.25% v/v, 12.5% v/v, 25.0% v/v, 50.0% v/v, and 100% v/v basis). Data were collected 30 and 60 d after treatment (DAT). An ATV-mounted roto-type weed-wiper experiment was established in a strip-plot arrangement, with mowing as the horizontal strip, the wiping method (unidirectional vs. bidirectional) randomized as the vertical strip with three dosages of each herbicide for a total of 12 wiping treatments. Data were collected at 35 and 90 DAT. The percent plant mortality was calculated using differences in pre- and posttreatment plant counts. ANOVA and log-logistic linear regression were used to analyze the data. The dose–response experiment showed that *S. indicus* var. *pyramidalis* mortality increased with herbicide concentration, and mortality was greater with the bidirectional wiping method compared with the unidirectional method. Treatments wiped bidirectionally with glyphosate at 70% v/v, hexazinone at 30% v/v, and hexazinone at 60% v/v resulted in *S. indicus* var. *pyramidalis* mortality ranging from 75% to 98% by 90 DAT across all locations. The ATV-mounted weed-wiper experiment showed that mowing before herbicide application with weed wipers decreased the efficacy of both herbicides. Overall, both experiments indicate that *S. indicus* var. *pyramidalis* should be wiped bidirectionally using either glyphosate (70% v/v) or hexazinone (at least 30% v/v) to obtain satisfactory control. Further work should be conducted to determine whether seasonality impacts the response of *S. indicus* var. *pyramidalis* to mowing and the application of these herbicides.

Introduction

Giant smutgrass [*Sporobolus indicus* (L.) R. Br. var. *pyramidalis* (P. Beauv.) Veldkamp] is an invasive species and one of the most problematic grass weed species in grasslands in Florida (Rana et al. 2012; Shay et al. 2022; Webster 2011). It is a perennial tussock-type grass that is commonly found in open areas, disturbed waste areas, and bahiagrass (*Paspalum notatum* Fluggé) pastures. Moreover, the Florida Exotic Pest Plant Council (FLEPPC) lists *S. indicus* var. *pyramidalis*. as a Category I species, implying that this species is increasing in number and causing ecological harm (FLEPPC 2019).

Cattle tend to avoid mature *S. indicus* var. *pyramidalis*, although young plants can be grazed. According to Mullahey (2000) and Ferrell and Mullahey (2006), cattle will readily consume tender regrowth of *S. indicus* var. *pyramidalis* when it is managed intensively, mowed, or burned. After mowing and burning, cattle will graze on *S. indicus* var. *pyramidalis* for about 2 wk, before the weed becomes unpalatable. Additionally, young *S. indicus* var. *pyramidalis* shoots have similar nutritive value as *P. notatum* (Mullahey 2000). Several weed control methods have been investigated, such as cultivation (McCaleb et al. 1963), burning (Walter et al. 2013), and

Management Implications

The handheld weed wiper appears to be a promising alternative control tool for an integrated *Sporobolus indicus* var. *pyramidalis* (giant smutgrass) long-term management plan in grasslands sprayed with glyphosate and hexazinone. Bidirectional wiping increases *S. indicus* var. *pyramidalis* mortality and control; hence, these herbicides should be applied bidirectionally to optimize *S. indicus* var. *pyramidalis* management when using this technology. However, because glyphosate is considerably cheaper compared with hexazinone, glyphosate is likely to be the preferred option. Mowing *S. indicus* var. *pyramidalis* plants to a 15-cm stubble height 21 d before herbicide application decreases herbicide efficacy, especially when there is little difference between the height of the target species and the desirable forage. Therefore, mowing before *S. indicus* var. *pyramidalis* treatment with either glyphosate or hexazinone using a weed wiper during the peak growing season is an unjustified expense and is not recommended. Future research should investigate the effects of additional concentrations, application timings, weed-wiper height, and different wiper applicators and models, as well as other weed control methods integrated with the use of weed wipers for short- and long-term *S. indicus* var. *pyramidalis* management in Florida.

grazing management (Mullahey 2000; Walter et al. 2013); however, effective management has mostly been accomplished using herbicides (Rana et al. 2012; Shay et al. 2022).

Glyphosate and hexazinone are the only two active ingredients labeled for use in grasslands in Florida that provide effective control of *S. indicus* var. *pyramidalis*. Hexazinone is absorbed by plant roots and foliage and is primarily translocated through the apoplast and xylem (McNeil et al. 1984; Shaner 2014). It is the only selective chemical control option that can be broadcast over the tops of *P. notatum* and bermudagrass [*Cynodon dactylon* (L.) Pers.] pastures (Mislevy et al. 2002). Although effective *S. indicus* var. *pyramidalis* control with hexazinone at 1.12 kg ai ha^{-1} has been reported previously (Ferrell et al. 2006; Rana et al. 2015; Wilder et al. 2011), it can be prohibitively expensive for some cattle operations, with costs exceeding US\$100 ha^{-1} (Ferrell et al. 2006). Furthermore, Ferrell et al. (2006) observed that control with hexazinone should not be employed until the *S. indicus* var. *pyramidalis* density is greater than 35%, which may result in forage losses until this economic threshold is attained.

Glyphosate is a broad-spectrum, nonselective, postemergence herbicide (Shaner 2014). In addition, it translocates efficiently in plants, primarily in the symplast (Shaner 2014), resulting in the death of both the aboveground and belowground portions of susceptible treated plants (Larsen 1987). These characteristics make glyphosate highly effective against perennial and annual weeds; however, due to glyphosate's lack of selectivity, its use is generally limited to preplant, post-directed, and postharvest applications for weed control (Nandula et al. 2008). Nevertheless, glyphosate can be selective if specialized equipment such as a weed wiper is used to apply the herbicide to specific plants while avoiding others.

Herbicide application with weed wipers provides an excellent opportunity to selectively manage difficult to control weed species in pastures. Weed wipers can be useful in pasture production systems, because cattle consume forage and typically avoid weeds, resulting in a height difference between weeds and desirable forages, allowing for targeted, accurate placement of herbicides on weeds (Johnson 2011). An additional advantage of this system is that it could allow for selective weed control in mixed swards of grass and legume forages and allows application adjacent to susceptible crops (Johnson 2011; Moyo et al. 2022). The amount of herbicide used by weed wipers is lower compared with broadcast application of herbicides and eliminates spray-particle drift concerns surrounding broadcast applications. However, the uniformity and quantity of herbicide output from weed wipers are constrained by the lack of a precise and easy to use mechanism for assessing herbicide deposition compared with known quantities in calibrated broadcast systems (Harrington and Ghanizadeh 2017).

Additionally, effective management of hard to control perennial invasive plants has long been recognized as requiring long-term integrated weed management (IWM) strategies (Benz et al. 1999; Miller 2016). The integration of mowing with systemic herbicides has been shown to effectively control other difficult to control perennial and invasive species (Allen et al. 2001; Beck and Sebastian 2000; Renz and DiTomaso 2006). Mowing has been suggested to enhance control of herbicide applications, because it changes the canopy structure of plants and improves herbicide contact on lower leaves (Hunter 1996), where it can preferentially be translocated to the root system (Renz and DiTomaso 2006). In addition, mowing may influence some physiological, biological, and morphological characteristics of plants, thus altering herbicide deposition patterns, absorption, or translocation in resprouting shoots (Renz and DiTomaso 2006). Thus, we hypothesized that mowing before glyphosate and hexazinone application with weed-wiper equipment will provide greater *S. indicus* var. *pyramidalis* control than either herbicide applied alone. Although hexazinone is not labeled to be applied with a weed wiper in grassland systems, and we did not expect it to be as foliarly active as glyphosate on *S. indicus* var. *pyramidalis*, we were still interested in investigating how it would perform in this study.

Given the need to develop new alternative IWM strategies to effectively manage *S. indicus* var. *pyramidalis* infestations, the objectives of this study were to determine (1) the effects of herbicide (glyphosate and hexazinone), wiping method (uni- and bidirectional), and concentration (v/v basis) on *S. indicus* var. *pyramidalis* control using handheld weed-wipers; and (2) the effects of mowing before uni- or bidirectional glyphosate or hexazinone application with field-scale weed-wiper equipment.

Material and Methods

Handheld Weed-Wiper Dose–Response Experiment

Field experiments were conducted in *P. notatum* pastures located at Bowling Green, FL, in 2017 (27.609578, 81.867939) and 2018 (27.606644, 81.867797). Both locations were naturally infested with *S. indicus* var. *pyramidalis*, with ground cover ranging from 20% to 50% throughout the experimental areas. The predominant soil at the 2017 site was a Sparr fine sand (loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults) with 1.75% organic matter and soil pH of 4.8; whereas the predominant soil at the research site in 2018 was a Farmton fine sand (sandy, siliceous, hyperthermic Arenic Ultic Alaquods) with 1.5% organic matter and soil pH of 5.2. Monthly rainfall and yearly totals for 2017 and 2018 were obtained from the weather station located at

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Table 1. Monthly rainfall (mm), yearly totals (mm), and average temperature (C) recorded at the weather stations located at the Range Cattle Research and Education Center (RCREC), near Ona, FL, and Buck Island Ranch, near Lake Placid, FL, in 2017 and 2018

	RCREC					Buck Island Ranch				
	Precipitation			Temperature		Precipitation			Temperature	
Month	2017	2018	20-yr average	2017	2018	2017	2018	20-yr average	2017	2018
	mm			C		mm			C	
January	26	69	46	17	14	13	25	42	17	15
February	42	13	47	19	21	12	17	45	19	21
March	35	12	61	19	17	13	39	68	19	18
April	2	61	55	22	22	66	88	57	22	22
May	44	344	94	25	24	50	159	101	25	23
June	321	126	207	26	26	255	213	212	26	26
July	144	126	173	27	27	146	280	180	27	27
August	213	168	228	27	27	249	56	178	27	27
September	220	131	181	26	27	314	33	180	27	27
October	36	39	51	23	25	166	29	65	24	24
November	21	60	40	20	21	46	14	44	21	21
December	18	163	51	18	18	31	71	50	18	18
Total	1,122	1,312	1,234	—	—	1,361	1,023	1,222	—	—

the Range Cattle Research and Education Center (RCREC; ~20 km from the experimental area) and are presented in Table 1.

Treatments consisted of a 2 × 2 × 5 factorial arrangement of two herbicides (glyphosate and hexazinone), two wiping methods (unidirectional or bidirectional), and five concentrations (% v/v basis) distributed in a randomized complete block design with four replications. A nontreated control was also included. Experimental units were 3 by 8 m, and all *S. indicus* var. *pyramidalis* clumps within plots were treated when the total number of clumps was fewer than 10, whereas a maximum of 10 clumps per plot was treated in highly infested plots.

Unidirectional applications consisted of one pass (wiped once) of the handheld wiper from the lower third (15-cm height) to the top of the *S. indicus* var. *pyramidalis* canopy, whereas bidirectional applications consisted of the same procedure but were employed twice in opposite directions. Glyphosate (Cornerstone®, 356 g ae L^{-1}, Winfield Solutions, St Paul, MN) and hexazinone (Velpar® L, 240 g ai L^{-1}, DuPont, Wilmington, DE) concentrations were 6.25% v/v, 12.5% v/v, 25.0% v/v, 50.0% v/v, and 100% v/v. Each concentration treatment for each herbicide was applied using a different nap paint roller (Wagner's Smart Roller, 18.5-cm roller length and 650-ml reservoir, Plymouth, MN) to avoid contamination from other treatments. Once the paint roller tubes were filled with the appropriate herbicide solution, the roller was saturated by using the trigger mechanism. The trigger was deployed between each *S. indicus* var. *pyramidalis* clump to ensure uniform application.

Herbicide treatments were applied on August 16, 2017, and August 6, 2018.

Because applications using a weed wiper are not as precise as applications with conventional broadcast sprayers, uniformity among treatments was inspected by constantly ensuring that the roller was evenly wet. Plants were approximately 45-cm tall at the time of application in both years. Natural rainfall within the first 7 DAT at the RCREC was 50 and 47 mm for 2017 and 2018, respectively, and occurred within 4 DAT in both years. *Sporobolus indicus* var. *pyramidalis* control was assessed at 30 and 60 DAT by determining the percentage of plant mortality using pre- and posttreatment plant counts. Differences in pre- and posttreatment plant counts were used to determine the percentage of plant mortality. Plants were considered dead when completely lacking green tissues. Assessments beyond 60 DAT were not conducted, as previous research has shown that *S. indicus* var. *pyramidalis* control at 120 and 365 DAT was comparable to control at 60 DAT (Mislevy et al. 2002). The number of *S. indicus* var. *pyramidalis* plants treated in each plot was recorded before herbicide application and were assessed for mortality at 30 and 60 DAT.

Normality, independence of errors, and homogeneity of variance were visually examined for percent plant mortality at 30 and 60 DAT, and no transformation was necessary. The effects of herbicides and their interaction with herbicide concentration were modeled using nonlinear regression models in R software v. 3.4.3 (R Core Team 2014). The effective concentration needed to provide 70% plant mortality (ED_{70}) was derived from a two-parameter log-logistic regression model using the *ED* function in the DRC package in R (Equation 1):

$$Y = exp[b(log\ x - log\ e)] \quad [1]$$

where Y is the response variable (percent plant mortality at 30 and 60 DAT), x is herbicide concentration (% v/v basis), b is the relative slope at the inflection point, and e is the inflection point (ED_{70}) of the fitted line. Model selection was based on Akaike's information criterion (AIC) in the QPCR package in R (Ritz and Spiess 2008). Additionally, a lack-of-fit test at the 95% level ($P \leq 0.05$) comparing the nonlinear regression models to ANOVA was conducted to test the appropriateness of model fit (Ritz and Streibig 2005). Differences among parameter estimates were compared using standard error (SE), *t*-, and *F*-tests at the 5% significance level (Knezevic et al. 2007).

ATV-mounted Weed-Wiper Experiment

Experiments were conducted at four sites in *P. notatum* pastures located in Myakka, Lake Placid (Buck Island Ranch), and Ona (RCREC), FL, in 2017 and 2018. Research locations that shared the same pasture were adjacent to each other. Specifics of each research site including their soil characteristics, application dates, and basic *S. indicus* var. *pyramidalis* information are provided in Tables 1 and 2. Natural rainfall recorded within the first 7 d after herbicide applications was 68, 24, 8, and 30 mm for Myakka, Buck Island

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Table 2. Research sites, locations, and soil characteristics

Research site	Location	Coordinates	Soil series	Soil taxonomy	Soil pH	Soil OM[a]
						—%—
Myakka	Myakka	27.386633, 82.069422	Delray	Loamy, siliceous, superactive, hyperthermic Grossarenic Argiaquolls	7.0	3.5
Buck Island (site 1)	Lake Placid	27.191447, 81.205175	Immokalee sand	Sandy, siliceous, hyperthermic Arenic Alaquods	4.5	1.5
Buck Island (site 2)	Lake Placid	27.19125, 81.202475	Immokalee sand	Sandy, siliceous, hyperthermic Arenic Alaquods	4.5	1.5
RCREC[b]	Ona	27.380811, 81.947178	Smyrna sand	Sandy, siliceous, hyperthermic Aeric Alaquods	5.5	2.2

[a]OM, organic matter.
[b]RCREC, Range Cattle Research and Education Center.

Table 3. Dates for mowing operations, treatment applications, treatment assessments, initial *Sporobolus indicus* var. *pyramidalis* cover and height, and weed-wiper height at Myakka, Buck Island, and Range Cattle Research and Education Center (RCREC) in Florida

Research site	Mowing	Wiper application	35 DAT[a] assessment	90 DAT[a] assessment	Initial cover	Average height	Wiper height
					— % —	——— cm ———	
Myakka	06/27/2017	08/02/2017	09/01/2017	10/31/2017	70	60	30
Buck Island (site 1)	07/05/2017	08/09/2017	09/08/2017	11/07/2017	70	55	30
Buck Island (site 2)	07/17/2018	08/28/2018	09/24/2018	11/15/2018	70	50	30
RCREC	09/06/2018	09/27/2018	10/24/2018	01/09/2019	≥90	45	28

[a]DAT, days after treatment.

(site 1), Buck Island (site 2), and RCREC, respectively, as recorded by weather stations located at the RCREC and Buck Island Ranch.

Each experiment was established in a randomized strip-plot design replicated four times, with mowing treatment as the horizontal strip and wiping treatment randomized as the vertical strip, similar to the experimental design described by Kyser et al. (2013). Wiping treatments consisted of two herbicides (glyphosate and hexazinone) at three concentrations each (17.5% v/v, 35% v/v, and 70% v/v for glyphosate and 15% v/v, 30% v/v, and 60% v/v for hexazinone) applied using two methods (uni- and bidirectionally).

Mowed plots (horizontal strips) were 80-m wide by 18-m long (1,440 m^2). These were crossed by the vertical wiping treatment strips, which were 6-m wide by 36-m long (crossing both mowed and not mowed strips), making individual herbicide treatment subplots 6-m wide by 18-m long (108 m^2, experimental unit) with a 12-m aisle between replications. Therefore, each replication included a total of 24 experimental units plus 2 nontreated controls (mowed and not mowed) per replication. Mowing was performed 21 d before herbicide application to a stubble height of 15 cm. Herbicide treatments were applied using an ATV-drawn roto-type weed wiper (Grass Works Manufacturing, Strafford, MS). Mowing and herbicide application dates, as well as other relevant application information, are provided in Table 3. Cattle were removed from the pasture where the experiments were established before mowing and then allowed access 1 wk before herbicide treatment application to potentially increase the difference in height between the *S. indicus* var. *pyramidalis* and *P. notatum* plants. The ATV-drawn roto-type weed-wiper height was adjusted to minimize contact and damage to *P. notatum* (Table 3).

Diagonal line transects were established in each subplot, and the number of *S. indicus* var. *pyramidalis* plants touching the lines was counted before herbicide application. The same line transects were evaluated at 35 and 90 DAT to determine the number of live *S. indicus* var. *pyramidalis* plants posttreatment. Plants were considered dead only when they completely lacked green tissues. Differences in pre- and posttreatment plant counts were used to determine percent plant mortality.

Data were subjected to ANOVA to test for location, mowing treatment, wiping treatment, and the effects of their interactions. Due to a location by mowing treatment by wiping treatment interaction, each location was analyzed separately using replication by mowing treatment as the error term for the vertical factor (mowing treatment), replication by wiping treatment for the horizontal factor (wiping treatment), and replication by mowing treatment by wiping treatment for the mowing treatment by wiping treatment interaction. The nontreated control was excluded from the analysis. Treatments were considered different when $P \leq 0.05$, and the interactions not discussed were not significant. Means were separated using Fisher's LSD test at a 5% level of significance when appropriate. When necessary, percent plant mortality data were arcsine square-root transformed to stabilize error variances; however, original values are reported (Beck and Sebastian 2000).

Results and Discussion

Handheld Weed-Wiper Dose–Response Experiment

There were no significant differences between herbicides at 30 DAT (Figure 1; Table 4); however, at 60 DAT, hexazinone effectiveness was greater than that of glyphosate (Figure 2; Table 5). *Sporobolus indicus* var. *pyramidalis* mortality increased as concentrations increased for both hexazinone and glyphosate when averaged over wiping methods. For example, glyphosate resulted in 29%, 45%, 53%, 66%, and 74% mortality at 6.25% v/v, 12.5% v/v, 25% v/v, 50% v/v, and 100% v/v, respectively. Similarly, hexazinone resulted in 35%, 45%, 62%, 73%, and 80% mortality at 6.25% v/v, 12.5% v/v, 25% v/v, 50% v/v, and 100% v/v, respectively. The ED_{70} values (Table 5) determined for both glyphosate and

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Table 4. Log-logistic regression parameter estimates (±SE) for percentage of *Sporobolus indicus* var. *pyramidalis* mortality at 30 d after treatment (DAT) from the handheld weed-wiper experiment, Florida, 2017 and 2018

	Parameter estimates[a]	
Treatments	b	ED_{70}[b]
Herbicide		
Glyphosate	−0.77 (±0.11)	55.12 a (±2.07)
Hexazinone	−0.52 (±0.08)	68.20 a (±2.33)
Wiping treatment		
Unidirectional	−0.69 (±0.09)	95.67 a (±3.02)
Bidirectional	−0.64 (±0.10)	33.11 b (±2.40)

[a]Log-logistic model: $Y = \exp[b(\log x - \log e)]$, where Y is the response (% of plant mortality), x is the concentration rate, b is the relative slope at the inflection point, and e is the inflection point of the fitted line (equivalent to the concentration in kg ae ha^{-1} to cause 70% response [ED_{70}]).
[b]ED_{70} estimates followed by the same letter within herbicides and within wiping method are not different according to t- and F-tests at the 5% significance level. Lack-of-fit test: P = 0.6383 for herbicides; P = 0.4867 for wiping method.

Table 5. Log-logistic regression parameter estimates (±SE) for percentage of *Sporobolus indicus* var. *pyramidalis* mortality at 60 d after treatment (DAT) from the handheld weed-wiper experiment, Florida, 2017 and 2018. Data were averaged across years and herbicides[a]

	Parameter estimates[b]	
	b	ED_{70}[c]
Herbicide		
Glyphosate	−0.77 (±0.09)	70.18 a (±12.44)
Hexazinone	−0.67 (±0.08)	44.13 b (±6.07)
Wiping treatment		
Unidirectional	−0.66 (±0.07)	94.63 a (±3.75)
Bidirectional	−0.80 (±0.09)	32.99 b (±17.01)

[a]Data were averaged across years and herbicides.
[b]Log-logistic model: $Y = \exp[b(\log x - \log e)]$, where Y is the response (% of plant mortality), x is the concentration rate, b is the relative slope at the inflection point, and e is the inflection point of the fitted line (equivalent to the concentration in g ae ha^{-1} to cause 70% response [ED_{70}]).
[c]ED_{70} estimates followed by the same letter within wiping method are not different according to t- and F-tests at the 5% significance level. Lack-of-fit test: P = 0.894.

hexazinone (70.2% and 44.1%, respectively) suggest that hexazinone exhibited better efficacy against *S. indicus* var. *pyramidalis* mortality at 60 DAT.

When averaged over herbicide treatments, wiping *S. indicus* var. *pyramidalis* plants bidirectionally provided greater *S. indicus* var. *pyramidalis* mortality compared with wiping plants unidirectionally at 30 DAT (Figure 3). *Sporobolus indicus* var. *pyramidalis* mortality ranged from 44% to 83% for the bidirectional wiping method, whereas mortality ranged from 30% to 72% for the unidirectional wiping method. Additionally, ED_{70} values based on plant mortality at 30 DAT were approximately 95.7% and 33.1% for the uni- and bidirectional wiping methods, respectively (Table 4). At 60 DAT, *S. indicus* var. *pyramidalis* mortality increased with herbicide concentration, and efficacy was greatest for the bidirectional method (Figure 4). Additionally, ED_{70} values observed at 60 DAT were 94.6% and 33.0% for uni- and bidirectional wiping methods, respectively (Table 5). Therefore, regardless of herbicide, treatments applied bidirectionally exhibited greater efficacy at 30 and 60 DAT compared with unidirectional treatments.

Collectively, these data indicate that the bidirectional wiping method and increasing concentrations enhanced the efficacy of both glyphosate and hexazinone. Although herbicide absorption and translocation were not investigated in this study, we hypothesized that wiping target plants in opposite directions (bidirectional wiping method) resulted in a significant increase in herbicide deposition on the leaf surface, leading to greater absorption, translocation, and ultimately greater mortality. Conversely, effective control was not expected when wiping hexazinone. As stated previously, hexazinone is classified as a soil-

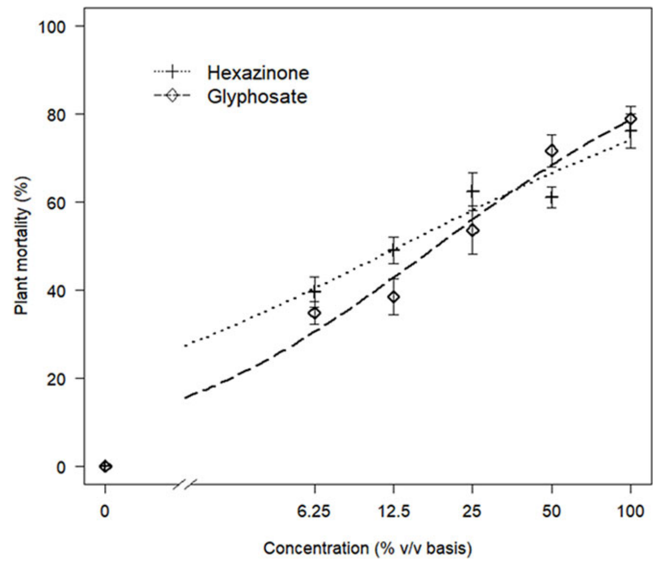

Figure 1. Percentage of *Sporobolus indicus* var. *pyramidalis* mortality (30 d after treatment) in response to glyphosate and hexazinone increasing concentrations applied with a handheld weed wiper in studies conducted under field conditions in Florida in 2017 and 2018. Dashed and dotted lines represent predicted values. Data were fit to a two-parameter log-logistic regression model: $Y = \exp[b(\log x - \log e)]$, where Y is the response, x is the concentration rate, b is the slope of the inflection point, and e is the inflection point of the fitted line (equivalent to the concentration necessary to promote 70% of *S. indicus* var. *pyramidalis* mortality [ED_{70}]).

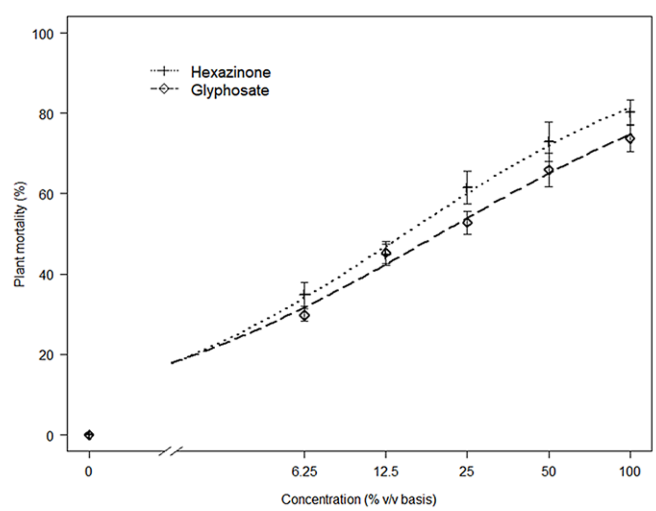

Figure 2. Percentage of *Sporobolus indicus* var. *pyramidalis* mortality (60 d after treatment) in response to glyphosate and hexazinone increasing concentrations applied with a handheld weed wiper in studies conducted under field conditions in Florida in 2017 and 2018. Dashed and dotted lines represent predicted values. Data were fit to a two-parameter log-logistic regression model: $Y = \exp[b(\log x - \log e)]$, where Y is the response, x is the concentration rate, b is the slope of the inflection point, and e is the inflection point of the fitted line (equivalent to the concentration necessary to promote 70% of *S. indicus* var. *pyramidalis* mortality [ED_{70}]).

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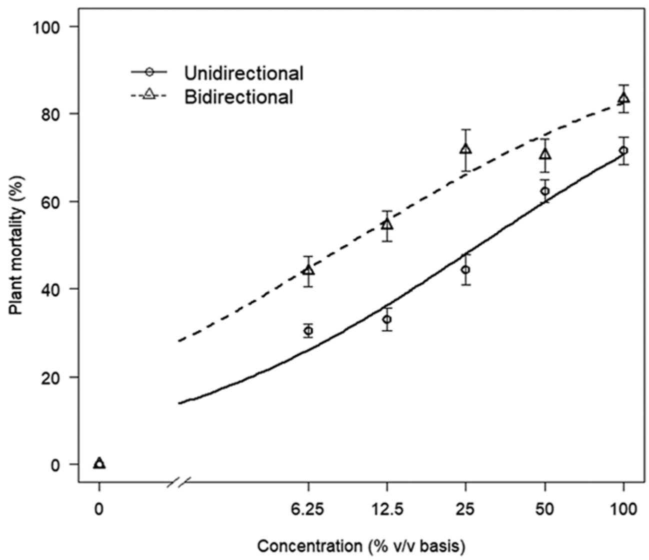

Figure 3. Percentage of *Sporobolus indicus* var. *pyramidalis* mortality (30 d after treatment) in response to wiping method (unidirectional vs. bidirectional) and increasing concentrations applied with a handheld weed wiper in studies conducted under field conditions in Florida in 2017 and 2018. Solid and dashed lines represent predicted values. Data were fit to a two-parameter log-logistic regression model: $Y = \exp[b(\log x - \log e)]$, where Y is the response, x is the concentration rate, b is the slope of the inflection point, and e is the inflection point of the fitted line (equivalent to the concentration necessary to promote 70% of *S. indicus* var. *pyramidalis* mortality [ED_{70}]). Data points were averaged across years and herbicides.

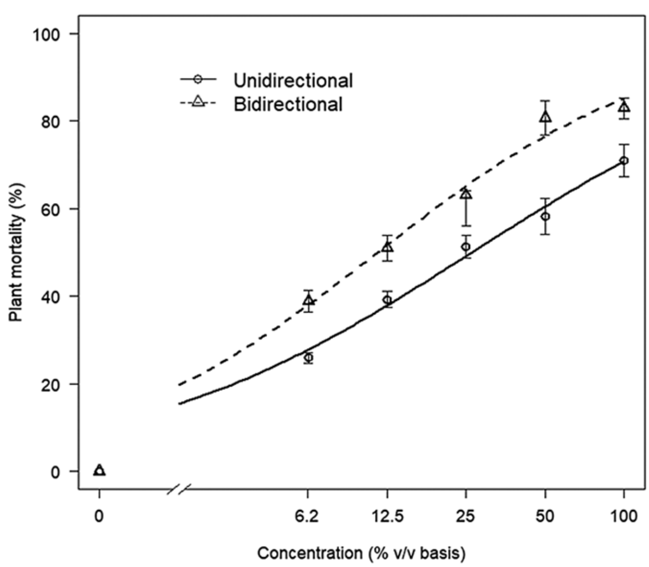

Figure 4. Percentage of *Sporobolus indicus* var. *pyramidalis* mortality (60 d after treatment) in response to wiping method (unidirectional vs. bidirectional) and increasing concentrations applied with a handheld weed wiper in studies conducted under field conditions in Florida in 2017 and 2018. Solid and dashed lines represent predicted values. Data were fit to a two-parameter log-logistic regression model: $Y = \exp[b(\log x - \log e)]$, where Y is the response, x is the concentration rate, b is the slope of the inflection point, and e is the inflection point of the fitted line (equivalent to the concentration necessary to promote 70% of *S. indicus* var. *pyramidalis* mortality [ED_{70}]). Data points were averaged across years and herbicides.

applied herbicide with limited translocation that occurs mainly through the xylem (Shaner 2014), and at least 6 mm of rainfall within 1 wk of application is necessary for effective *S. indicus* var. *pyramidalis* control (Dias 2019). Glyphosate, however, is classified as a foliar herbicide with symplastic translocation, occurring mainly through the phloem (Shaner 2014). Therefore, we hypothesized that glyphosate would exhibit greater herbicidal efficacy than hexazinone using this application method. Although the reasons why hexazinone and glyphosate performed similarly in this study are unclear, we assume that the rainfall pattern after the application was likely sufficient to transfer lethal hexazinone concentrations to the root zone of the *S. indicus* var. *pyramidalis* plants, as rainfall was 213 and 168 mm during the months of application in 2017 and 2018, respectively.

ATV-mounted Weed-Wiper Experiment

Mowing

Mowing before herbicide application was detrimental to herbicide performance. When plots were not mowed, *S. indicus* var. *pyramidalis* mortality was 2.1-, 1.5-, 1.2-, and 1.6-fold greater at Myakka, Buck Island (site 1), Buck Island (site 2), and RCREC at 35 DAT, respectively (Table 6). Similar to the data at 35 DAT, data at 90 DAT indicated pre-herbicide mowing was generally detrimental to herbicide efficacy. Additionally, plots not mowed had significantly increased mortality compared with plots mowed before herbicide application in the locations, except at Buck Island (site 2; Table 6).

We hypothesized that pre-herbicide mowing would enhance the overall *S. indicus* var. *pyramidalis* management with glyphosate and hexazinone applied with a weed wiper. However, we rejected this hypothesis, as mowing before herbicide application with a weed wiper was detrimental rather than beneficial. Similarly, Mislevy et al. (2002) and Ferrell and Mullahey (2006) have shown that mowing before broadcast application of hexazinone did not improve *S. indicus* var. *pyramidalis* control. We postulate that mowing before herbicide application decreased the total available leaf area, leading to less herbicide being deposited on the target plants, resulting in decreased efficacy. Similarly, Teuton et al. (2004) attributed decreased herbicidal efficacy on torpedograss (*Panicum repens* L.) control after mowing, likely due to the decreased residual leaf surface area, which would decrease the amount of herbicide uptake and efficacy. Additionally, it is possible that cattle grazed the tender regrowth of *S. indicus* var. *pyramidalis* in the mowed strips, resulting in little or no height differential between the target and non-target species. Several authors have also stated that many questions remain regarding the influence of mowing on herbicide efficacy. For example, Beam et al. (2005) suggested that mowing height and frequency could have contributed to decreased perennial ryegrass (*Lolium perenne L. ssp. multiflorum* (Lam.) Husnot.) control with nicosulfuron in Virginia. Similarly, Beck and Sebastian (2000) stated that inconsistent results prohibited them from concluding that mowing before spraying consistently improves Canada thistle [*Cirsium arvense* (L.) Scop.] control. Therefore, mowing before herbicide application should be thoroughly examined to preclude any unwanted weed management costs.

Wiping Method

Sporobolus indicus var. *pyramidalis* mortality was greater when plants were wiped bidirectionally versus unidirectionally at all locations at both 35 and 90 DAT (Table 7). Herbicides wiped bidirectionally caused greater mortality compared with the same treatments applied unidirectionally.

Although the effects of the wiping method were not individually investigated as a factor in the ATV-wiper experiments, the data

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Table 6. *Sporobolus indicus* var. *pyramidalis* mortality at 35 and 90 d after treatment (DAT) on mowed and not-mowed plants at the Myakka, Buck Island (site 1), Buck Island (site 2), and Range Cattle Research and Education Center (RCREC) research locations in Florida, 2017 and 2018[a]

	Myakka		Buck Island 1		Buck Island 2		RCREC	
Mowing treatment	35 DAT	90 DAT	35 DAT	90 DAT	35 DAT	90 DAT	35 DAT	90 DAT
	Mortality — % —							
Mowed	19.2 b	23.5 b	26.1 b	33.0 b	55.6 b	56.5 a	33.7 b	31.6 b
Not mowed	41.2 a	48.3 a	39.7 a	48.6 a	65.7 a	64.9 a	54.3 a	47.1 a
P-value	<0.001	<0.001	0.001	0.003	0.044	0.092	<0.001	0.002

[a]Means within locations and DAT followed by the same lowercase letter are not significantly different according to Fisher's LSD test at $P \leq 0.05$.

Table 7. *Sporobolus indicus* var. *pyramidalis* mortality at 35 and 90 d after treatment (DAT) in unidirectional vs. bidirectional wiping treatments at the Myakka, Buck Island (site 1), Buck Island (site 2), and Range Cattle Research and Education Center (RCREC) research locations in Florida, 2017 and 2018[a]

		Myakka		Buck Island 1		Buck Island 2		RCREC	
Wiping treatment	Herbicide treatment[b]	35 DAT	90 DAT	35 DAT	90 DAT	35 DAT	90 DAT	35 DAT	90 DAT
		Mortality — % —							
Unidirectional	G-17.5%	13.8 c	11.2 c	16.9 de	30.4 de	19.4 f	41.9 d	44.4 ab	20.0 e
	G-35%	27.5 abc	26.2 c	15.0 e	16.9 e	46.2 ef	44.4 d	56.2 a	30.5 bcd
	G-70%	33.8 abc	30.0 bc	28.8 b-e	28.1 de	48.8 e	47.2 cd	55.6 a	29.4 cde
	H-15%	14.4 bc	26.0 c	18.1 de	29.0 de	50.6 de	42.5 d	16.2 b	15.0 e
	H-30%	25.6 abc	28.1 c	15.0 e	19.4 e	46.8 e	40.6 d	36.9 ab	26.2 de
	H-60%	30.6 abc	38.1 abc	39.4 a-d	35.6 cde	76.2 a-d	61.6 bcd	33.1 ab	49.4 a-d
Bidirectional	G-17.5%	21.2 bc	22.6 c	33.8 b-e	40.6 b-e	55.0 cde	65.6 a-d	38.8 ab	31.9 bcd
	G-35%	43.1 ab	38.8 abc	45.0 abc	53.4 bcd	78.9 abc	90.6 a	54.0 a	57.8 ab
	G-70%	52.4 a	69.6 a	51.9 ab	67.2 ab	82.6 ab	85.0 ab	57.5 a	61.2 a
	H-15%	18.5 bc	12.5 c	22.4 cde	21.2 e	57.5 b-e	47.5 cd	33.8 ab	24.4 de
	H-30%	41.9 abc	69.8 a	45.6 abc	60.6 abc	79.8 abc	73.2 abc	46.2 a	55.1 abc
	H-60%	40.0 abc	60.8 ab	63.1 a	86.9 a	86.2 a	88.1 ab	58.1 a	73.1 a
P-value		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a]Means within locations and DAT followed by the same lowercase letter are not significantly different according to Fisher's LSD test at $P \leq 0.05$.
[b]Abbreviations: G-17.5%, glyphosate at 17.5%;, glyphosate at 35%; G-70%, glyphosate at 70%; H-15%, hexazinone at 15%; H-30%, hexazinone at 30%; H-60%, hexazinone at 60%.

indicate that the wiping method (uni- vs. bidirectional application) plays an important role in *S. indicus* var. *pyramidalis* control, as bidirectional applications of herbicides resulted in enhanced mortality. A previous study by Lemus et al. (2013) reported similar results, stating that the control of *S. indicus* var. *pyramidalis* control with glyphosate at 33% and 50% (356 g ae L^{-1}) was 3.25- and 1.12-fold greater when bidirectionally wiped compared with unidirectional applications at 365 DAT. Furthermore, the manufacturer's label states that performance may be improved by applying the herbicide twice in opposite directions (Anonymous 2019).

Interaction of Mowing and Wiping Treatment

A location by mowing by wiping treatment effect was observed for *S. indicus* var. *pyramidalis* mortality at 35 DAT ($P = 0.0157$) and 90 DAT ($P = 0.0002$); therefore, the results are presented separately by location (Tables 8 and 9). The greatest *S. indicus* var. *pyramidalis* mortality recorded in not-mowed plots among all unidirectionally wiped treatments was 49%, 44%, 84%, and 70% at Myakka, Buck Island (site 1), Buck Island (site 2), and RCREC, respectively (Table 8). Conversely, not-mowed plots had the greatest *S. indicus* var. *pyramidalis* mortality of 69%, 89%, 98%, and 73% when wiped bidirectionally at these locations, respectively. Treatments with the greatest mortality at 35 DAT were Bi-glyphosate-35%, Bi-glyphosate-70%, Bi-hexazinone-30%, and Bi-hexazinone-60% applied to not-mowed plots. *Sporobolus indicus* var. *pyramidalis* mortality recorded for these treatments ranged from 58% to 69%, 58% to 89%, 83% to 98%, and 61% to 73% at Myakka, Buck Island (site 1), Buck Island (site 2), and RCREC, respectively.

Wiping bidirectionally with herbicides significantly increased mortality at all locations (Table 9). The treatments causing the greatest mortality at 90 DAT included Bi-glyphosate-70%, Bi- hexazinone-30%, and Bi-hexazinone-60% applied in not-mowed plots. *Sporobolus indicus* var. *pyramidalis* mortality from these treatments ranged from 83% to 96%, 70% to 95%, 85% to 98%, and 75% to 79% at Myakka, Buck Island (site 1), Buck Island (site 2) and RCREC, respectively. These results corroborate previous work conducted by Lemus et al. (2013) in Mississippi. Those authors reported that glyphosate at 33% (356 g ae L^{-1}) wiped twice onto not-mowed plants provided 65% *S. indicus* control 365 DAT. However, *S. indicus* control was 90% when glyphosate at 50% v/v was wiped twice.

Additionally, lower mortality was observed at Myakka and RCREC compared with the other two locations at 90 DAT (Table 9). Several factors were likely responsible for this variability, including rainfall patterns and application timing, as well as variations in the target plants such as size and maturity stage. Total rainfall recorded at Myakka, Buck Island (site 1), Buck Island (site 2), and RCREC during the month of herbicide application was 213, 131, 249, and 56 mm, respectively, which was equal to 7% below, 28% below, 40% above, and 69% below the 20-yr monthly average, respectively (Table 1). Lack of or excessive rainfall after

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Table 8. *Sporobolus indicus* var. *pyramidalis* mortality at 35 d after treatment (DAT) with different wiping treatments applied to mowed and not-mowed plants at the Myakka, Buck Island (site 1), Buck Island (site 2), and Range Cattle Research and Education Center (RCREC) research locations in Florida, 2017 and 2018[a]

	Myakka		Buck Island (site 1)		Buck Island (site 2)		RCREC	
Wiping treatment[b]	Mowed	Not mowed	Mowed	Not mowed	Mowed	Not mowed	Mowed	Not mowed
	Mortality — % —							
UNI-G-17.5%	10.0 g	17.5 fg	12.5 fg	21.2 efg	18.8 f	20.0 f	30.0 c-f	58.8 a-d
BI-G-17.5%	10.0 g	32.5 d-g	41.2 b-e	26.2 efg	55.0 b-f	55.0 b-f	32.5 c-f	45.0 a-e
UNI-G-35%	23.8 efg	31.2 efg	12.5 fg	17.5 efg	43.8 def	48.8 c-f	43.8 a-e	68.8 ab
BI-G-35%	27.5 efg	58.8 a-d	35.0 b-g	55.0 bcd	74.8 a-e	83.0 a-d	46.2 a-e	61.8 abc
UNI-G-70%	26.2 efg	41.2 b-f	27.5 d-g	30.0 c-g	53.8 b-f	43.8 def	41.2 a-e	70.0 ab
BI-G-70%	36.0 c-g	68.8 a	42.2 b-e	62.5 ab	72.8 a-e	92.5 ab	42.5 a-e	72.5 a
UNI-H-15%	13.8 g	15.0 fg	12.5 fg	23.8 efg	47.5 c-f	53.8 b-f	7.5 f	25.0 def
BI-H-15%	20.0 fg	17.0 fg	17.5 efg	27.2 d-g	45.0 c-f	70.0 a-e	25.0 def	39.0 b-f
UNI-H-30%	15.0 fg	36.2 c-g	7.5 g	22.5 efg	38.5 ef	55.0 b-f	26.2 def	47.5 a-e
BI-H-30%	18.8 fg	65.0 ab	33.8 c-g	57.5 bc	73.8 a-e	85.8 abc	30.0 c-f	62.5 abc
UNI-H-60%	12.5 g	48.8 a-e	35.0 b-g	43.8 b-e	68.8 a-e	83.8 a-d	31.2 c-f	35.0 c-f
BI-H-60%	17.5 fg	62.5 abc	37.5 b-f	88.8 a	75.0 a-e	97.5 a	46.2 a-e	70.0 ab
Mowing × Wiping treatment	<0.0001		<0.0001		0.0005		0.0005	

[a]Means within locations followed by the same lowercase letter are not significantly different according to Fisher's LSD test at P ≤ 0.05.
[b]Abbreviations: UNI-G-17.5, unidirectional glyphosate at 17.5%; UNI-G-35%, unidirectional glyphosate at 35%; UNI-G-70%, unidirectional glyphosate at 70%; UNI-H-15%, unidirectional hexazinone at 15%; UNI-H-30%, unidirectional hexazinone at 30%; UNI-H-60%, unidirectional hexazinone at 60%; BI-G-17.5%, bidirectional glyphosate at 17.5%; BI-G-35%, bidirectional glyphosate at 35%; BI-G-70%, bidirectional glyphosate at 70%; BI-H-15%, bidirectional hexazinone at 15%; BI-H-30%, bidirectional hexazinone at 30%; BI-H-60%, bidirectional hexazinone at 60%.

Table 9. *Sporobolus indicus* var. *pyramidalis* mortality at 90 d after treatment (DAT) with different wiping treatments applied onto mowed and not-mowed plants at the Myakka, Buck Island (site 1), Buck Island (site 2), and Range Cattle Research and Education Center (RCREC) research locations in Florida, 2017 and 2018[a]

	Myakka		Buck Island (site 1)		Buck Island (site 2)		RCREC	
Wiping treatment[b]	Mowed	Not mowed	Mowed	Not mowed	Mowed	Not mowed	Mowed	Not mowed
	Mortality — % —							
UNI-G-17.5%	12.5 fg	10.0 g	28.0 fgh	32.8 fgh	51.2 c-g	32.5 g	18.8 de	21.2 de
BI-G-17.5%	15.0 efg	30.2 c-g	40.0 e-h	41.2 d-h	61.2 a-g	70.0 a-f	28.8 de	35.0 de
UNI-G-35%	16.2 efg	36.2 c-g	13.8 gh	20.0 fgh	10.0 fg	48.8 c-g	21.2 de	39.8 cde
BI-G-35%	27.5 d-g	50.0 cd	31.2 fgh	75.5 a-d	85.0 abc	96.2 a	41.5 b-e	74.0 ab
UNI-G-70%	17.5 efg	42.5 cde	25.0 fgh	31.2 fgh	45.8 d-g	48.8 c-g	30.0 de	28.8 de
BI-G-70%	43.8 cde	95.5 a	53.8 b-f	80.8 ab	81.2 a-d	88.8 ab	47.0 a-d	75.0 a
UNI-H-15%	12.5 fg	12.5 fg	28.0 fgh	30.0 fgh	51.2 c-g	33.8 fg	18.8 de	11.2 e
BI-H-15%	9.5 g	42.5 cde	7.5 h	35.0 fgh	36.2 fg	58.8 b-g	16.7 de	29.0 de
UNI-H-30%	16.2 efg	40.0 c-f	13.8 gh	25.0 fgh	40.0 fg	41.2 efg	21.2 de	31.2 de
BI-H-30%	56.2 bcd	83.2 ab	51.2 b-f	70.0 a-e	49.0 c-g	97.5 a	31.2 de	79.0 a
UNI-H-60%	17.5 efg	58.8 bc	25.0 fgh	46.2 c-g	45.8 d-g	77.5 a-e	30.0 de	68.8 abc
BI-H-60%	37.5 c-g	84.0 ab	78.8 abc	95.0 a	91.2 ab	85.0 abc	70.0 abc	76.2 a
Mowing × wiping treatment	<0.0001		0.037		<0.0001		0.0003	

[a]Means within locations followed by the same lowercase letter are not significantly different according to Fisher's LSD test at P ≤ 0.05.
[b]Abbreviations: UNI-G-17.5, unidirectional glyphosate at 17.5%; UNI-G-35%, unidirectional glyphosate at 35%; UNI-G-70%, unidirectional glyphosate at 70%; UNI-H-15%, unidirectional hexazinone at 15%; UNI-H-30%, unidirectional hexazinone at 30%; UNI-H-60%, unidirectional hexazinone at 60%; BI-G-17.5%, bidirectional glyphosate at 17.5%; BI-G-35%, bidirectional glyphosate at 35%; BI-G-70%, bidirectional glyphosate at 70%; BI-H-15%, bidirectional hexazinone at 15%; BI-H-30%, bidirectional hexazinone at 30%; BI-H-60%, bidirectional hexazinone at 60%.

herbicide application has been suggested to decrease hexazinone efficacy (Ferrell and Mullahey 2006; Rana et al. 2015). In addition, wiping treatments were applied on September 27, 2018, at the RCREC site, whereas they were applied at the beginning of August at the Myakka and Buck Island (site 1), and on August 28, 2018, at Buck Island (site 2) (Table 3).

Hexazinone was applied in August, which is the peak rainfall month in southern Florida. Rainfall is required for hexazinone to be incorporated into the soil root zone and absorbed by plants (Dias 2019; Wang et al. 2019). Thus, applying hexazinone early in the season when *P. notatum* is growing slowly due to limited rainfall would likely result in decreased hexazinone efficacy compared with what was observed in these experiments. However, due to the limited growth of *P. notatum*, the increased height differential between *S. indicus* var. *pyramidalis* and *P. notatum* would likely result in increased glyphosate deposition onto *S. indicus* var. *pyramidalis* plants, ultimately resulting in increased control with glyphosate; therefore, we would expect results to be significantly different if this work were conducted earlier in the growing season. However, this would need to be validated with further research.

Finally, it is noteworthy that several factors can significantly change the outcomes of the interaction between mowing before herbicide application and herbicide application, including the period between these two events, the number of consecutive mowing events before herbicide application, application timing, edaphoclimatic conditions before and after herbicide application,

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and weed species growth habit and life cycle. Therefore, mowing before herbicide application is a complex interaction that requires further investigation.

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Competing interests. The authors declare no conflict of interest.

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