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Southern Sandbur (*Cenchrus echinatus* L.) Control in Bermudagrass Pastures with Indaziflam Herbicide Systems

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Abstract

Field studies were conducted during the 2019 growing season in north-central, south-central, and the Coastal Bend areas of Texas to evaluate indaziflam herbicide systems for southern sandbur control and Coastal bermudagrass tolerance. Indaziflam caused no bermudagrass stunting at any location when applied preemergence (PRE) at 0.04 to 0.07 kg ai ha^{-1}. Glyphosate at 0.35 kg ae ha^{-1} caused bermudagrass stunting which ranged from 16 to 65% when evaluated 3 to 5 weeks after application; however, when evaluated at the end of the growing season, no bermudagrass stunting was evident when compared with the untreated check. Southern sandbur control with indaziflam, when evaluated 28 to 32 weeks after the initial indaziflam PRE application, ranged from 85 to 99% in north-central Texas, 65 to 95% in south-central Texas, and 95 to 100% in the Coastal Bend region. Southern sandbur control with pendimethalin PRE systems ranged from 74 to 100%, 11 to 85%, and 100% in those regions, respectively. Indaziflam represents a safe option for forage and hay producers in Texas to control southern sandbur.

Keywords: *Cenchrus Echinatus* L.; 'Coastal' Bermudagrass; *Cynodon Dactylon* (L.); N-[(1R.2S)-2,3-Dihydro-2,6-Dimethyl-1H-Inden-1-Yl]-6-(1-Fluoroethyl)-1,3,5-Triazine-2,4-Diamine.

Introduction

Cenchrus echinatus (southern sandbur) is an annual grassy weed commonly found in pastures throughout Texas (Gould, 1975) and can also be found in the southern United States from California to North Carolina (Holm *et al.*, 1991). It is adapted to dry, sandy soils (Holm *et al.*, 1991). When conditions are dry, southern sandbur can be short-lived and produces few burrs, while with adequate soil moisture it may be long-lived, grow much larger, and produce numerous burrs (Holm et al., 1991). Southern sandbur competes with forage grasses causing delays in establishment and reducing yield and quality (Walker *et al.*, 1998).

Texas cattle producers depend on good quality bermudagrass forage and hay and the presence of sandbur spp. reduces hay value, nutritional quality, and animal productivity. Indaziflam belongs to the alkylazine chemical class and acts on cell wall biosynthesis without affecting the synthesis of polysaccharide polymers. The action is inhibitory and most likely occurs at some point during the cross-linking stage of cellulose microfibrils (Torres *et al.*, 2018). Inhibition of cell division in meristematic tissue has also been proposed as a secondary mode of action (Torres *et al.*, 2018). Indaziflam is classified as moderately mobile in the soil and is a weak acid and anionic at soil pH values of 5.4 and above (Alonso et al., 2011; US EPA, 2010). It is not volatile and its dissipation in the environment takes place primarily through degradation and leaching (US EPA, 2010).

Indaziflam is registered in several perennial crops (Grey *et al.*, 2016; Jhala and Singh 2012; Marble *et al.*, 2016) and is also registered for use in multiple warm-season turfgrasses (Anonymous, 2017). It has a pending registration for bermudagrass forage production with a maximum use rate of 0.094 kg ha^{-1} over a 12-month period (Hurdle *et al.*, 2019). Indaziflam provides broad spectrum control of several annual grasses including smooth crabgrass (*Digitaria ischaemum* L.), annual bluegrass (*Poa annua* L.), downy brome (*Bromus tectorum* L.), Japanese broom (*Bromus japonicas* Thunb. or *Bromus arvensis* L.), and jointed goatgrass (*Aegilops cylindrical* L.) (Brosnan and Breeden, 2012, Brosnan *et al.*, 2012, Sebastian, *et al.* 2017a).

Brosnan and Breeden (2012) reported that indaziflam provided similar control of nontillered smooth crabgrass to dithiopyr at 0.56 kg ha^{-1} or quinclorac at 0.84 kg ha^{-1}. In Tennessee, control of annual bluegrass, 4 and 8 weeks after planting, was 88 to 100% when indaziflam was applied preemergence (PRE) at 0.035 and 0.054 kg ha^{-1} (Brosnan et al., 2012). In Georgia, Brosnan et al. (2012) reported that annual bluegrass control was 97 to 100% when compared to the untreated check.

Previous attempts at control of sandbur spp. in bermudagrass pastures have focused on either using low rates of glyphosate applied soon after forage harvest, pendimethalin applied PRE before sandbur emerges, or nicosulfuron plus metsulfuron combinations applied postemergence (POST). There are currently few herbicides labeled for selective PRE control of southern sandbur in bermudagrass pastures and southern sandbur control using indaziflam has not been previously reported. Therefore, the objective of this study was to determine bermudagrass tolerance and southern sandbur control with indaziflam applied PRE to sandbur emergence in a systems approach to control this weed.

Materials and Methods

Field studies were conducted during the 2019 growing season at several locations across Texas including Burleson County (south-central Texas), in Hill County (north-central Texas), and in San Patricio County (Coastal Bend area of Texas) (Table 1). All test locations were infested with natural populations of southern sandbur with 7 plants/m^2 in Burleson County, 4 plants/m^2 in Hill County, and 5 plants/m^2 in San Patricio County. All other information about the trials is included in Table 1. The experimental design at all locations was a randomized complete block with four replications. Each plot at the Burleson County location was 3.0 m wide by 6.1 m long; at the Hill County location, plots were 3.0 m wide by 10.7 m long, while plots at the San Patricio location were 3.0 m wide by 9.1 m long.

Herbicide applications timings were planned to correspond with a late winter (prior to seedling sandbur emergence) application (A), early summer (after the 1st cutting) application (B), and late summer (after the 2nd cutting) application (C). Herbicide treatments included: (1) indaziflam at 0.07 kg ai ha^{-1} plus metsulfuron at 0.03 kg ai ha^{-1} plus chlorsulfuron at 0.01 kg ai ha^{-1} applied at A followed by nicosulfuron at 0.06 kg ai ha^{-1} plus metsulfuron at 0.02 kg ai ha^{-1} plus glyphosate at 0.35 kg ae ha^{-1} applied at B, (2) indaziflam at 0.04 kg ai ha^{-1} plus metsulfuron at 0.03 kg ai ha^{-1} plus chlorsulfuron at 0.01 kg ai ha^{-1} applied at A followed by indaziflam at 0.04 kg ai ha^{-1} applied at B, (3) indaziflam at 0.04 kg ai ha^{-1} plus metsulfuron at 0.03 kg ai ha^{-1} plus chlorsulfuron at 0.01 kg ai ha^{-1} applied at A followed by nicosulfuron at 0.06 kg ai ha^{-1} plus metsulfuron at 0.02 kg ai ha^{-1} plus glyphosate at 0.35 kg ae ha^{-1} plus indaziflam at 0.04 kg ha^{-1} applied at B, (4) indaziflam at 0.04 kg ai ha^{-1} plus nicosulfuron at 0.06 kg ai ha^{-1} plus metsulfuron at 0.02 kg ai ha^{-1} plus glyphosate at 0.35 kg ae ha^{-1} applied at B followed by indaziflam at 0.04 kg ha^{-1} applied at C, (5) indaziflam at 0.04 kg ai ha^{-1} plus nicosulfuron at 0.06 kg ai ha^{-1} plus metsulfuron at 0.02 kg ai ha^{-1} plus glyphosate at 0.35 kg ae ha^{-1} applied at B, (6) pendimethalin at 2.12 kg ha^{-1} plus metsulfuron at 0.03 kg ai ha^{-1} plus chlorsulfuron at 0.01 kg ai ha^{-1} applied at A followed by pendimethalin at 2.12 kg ha^{-1} applied at B, (7) pendimethalin at 2.12 kg ai ha^{-1} plus nicosulfuron at 0.06 kg ai ha^{-1} plus metsulfuron at 0.02 kg ai ha^{-1} plus glyphosate at 0.35 kg ae ha^{-1} applied at B followed by pendimethalin at 2.12 kg ha^{-1} applied at C, and (8) an untreated check. All herbicide treatments included a non-ionic surfactant, Induce (Helena Agri-Enterprises, LLC, 225 Schilling Blvd., Collierville, TN 38017) at 0.25% v/v.

At the Burleson County location, test plots were cut to simulate the 1st and 2nd cuttings and residue removed from plots, with herbicide application soon afterwards; however, forage yield was not taken at any cutting. At

the Hill County location, there was very little vegetation at the initiation of the study and herbicide applications were timed based on the actions of neighbors and plots were never cut for yield. At the San Patricio County location, the test area was cut and raked prior to the initiation of the study but never cut at any time during the growing season. Also, herbicide applications were based on the actions of neighbors as at the Hill County location. Weed control and bermudagrass injury were estimated visually on a scale of 0 to 100 (0 indicating no control or plant death and 100 indicating complete control or plant death) relative to the untreated check (Frans *et al.* 1986). Weed control and bermudagrass injury evaluations were recorded 13 to 15 weeks and 28 to 32 weeks after the initial late winter application. Bermudagrass stunting was used when making the visual injury estimates.

Table 1. Variables associated with this study at each location in 2019.

	Location (county)		
Variables	**Burleson**	**Hill**	**San Patricio**
Coordinates	30.4245° N, 96.4373° W	32.0043° N 97.2639° W	27.9516° N 97.6788° W
Bermudagrass variety	Coastal	Coastal	Coastal
Soil name	Singleton	Gasil	Sinton
Soil type	Fine sandy loam	Fine sandy loam	Sandy clay loam
Sand (%)	91	60	43
Silt (%)	6	28	12
Clay (%)	3	11	45
Organic matter (%)	0.5	0.75	1.9
pH	6.6	7.0	6.3
Herbicide application			
Prior to sandbur emergence (A)	March 21	Feb 27	Feb 13
Early summer (B)	May 16	June 20	May 29
Mid to late summer (C)	July 15	Aug 19	June 28
CO_2 backpack sprayer			
Operating pressure (kPa)	172	207	262
Spray volume (L ha^{-1})	140	140	140
Spray nozzles	8003FF	80011VS	11002AM
Bermudagrass height at application (cm)			
Prior to sandbur emergence	5-15	-	-
Early summer	10-46	12-20	15-20
Mid to late summer	25-91	25-75	30-40
Sandbur height at application (cm)			
Prior to sandbur emergence	-	-	-
Early summer	5-15	7-15	10-15
Mid to late summer	15-46	15-25	15-20

Weed efficacy data were arcsine square root transformed before analysis, but only the nontransformed data are reported because transformation did not affect data interpretation. The untreated control was included in weed control analysis. Fisher's Protected LSD at the 0.05 level of probability was used for separation of mean differences. Since evaluations timings varied across locations no attempt was made to combine any data over locations.

Results and Discussion

'Coastal' Bermudagrass injury.

Bermudagrass injury was characterized as stunting of growth compared to the untreated check. Indaziflam applications did not result in any bermudagrass injury (Table 2). Jones *et al*., (2013a) evaluated the effect of organic matter content on hybrid bermudagrass (*C. dactylon* x *C. transvaalensis*) injury following the application of indaziflam in minirhizotron cultures. Bermudagrass injury decreased with increasing organic matter content.

In a greenhouse study, Jones *et al*., (2013b) indicated that foliar injury and reductions in root-length density of hybrid bermudagrass from indaziflam were greatest at rooting depth of 5 cm than 10 to 15 cm. Also, the study revealed more indaziflam injury in bermudagrass established in sand with no organic carbon than in silt loam with organ carbon content. Stunting was not reported at the Hill County location and this was due to the evaluation taken just 2 weeks after the glyphosate early summer application (B) postemergence (POST) applications of glyphosate; however, stunting was observed at the other locations when evaluations were completed within five weeks of the early summer application (Table 2).

At the Burleson County location, bermudagrass stunting ranged from 35 to 65% while at the San Patricio location bermudagrass injury was $\leq$ 18%. When evaluated 28 and 32 weeks after the initial application, no bermudagrass injury was noted.

Glyphosate applications for sandbur control after bermudagrass forage harvest requires timely application (prior to bermudagrass developing new leaves), otherwise significant crop injury may result. After application, glyphosate is translocated to the roots and accumulation in the roots of perennial plants can kill root buds and can cause disruption of vegetative reproduction (Gottrup *et al*., 1976; Sandberg *et al*., 1980; Claus and Behrens, 1976; Waldecker and Wyse, 1985).

In a study in south-central Texas, when glyphosate was applied within 8 days of bermudagrass cutting, no injury with glyphosate at 1.17 L ha^{-1} was seen while glyphosate at 2.24 L ha^{-1} resulted in $\leq$ 11% stunting. However, when glyphosate application was delayed until 17 days after cutting, bermudagrass injury with glyphosate at either rate ranged from 36 to 80% (Grichar *et al*., 2000). They concluded that glyphosate applications must be done with 3 to 8 days after cutting and before the bermudagrass stolons begin to develop new leaves.

Southern Sandbur Control.

13 to 17 weeks after initial late winter, early spring application. In Burleson County (evaluation taken 13 weeks after the initial late winter, early spring application and 5 weeks after the early summer application), all treatments which included indaziflam applied either late winter, early spring or late spring, early summer controlled southern sandbur at least 96% while the pendimethalin plus metsulfuron plus chlorsulfuron applied late winter, early spring followed by pendimethalin applied early summer controlled only 14% sandbur (Table 3). The pendimethalin plus nicosulfuron plus metsulfuron plus glyphosate treatment applied early summer controlled southern sandbur 91%. At the Hill County location (evaluations taken 17 weeks after late winter, early spring application and 2 weeks after the early summer application), all indaziflam treatments, with the exception of indaziflam plus metsulfuron plus chlorsulfuron applied late winter, early spring followed by indaziflam applied early summer, controlled southern sandbur 100% (Table 3). Pendimethalin plus metsulfuron plus chlorsulfuron applied late winter, early spring followed by pendimethalin applied early summer provided 84% of this weed.

At the San Patricio location (evaluations taken 17 weeks after late winter, early spring application and 4 weeks after the early summer application), all treatments which contained indaziflam controlled southern sandbur 78 to 83% while pendimethalin plus metsulfuron plus chlorsulfuron applied late winter, early spring followed by pendimethalin applied early summer provided 75% control. Pendimethalin plus nicosulfuron plus metsulfuron plus glyphosate applied early summer controlled 83% southern sandbur.

Table 2. Coastal bermudagrass injury with indaziflam combinations.

			Counties[c]				
			Burleson		San Patricio		
			Weeks after initial application				
Herbicide treatments[a]	**Rate**	**Appl[b]**	**13[d]**	**28**	**10**	**17[e]**	**32**
	Kg ai (ae)/ ha^{-1}		**%**				
Indaziflam +	0.07 +	A					
Metsulfuron + chlorsulfuron	0.03 + 0.01						
Nicosulfuron + metsulfuron +	0.06 + 0.02 +	B					
Glyphosate	0.35		35	0	0	18	0
Indaziflam +	0.04 +	A					
Metsulfuron + chlorsulfuron	0.03 + 0.01						
Indaziflam	0.04	B	0	0	0	0	0
Indaziflam +	0.04 +	A					
Metsulfuron + chlorsulfuron	0.03 + 0.01						
Nicosulfuron + metsulfuron +	0.06 + 0.02 +	B					
Glyphosate + indaziflam	0.35 + 0.04		65	0	0	16	0
Indaziflam +	0.04 +	B					
Nicosulfuron + metsulfuron +	0.06 + 0.02 +						
Glyphosate	0.35						
Indaziflam	0.04	C	56	0	0	18	0
Indaziflam +	0.04 +	B					
Nicosulfuron + metsulfuron +	0.06 + 0.02 +						
Glyphosate	0.35		60	0	0	16	0
Pendimethalin +	2.12 +	A					
Metsulfuron + chlorsulfuron	0.03 + 0.01						
Pendimethalin	2.12	B	0	0	0	0	0
Pendimethalin +	2.12 +	B					
Nicosulfuron + metsulfuron +	0.06 + 0.02 +						
Glyphosate	0.35						
Pendimethalin	2.12	C	15	0	0	18	0
Untreated	-	-	0	0	0	0	0
LSD (0.05)			19	-	-	3	-

[a] All treatments included a nonionic surfactant (Induce) added at 0.25% v/v.

[b] Application timing: A, in late winter, early spring prior to sandbur emergence; B, early summer; C, mid to late summer.

[c] No injury reported at the Hill County location.

[d] Five weeks after the early summer application.

[e] Three weeks after the early summer application.

28 to 32 weeks after initial late winter, early spring application. In Burleson County when evaluated 28 weeks after the late winter, early spring application, treatments which included indaziflam controlled southern sandbur at least 91% with the exception of the treatment of indaziflam plus metsulfuron plus chlorsulfuron applied late winter, early spring followed by nicosulfuron plus metsulfuron plus glyphosate applied early summer which

controlled southern sandbur only 65% (Table 4). Pendimethalin plus metsulfuron plus chlorsulfuron applied late winter, early spring followed by pendimethalin applied early summer provided only 11% control while pendimethalin plus nicosulfuron plus metsulfuron controlled 85% southern sandbur.

Table 3. Southern sandbur (*Cenchrus echinatus* L.) control with indaziflam combinations 13 to 17 weeks after late winter/early spring (A) application.

			Counties[c]		
Herbicide treatments[a]	**Rate**	**Appl[b]**	**Burleson**	**Hill**	**San Patricio**
	Kg ai (ae)/ ha^{-1}		**%**		
Indaziflam +	0.07 +	A			
Metsulfuron + chlorsulfuron	0.03 + 0.01				
Nicosulfuron + metsulfuron +	0.06 + 0.02 +	B			
Glyphosate	0.35		96	100	83
Indaziflam +	0.04 +	A			
Metsulfuron + chlorsulfuron	0.03 + 0.01				
Indaziflam	0.04	B	98	76	78
Indaziflam +	0.04 +	A			
Metsulfuron + chlorsulfuron	0.03 + 0.01				
Nicosulfuron + metsulfuron +	0.06 + 0.02 +	B			
Glyphosate + indaziflam	0.35 + 0.04		100	100	83
Indaziflam +	0.04 +	B			
Nicosulfuron + metsulfuron +	0.06 + 0.02 +				
Glyphosate	0.35				
Indaziflam	0.04	C	96	100	80
Indaziflam +	0.04 +	B			
Nicosulfuron + metsulfuron +	0.06 + 0.02 +				
Glyphosate	0.35		99	100	83
Pendimethalin +	2.12 +	A			
Metsulfuron + chlorsulfuron	0.03 + 0.01				
Pendimethalin	2.12	B	14	84	75
Pendimethalin +	2.12 +	B			
Nicosulfuron + metsulfuron +	0.06 + 0.02 +				
Glyphosate	0.35				
Pendimethalin	2.12	C	91	98	83
Untreated	-	-	0	0	0
LSD (0.05)			8	14	11

[a] All treatments included a nonionic surfactant (Induce) added at 0.25% v/v.

[b] Application timing: A, in late winter, early spring prior to sandbur emergence; B, early summer; C, mid to late summer.

[c] Evaluations in Burleson County taken 13 weeks after late winter, early spring application and 5 weeks after the early summer application; at the Hill County locations, evaluations taken 17 weeks after late winter, early spring application and 2 weeks after the early summer application; at the San Patricio County location, evaluations taken 17 weeks after late winter, early spring application and 4 weeks after the early summer application.

At the Hill County location when evaluated 28 weeks after the late winter, early spring application, all indaziflam treatments provided 85 to 99% southern sandbur control compared with either pendimethalin plus metsulfuron plus chlorsulfuron applied late winter, early spring which provided 100% control or pendimethalin plus nicosulfuron plus metsulfuron which controlled 74% southern sandbur (Table 4). At the San Patricio County location when evaluated 32 weeks after the late winter, early spring application, all herbicide treatments controlled southern sandbur at least 95% including those treatments that did not include indaziflam (Table 4).

Table 4. Southern sandbur (*Cenchrus echinatus* L.) control with indaziflam combinations 28 to 32 weeks after late winter/early spring (A) application[a].

			Control		
			Counties[d]		
Herbicide treatments[b]	**Rate**	**Appl[c]**	**Burleson**	**Hill**	**San Patricio**
	Kg ai (ae)/ ha^{-1}		%		
Indaziflam +	0.07 +	A			
Metsulfuron + chlorsulfuron	0.03 + 0.01				
Nicosulfuron + metsulfuron +	0.06 + 0.02 +	B			
Glyphosate	0.35		65	99	100
Indaziflam +	0.04 +	A			
Metsulfuron + chlorsulfuron	0.03 + 0.01				
Indaziflam	0.04	B	95	85	100
Indaziflam +	0.04 +	A			
Metsulfuron + chlorsulfuron	0.03 + 0.01				
Nicosulfuron + metsulfuron +	0.06 + 0.02 +	B			
Glyphosate + indaziflam	0.35 + 0.04		91	90	100
Indaziflam +	0.04 +	B			
Nicosulfuron + metsulfuron +	0.06 + 0.02 +				
Glyphosate	0.35				
Indaziflam	0.04	C	95	90	95
Indaziflam +	0.04 +	B			
Nicosulfuron + metsulfuron +	0.06 + 0.02 +				
Glyphosate	0.35		91	88	100
Pendimethalin +	2.12 +	A			
Metsulfuron + chlorsulfuron	0.03 + 0.01				
Pendimethalin	2.12	B	11	100	100
Pendimethalin +	2.12 +	B			
Nicosulfuron + metsulfuron +	0.06 + 0.02 +				
Glyphosate	0.35				
Pendimethalin	2.12	C	85	74	100
Untreated	-	-	0	0	0
LSD (0.05)			12	8	5

[a] No injury reported at any locations.

[b] All treatments included a nonionic surfactant (Induce) added at 0.25% v/v.

[c] Application timing: A, in late winter, early spring prior to sandbur emergence; B, early summer; C, mid to late summer.

[d] Evaluations in Burleson and Hill Counties taken 28 weeks after late winter, early spring application while evaluations in San Patricio County evaluations taken 32 weeks after late winter, early spring application.

This late evaluation shows the long residual activity of indaziflam and other studies have also noted this long residual (Sebastian *et al.*, 2017a, b; Shaner, 2014). Indaziflam has several chemical properties that result in enhanced residual weed control including root inhibition at low concentrations, lipophilicity (log K_{ow} = 2.8), low water solubility (2.8 mg L^{-1}), no photodegration, and a moderate positive correlation between sorption and soil organic matter (Shaner, 2014; Sebastian *et al.*, 2017a). Therefore, lethal indaziflam concentrations are biologically available at the soil surface with sufficient moisture for plant uptake, resulting in extended weed control (Sebastian et al., 2017b).

Conclusions

Matocha et al., (2010) reported that field sandbur (*Cenchrus spinifex* M. A. Curtis) control with single or sequential applications of nicosulfuron plus metsulfuron tank mix combinations were comparable to that reported with imazapic plus 2,4-D (Grichar *et al.*, 2008). Grichar *et al.*, (2000) also reported that glyphosate or glufosinate were effective for field sandbur control but since these herbicides do not possess any residual activity, repeat applications after each cutting would be necessary for effective control. Pendimethalin applied PRE will control *Cenchrus* spp. provided sandbur has not emerged prior to herbicide application and adequate rainfall/irrigation (1.2 to 1.9 mm) is received soon after application (authors personal observations).

Indaziflam offers forage and hay producers another PRE option for sandbur control. These studies demonstrated the ability of indaziflam-based herbicide systems to provide excellent control of southern sandbur. No bermudagrass injury was seen with PRE applications of indaziflam and only injury with glyphosate was noted. Also, in view of the use of herbicides in forage production with the same mode of action, the use of indaziflam as an alternative for sandbur control, would provide high level weed management systems for bermudagrass forage production in the southwest, while also avoiding the potential development of herbicide resistant weeds.

Data Availability

Any of this data can be obtained from the corresponding author at w-grichar@tamu.edu.

Conflicts of Interest

There are no conflicts of interest.

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References

1. Alsonso, D. G., Koskinen, W. C., Oliveira Jr., R. S., Constantin, J., and Mislankar, S. (2011). Sorption-desorption of indaziflam in selected agricultural soils. J. Agric. and Food Chem. 59:13096-13101. doi: 10.1021/jf203014gPMID:22070170

2. Anonymous. (2017). Registration of Specticle FLO. https://www3.epa.gov/pesticides/chem_search/ppls/000432-01518-20110907.pdf

3. Brosnan, J. T., and Breeden, G. K. (2012). Application placement affects postemergence smooth crabgrass (*Digitaria ischaemum*) and annual bluegrass (*Poa annua*) control with indaziflam. Weed Technol. 26:661-665.

4. Brosnan, J. T., Breeden, G. K., McCullough, P. E., and Henry, G. M. (2012). PRE and POST control of annual bluegrass with indaziflam. Weed Technol. 26:48-53.

5. Claus, J. S. and Behrens, R. (1976). Glyphosate translocation and quackgrass rhizome bud kill. Weed Sci. 24:149-152.

6. Frans, R., Talbert, R., Marx, D., and Crowley, H. (1986). Experimental design and techniques for measuring and analyzing plant responses to weed control practices. In: Camper, N. D., (ed.) Research Methods in Weed Science. 3rd ed. Champaign, IL: Southern Weed Science Society. Pp.29-46.

7. Gottrup, D., O'Sullivan, P. A., Schraa, R. J., and Vanden Born, W. H. (1976). Uptake, translocation, metabolism, and selectivity of glyphosate in Canada thistle and leafy spurge. Weed Res. 16:197-201.

8. Gould, F. W. (1975). The Grasses of Texas. Texas A&M University Press, College Station, TX. pp. 565-567.

9. Grichar, W. J., Jaks, A. J., and Nerada, J. D. (2000). Field sandbur (*Cenchrus pauciflorus*) control in pastures using Gramoxone, Roundup Ultra, or Touchdown. Texas J. of Agri. and Natl. Resources. 13:1-7.

10. Grichar, W. J., Baumann, P. A., Baughman, T. A., and Nerada, J. D. (2008). Weed control and bermudagrass tolerance to imazapic plus 2,4-D. Weed Technol. 22:97-100.

11. Grey, T. L., Luo, X., Rucker, K., and Webster, T. M. (2016). High density plantings of olive trees are tolerant to repeated applications of indaziflam. Weed Sci. 64:766-771.

12. Holm, L. G., Plunknett, D. L., Pancho, J. W., and Herberger, J. P. (1991). The World's Worst Weeds. Distribution and Biology. Krieger Publ., Malabar, FL.

13. Hurdle, N. L., Grey, T. L., McCullough, P. E., Shilling, D., and Belcher, J. (2019). Bermudagrass tolerance of indaziflam PRE applications in forage production. Weed Technol. doi. 10.1017/wet.2019.76.

14. Jhala, A. J. and Singh, M. (2012). Leaching of indaziflam compared with residual herbicides commonly used in Florida citrus. Weed Technol. 26:602-607.

15. Jones, P. A., Brosnan, J. T., Kopsell, D. A., and Breeden, G. K. (2013a). Effect of reed-sedge peat moss on hybrid bermudagrass injury with indaziflam and prodiamine in sand-based root zones. Weed Technol. 27:547-551.

16. Jones, P. A., Brosnan, J. T., Kopsell, D. A., and Breeden, G. K. (2013b). Soil type and rooting depth affect hybrid bermudagrass injury with preemergence herbicides. Crop Sci. 53:660-665.

17. Marble, S. C., Chandler, A., and Archer, M. (2016). Impact of application rate, timing, and indaziflam formulation on early POST control of *Oxalis stricta*. Weed Technol. 30:701-707.

18. Matocha, M. A., Grichar, W. J., and Grimes C. (2010). Field sandbur (*Cenchrus spinifex*) control and bermudagrass response to nicosulfuron tank mix combinations. Weed Technol. 24:510-514.

19. Sandberg, C. L., Meggitt, W. F., Penner, D. (1980). Absorption, translocation, and metabolism of ^{14}C-glyphosate in several weed species. Weed Res. 20:195-200.

20. Sebastian, D. J., Nissen, S. J., Westra, P., Shaner, D. L., and Butters, G. (2017a). Influence of soil properties and soil moisture on the efficacy of indaziflam and flumioxazin on *Kochia scoparia* L. Pest Manag. Sci. 73:444-451.

21. Sebastian, D. J., Fleming, M. B., Patterson, E. L., Sebastian, J. R., and Nissen, S. J. (2017b). Indaziflam: a new cellulose biosynthesis inhibiting herbicide provides long-term control of invasive winter annual grasses. Pest Manag. Sci. 73:2149-2162.

22. Shaner, D. L., ed. (2014). Herbicide Handbook. 10th edition. Weed Science Society of America. Champaign, IL. 500 pgs.

23. Torres, B. A., Meneghin, S. P., Ribeiro, N. M., dos Santos, P. H. V., Schedenffeldt, B. F., and Monquero, P. A. (2018). Saflufenacil and indazifam herbicide effects on agricultural crops and microorganisms. African J. Agric. Res. 13:872-885.

24. US EPA. Pesticide fact sheet. Conditional registration. July 26, 2010; pp. 1-108.

25. Waldecker, M. A. and Wyse, D. L. (1985). Soil moisture effects on glyphosate absorption and translocation in common milkweed (*Asclepias syriaca*). Weed Sci. 33:299-305.

26. Walker, R. H., Wehtje, G., and Richburg III, J. S. (1998). Interference and control of large crabgrass (*Digitaria sanguinalis*) and southern sandbur (*Cenchrus echinatus*) in forage bermudaagrass (*Cynodon dactylon*). Weed Technol. 12:707-710.