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EFFICACY OF THE HERBICIDES INDAZIFLAM AND CLOMAZONE ON PROBLEMATIC WEEDS OF FAMILY POACEAE TO SUGARCANE CROP

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Abstract
It is believed that indaziflam gives a longer period of weed control compared to clomazone, irrespective of the type or texture of the soil. Thus, the aim of this study was to evaluate pre-emergent control in five problematic weed species of family Poaceae to sugarcane, using the herbicides indaziflam and clomazone in two soils of different textures. Two experiments were carried out, one in a soil of a sandy-loam texture and the other in a clayey soil. For both experiments, a randomised block design of split plots was chosen, with four replications. The treatments consisted of the herbicides indaziflam (75 and 100 g ai ha^{-1}), clomazone (1080 g ai ha^{-1}) and a control with no herbicide. In the subplots, the treatments were *Digitaria horizontalis*, *Panicum maximum*, *Rottboellia cochinchinensis*, *Urochloa decumbens* and *Urochloa plantaginea*. Both herbicides were more effective in the clayey soil, but with indaziflam (100 g ai ha^{-1}), more than 90% control of the weeds remained after 240 days after application (DAA), whereas for clomazone, control remained only up to 90 DAA. The herbicide clomazone did not satisfactorily control the weeds in the sandy-loam soil. The herbicide indaziflam did not control *U. decumbens* in the sandy-loam soil. *D. horizontalis* and *R. cochinchinensis* were the most sensitive species to the herbicide indaziflam, irrespective of soil texture.

Keywords: Chemical control. *Digitalis horizontalis*. *Panicum maximum*. *Rottboellia cochinchinensis*. *Urochloa* spp.

1. Introduction

Monocot weeds of the Poaceae family are known to cause major damage to sugarcane production. One example are the areas infested with *Rottboellia cochinchinensis*, with losses of 80% in ratoon cane and 100% in plant cane (Arévalo and Bertocini 1994). Correia and Gomes (2014) also highlighted a fall in yield for ratoon cane with a high infestation of *R. cochinchinensis*, in this case, with losses of 56%.

Other weeds have also caused significant losses in sugarcane mills. Losses were 40% when *Urochloa decumbens* and *Panicum maximum* were the principal weed species in the area (Kuva et al. 2003), and 82% when the predominant species was *U. decumbens* (Kuva et al. 2001). *Urochloa plantaginea* and *Digitaria horizontalis* are also noteworthy, since a mixed infestation of these species achieved losses of 31% (Santos et al. 2011).

As such, these infesting weed species are important in sugarcane fields. In general, they are aggressive, and may exhibit vigorous and faster vegetative growth compared to the sugarcane, which has slow sprouting and initial growth (Procopio et al. 2016). These characteristics have a negative influence on rapid canopy closure, allowing the weeds access to light, and consequently prolonging the period the sugarcane needs to be free from weed interference (Galon et al. 2011).

In fact, the minimum control period was 138 and 127 days, allowing for a 5% loss in sugarcane yield (Kuva et al. 2001; Kuva et al. 2003). If only a 2% loss in sugarcane yield is considered, this period can even extend up to 200 days (Meirelles et al. 2009). For this reason, long-term control is necessary to avoid weed competition.

Weed control can be carried out correctly by the integration of several methods, including the use of herbicides. Between 2010 and 2014, almost 100% of the area cultivated with sugarcane in the state of São Paulo was treated with herbicides (Reis et al. 2019). This can be explained by the need for long-term weed control, where the application of herbicides with lasting residual action is essential. These herbicides have an exclusive or preferential mode of action in the soil, controlling weed germination, which, in the medium and long term, influences the soil seed bank (Amim et al. 2016).

There are currently many options of registered herbicides for sugarcane (Rodrigues and Almeida 2018). Carotenoid biosynthesis inhibiting herbicides are strongly recommended for the control of monocot species in sugarcane (Reis et al. 2019). Among these is clomazone (2-(2-chlorobenzyl)-4,4-dimethyl-1,2-oxazolidin-3-one) from the isoxazolidinone group of chemicals, used in the preemergent control of Poaceae species and some eudicots in sugarcane (Rodrigues and Almeida 2018).

Since 2016, a new alternative for weed control in sugarcane has been available in Brazil, indaziflam (N-[(1R,2S)-2,3-dihydro-2,6-dimethyl-1H-inden-1-yl]-6-[(1R)-1-fluoroethyl]-1,3,5-triazine-2,4-diamine), from the alkylazine group of chemicals (Amim et al. 2016). Indaziflam mainly controls weeds of the Poaceae family and some eudicots in pre-emergence, acting as a pfotent inhibitor of cellulose biosynthesis (Brabham et al. 2014).

Compared to other pre-emergent herbicides which are often applied in sugarcane, such as clomazone, indaziflam appears to have greater persistence in the soil. The half-life of clomazone is close to 60 days (Gallandt et al.1989; Mills et al. 1989; Kirksey et al. 1996; Tomco et al. 2010; Du et al. 2018), however, up to 84 days, was considered an acceptable estimate (Weed Science Society of America [WSSA] 1989). In contrast, indaziflam has a longer half-life in the soil, of more than 150 days (Kaapro and Hall 2012), which may allow residual weed control for several months.

In addition to the marked differences in the physicochemical characteristics of the herbicide molecules, the residual control of clomazone and indaziflam may be influenced by the physical, chemical and biological properties of the soil; the most important being organic matter, the clay type and content, and the pH value of the soil (Monqueiro and Silva 2021). This is due to their influence on herbicide persistence and availability in the soil solution, mainly regulating the processes of sorption and degradation.

In this context, it is assumed that indaziflam, at the two rates under test, gives a longer period of weed control compared to clomazone used as standard, irrespective of the type or texture of the soil. To confirm this hypothesis, the aim of this study was to evaluate the pre-emergent control of the herbicides indaziflam and clomazone in five problematic weed species of the Poaceae family in sugarcane fields in two soils of different textures.

2. Material and Methods

Two experiments were carried out under field conditions, one in soil of a sandy-loam texture (22º43'00.63"S; 47º37'04.19"W; altitude 586 m) and the other in a clayey soil (22º42'50.67" S; 47º37'23.17" W; altitude 560 m), from 01/01/2018 to 01/01/2019, in Piracicaba, in the state of Sao Paulo, Brazil. According to the Köppen classification, the climate is of type Cfa, humid subtropical with an oceanic climate, the absence of a dry season and hot summers (Alvares et al. 2014).

The first experiment was carried out in a sandy-loam soil (16.8% clay, 72.1% sand, 11.1% silt; pH: 5.5; 7 g dm^{-3} OM; V: 58%) and the second in a clayey soil (52.7% clay, 42.6% sand, 4.7% silt; pH: 5.3; 20 g dm^{-3} OM; V: 74%). Rainfall and temperature data for the period of the experiment can be found in Figure 1.

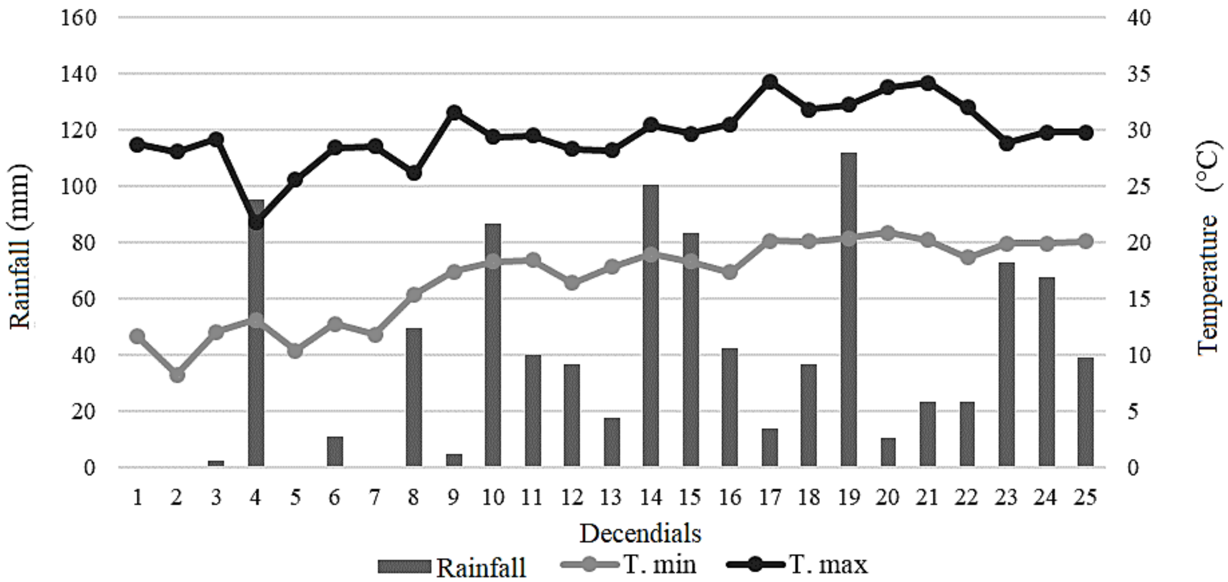

Figure 1. Rainfall values and temperature per decencial recorded from 07/01/2018 to 03/10/2019. Data derived from the Automatic Meteorological Station - LEB – USP/ESALQ, Piracicaba, São Paulo, Brazil.

Seeds of weeds from the Poaceae family were acquired in Engenheiro Coelho, São Paulo (Empresa Agrocosmos, 22º30'25.25"S; 47º10'36.97"W; altitude of 660 m). For both experiments, a randomised block design of split plots was used with four replications. The plots consisted of the treatments with the herbicides indaziflam (75 g ai ha^{-1}), indaziflam (100 g ai ha^{-1}) and clomazone (1080 g ai ha^{-1}), and a control treatment where no product was applied, while the subplots consisted of the weed species *Urochloa decumbens*, *Urochloa plantaginea*, *Digitaria horizontalis*, *Panicum maximum* and *Rottboellia cochinchinensis*. The rates of these herbicides follow the recommendation label to sugar-cane.

The experiment area was fallow, and had no history of application of other herbicides. The soil was prepared by subsoiling (to a depth of ±0.30 m) and surface harrowing to loosen, level and declump the soil about seven days before sowing. The areas were artificially infested with the five weed species on 07/02/2018, with the seeds distributed in rows and later incorporated into the surface with the aid of a rake. The amount of seed was enough to provide a minimum emergence of 20 plants m^{-2}.

The plots (herbicides) were 4 m wide and 6 m long (24 m²), and the subplots (species), 0.5 m wide and 4 m long (2 m^2). Due to the low rainfall preceding the start of the experiment, conventional irrigation was carried out by sprinkler 48 hours after application of the herbicides, to simulate 30 mm of rain. The experimental units were kept free of other weeds of no interest to the study, with the manual elimination of any weeds on the inicial stage, that 'escaped chemical control'; manual removal was also used in the control treatment where there was no product application. This practice was carried out four times during the experiment, always when reinfestation of these weeds occurred, where they were removed from the experimental area.

The commercial products used in the experiment contained 500 g L^{-1} indaziflam in the form of a suspension concentrate (SC) of toxicity class III (moderately toxic), and the other, 360 g L^{-1} clomazone in a capsule suspension (CS) of toxicity class III (moderately toxic) (Rodrigues and Almeida 2018).

The herbicides were applied 24 hours after sowing the weeds at 9:00 to 10:15 am, with the aid of a pressurised hand sprayer equipped with a three-metre bar and six XR 110.02 spray nozzles (0.5 m between nozzles). The sprayer was operated at a pressure of 200 kPa, supplying a volume equal to 200 L ha^{-1}. At the time of application, a relative humidity of 35.6%, air temperature of 28.5ºC, wind speed of 5.0 km h^{-1} and 0% cloudiness were recorded.

At 30, 90, 180 and 240 days after application (DAA), visual evaluations were made using a scale of 0 to 100%, where zero means no control and 100% means complete control (Velini et al. 1995). Control scores were assigned individually to each weed species (subplot).

To verify the reduction in weed dry matter, green shoots were collected close to the ground at 240 DAA. The samples were taken using hollow rectangles (0.25 x 0.5 m) thrown twice randomly into each subplot. The plant material was placed in an oven to dry at 65ºC until reaching constant weight. The dry-matter data were expressed as percentage values, comparing the dry-matter weight obtained after application of the herbicides with the dry-matter weight of the control (with no product application), considered 100%.

In the analysis of variance, the data were submitted to the F-test. The normality of the residuals was verified by the Shapiro-Wilk test, with homogeneity determined by Bartlett's test. When significant, the effects of the herbicides (plot) and species (subplot) were compared by Tukey's test at α=0.05. The control-score data and dry-matter data of the control treatment (with no product application) were not included in the analysis of variance, as suggested by Carvalho et al. (2012). The statistical analysis was carried out using the R v3.0.3 software.

3. Results

In the sandy-loam soil (first experiment), the factors, both in isolation and their interaction (herbicides x species), had a significant influence on weed control, except at 30 days after application (30 DAA), when only the species had an effect (Table 1). In this evaluation, indaziflam (75 and 100 g ai ha^{-1}) and clomazone (1080 g ai ha^{-1}) gave on average more than 95% control. The difference in control between species demonstrated a slight escape of *U. decumbens* after the herbicides were applied.

In the clayey soil (second experiment), the interaction between the factors herbicide and species significantly affected the variables, except for the control at 90 DAA, which was not influenced by any treatment. Indaziflam (75 and 100 g ai ha^{-1}) and clomazone (1080 g ai ha^{-1}) gave over 90% control at 30 and 90 DAA in all species (Tables 1 and 2).

Table 1. Weed control in sandy-loam and clayey soil at 30 DAA. Piracicaba, 2018.

Herbicide	Rate[1] g ai ha^{-1}	Control (%) *D. horinzontalis*	*P. maximum*	*R. conchinchinensis*	*U. decumbens*	*U. plantaginea*	Mean
		sandy-loam soil					
indaziflam	75	100	99.5	97.0	95.0	97.3	97.8
indaziflam	100	100	99.0	100	95.3	99.5	98.7
clomazone	1080	100	99.3	93.5	91.3	94.3	95.7
Mean		100 A	99.3 AB	96.8 AB	93.8 B	97.0 AB	
$F_{(Herb\ x\ Sp)}$ = 1.2^{NS} $F_{(Herb)}$ = 1.3^{NS} $F_{(Sp)}$ = 8.2** $LSD_{(Sp)}$ = 5.9 $CV_{(Herb)}$ = 6.4 $CV_{(Sp)}$ = 3.0							
		clayey soil					
indaziflam	75	100 Aa	100 Aa	100 Aa	100 Aa	100 Aa	100
indaziflam	100	100 Aa	100 Aa	100 Aa	100 Aa	100 Aa	100
clomazone	1080	100 Aa	99.5 Aa	98.5 Bb	99.8 Aa	100 Aa	99.6
Mean		100	99.8	99.5	99.9	100	
$F_{(Herb\ x\ Sp)}$ = 3.7** $F_{(Herb)}$ = 6.9* $F_{(Sp)}$ = 3.7* $LSD_{(Herb)}$ = 0.7 $LSD_{(Sp)}$ = 0.8 $CV_{(Herb)}$ = 0.4 $CV_{(Sp)}$ = 0.4							

^{NS}Not significant; *Significant at 5%; **Significant at 1%. Means followed by equal letters, uppercase letters (lines) and lowercase letters (columns) do not differ by Tukey's test at 5% probability.

At 90 DAA, *P. maximum* was the only species controlled efficiently (≥95%) by both herbicides (Table 2). For the other weeds, clomazone gave poor control, with 23.8 to 70.0% depending on the species. In general, the treatments with indaziflam were more effective, and, apart from *U. decumbens*, weed control of greater than 85% was obtained. This species demonstrated lower susceptibility to indaziflam, confirmed by the poor levels of control, especially at the lowest dose of the herbicide.

Effective control of *D. horinzontalis*, *P. maximum* and *R. conchinchinensis* was seen at 180 and 240 DAA using 75 and 100 g ai ha^{-1} indaziflam (Table 3 and 4). The poorer control of *U. plantaginea* was attributed to the lower dose of indaziflam, as the higher dose also provided over 90% control. In contrast, *U. decumbens* was not efficiently controlled at 180 or 240 DAA, and even at the highest dose of indaziflam, control did not reach 30%. In general, residual weed control with clomazone (1080 g ai ha^{-1}) worsened over time, and as such, the herbicide was not effective on any species at 180 or 240 DAA.

At 180 and 240 DAA, ≥90% control was obtained in all the weed species with only 100 g ai ha^{-1} indaziflam (Tables 3 and 4), in contrast to the dose of 75 g ai ha^{-1}, which after 90 DAA, no longer satisfactorily controlled *U. decumbens* or *P. maximum*. Clomazone, however, was not effective on any weed species at 180 or 240 DAA, with levels of control ≤76%, demonstrating the lower persistence of the herbicide when submitted to long periods of evaluation.

Table 2. Weed control in sandy-loam and clayey soil at 90 DAA. Piracicaba, 2018.

Herbicide	Rate	Control (%)					Mean
		D. horinzontalis	*P. maximum*	*R. conchinchinensis*	*U. decumbens*	*U. plantaginea*	
	g ai ha^{-1}	sandy-loam soil					
indaziflam	75	100 Aa	99.3 Aa	97.5 Aa	56.3 Ba	86.3 Aa	87.9
indaziflam	100	100 Aa	99.3 Aa	98.8 Aa	67.5 Ba	98.3 Aa	92.8
clomazone	1080	70.0 Bb	95.0 Aa	45.0 Ca	23.8 Cb	23.8 Cb	51.5
Mean		90.0	97.8	80.4	49.2	69.4	
$F_{(Herb\ x\ Sp)}$ = 6.2** $F_{(Herb)}$ = 53.5** $F_{(Sp)}$ = 32.2** $LSD_{(Herb)}$ = 20.8 $LSD_{(Sp)}$ = 23.6 $CV_{(Herb)}$ = 17.8 $CV_{(Sp)}$ = 15.0							
		clayey soil					
indaziflam	75	100	99.8	100	98.8	99.3	99.6
indaziflam	100	100	100	100	99.8	100	99.9
clomazone	1080	100	99.5	91.0	97.3	96.3	96.8
Mean		100	99.8	97.0	98.6	98.5	
$F_{(Herb\ x\ Sp)}$ = 1.2^{NS} $F_{(Herb)}$ = 4.0^{NS} $F_{(Sp)}$ = 1.2^{NS} $CV_{(Herb)}$ = 1.7 $CV_{(Sp)}$ = 1.6							

^{NS}Not significant; *Significant at 5%; **Significant at 1%. Means followed by equal letters, uppercase letters (lines) and lowercase letters (columns) do not differ by Tukey's test at 5% probability.

Table 3. Weed control in sandy-loam and clayey soil at 180 DAA. Piracicaba, 2018.

Herbicide	Rate	Control (%)					Mean
		D. horinzontalis	*P. maximum*	*R. conchinchinensis*	*U. decumbens*	*U. plantaginea*	
	g ai ha^{-1}	sandy-loam soil					
indaziflam	75	98.0 Aa	96.3 Aa	95.0 Aa	15.0 Ca	53.8 Bb	71.6
indaziflam	100	100 Aa	98.8 Aa	100 Aa	28.8 Ba	96.5 Aa	84.8
clomazone	1080	25.0 Bb	60.0 Ab	15.0 Bb	17.5 Ba	11.3 Bc	25.8
Média		74.3	85.0	70.0	20.4	53.8	
$F_{(Herb\ x\ Sp)}$ = 11.3** $F_{(Herb)}$ = 389.1** $F_{(Sp)}$ = 52.3** $LSD_{(Herb)}$ = 19.3 $LSD_{(Sp)}$ = 24.8 $CV_{(Herb)}$ = 11.6 $CV_{(Sp)}$ = 19.9							
		clayey soil					
indaziflam	75	100 Aa	73.0 Bb	100 Aa	61.5 Bb	97.5 Aa	86.4
indaziflam	100	100 Aa	100 Aa	100 Aa	92.5 Aa	100 Aa	98.5
clomazone	1080	56.8 ABb	75.8 Ab	10.0 Db	29.5 Cc	38.8 BCb	42.4
Média		51.4	82.9	70.0	61.2	78.8	
$F_{(Herb\ x\ Sp)}$ = 14.5** $F_{(Herb)}$ = 130.4** $F_{(Sp)}$ = 12.5** $LSD_{(Herb)}$ = 18.1 $LSD_{(Sp)}$ = 26.6 $CV_{(Herb)}$ = 15.7 $CV_{(Sp)}$ = 13.4							

^{NS}Not significant; *Significant at 5%; **Significant at 1%. Means followed by equal letters, uppercase letters (lines) and lowercase letters (columns) do not differ by Tukey's test at 5% probability.

Table 4. Weed control in sandy-loam and clayey soil at 180 DAA. Piracicaba, 2018.

Herbicide	Rate	Control (%)					Mean
		D. horinzontalis	*P. maximum*	*R. conchinchinensis*	*D. horinzontalis*	*U. plantaginea*	
	g ai ha^{-1}	sandy-loam soil					
indaziflam	75	97.5 Aa	95.5 Aa	93.8 Aa	13.8 Ca	52.5 Bb	70.6
indaziflam	100	99.5 Aa	98.8 Aa	100 Aa	26.3 Ba	94.8 Aa	83.9
clomazone	1080	21.3 Bb	57.5 Ab	11.3 Bb	17.5 Ba	10.0 Bc	23.5
Mean		72.75	83.92	68.33	19.17	52.42	
$F_{(Herb\ x\ sp)}$ = 13.1** $F_{(Herb)}$ = 504.9** $F_{(Sp)}$ = 55.6** $LSD_{(Herb)}$ = 18.6 $LSD_{(Sp)}$ = 23.6 $CV_{(Herb)}$ = 10.6 $CV_{(Sp)}$ = 19.6							
		clayey soil					
indaziflam	75	100 Aa	53.8 Bb	100 Aa	47.5 Bb	93.8 Aa	79.0
indaziflam	100	100 Aa	96.3 Aa	100 Aa	92.5 Aa	95.0 Aa	96.8
clomazone	1080	20.0 Bb	57.5 Ab	10.0 Bb	10.0 Bc	35.0 ABb	26.5
Mean		73.3	69.2	70.0	50.0	74.6	
$F_{(Herb\ x\ Sp)}$ = 10.1** $F_{(Herb)}$ = 183.6** $F_{(Sp)}$ = 7.4** $LSD_{(Herb)}$ = 21.6 $LSD_{(Sp)}$ = 25.7 $CV_{(Herb)}$ = 17.9 $CV_{(Sp)}$ = 18.8							

^{NS}Not significant; *Significant at 5%; **Significant at 1%. Means followed by equal letters, uppercase letters (lines) and lowercase letters (columns) do not differ by Tukey's test at 5% probability.

The interaction between herbicide and species significantly affected the reduction in weed dry matter (Table 5). At 240 DAA, the two doses of indaziflam drastically suppressed (≥90%) dry matter accumulation in *D. horinzontalis*, *P. maximum* and *R. conchinchinensis*. A large reduction in dry matter (≥90%) in *U. plantaginea* was also obtained, but at the highest dose of indaziflam (100 g ai ha^{-1}). For *U. decumbens*, indaziflam was not effective in reducing dry matter, corroborating the poor levels of control. Furthermore, clomazone did not efficiently inhibit dry-matter production in any of the weeds, however, a 70% reduction in dry matter in *P. maximum* was achieved with application of the herbicide.

In general, the treatments with indaziflam were more effective in suppressing dry matter-production in the weeds, despite the application of 75 g ai ha^{-1} of the herbicide not being effective on *P. maximum* or *U. decumbens*, with reductions of <50% (Table 5). As for clomazone, dry-matter production was not efficiently suppressed in any of the weeds, especially in *D. horizontalis* and *R. conchinchinensis*, the two species that produced most dry matter even when treated with herbicide. Clomazone gave the same level of dry matter reduction in *P. maximum* and *U. decumbens* as the 75 g ai ha^{-1} dose of indaziflam.

Table 5. Reduction in weed dry mass in sandy-loam and clayey soil at 240 DAA. Piracicaba, 2018.

Herbicide	Rate	Reduction dry mass (%)					Mean
		D. horinzontalis	*P. maximum*	*R. conchinchinensis*	*U. decumbens*	*U. plantaginea*	
	g ai ha^{-1}	sandy-loam soil					
indaziflam	75	98.3 Aa	91.6 Aa	89.6 Aa	19.1 Ba	72.3 Aa	74.2
indaziflam	100	99.1 Aa	98.5 Aa	100 Aa	38.2 Ba	96.2 Aa	86.4
clomazone	1080	37.9 ABb	73.7 Aa	16.8 Bb	30.0 Ba	18.5 Bb	35.4
Mean		78.5	87.9	68.8	29.1	62.3	
$F_{(Herb \times Sp)}$ = 4.5** $F_{(Herb)}$ = 79.0** $F_{(Sp)}$ = 17.6** $LSD_{(Herb)}$ = 30.3 $LSD_{(Sp)}$ = 37.6 $CV_{(Herb)}$ = 20.4 $CV_{(Sp)}$ = 28.5							
		clayey soil					
indaziflam	75	100 Aa	47.8 Bb	100 Aa	45.0 Bb	93.4 Aa	77.2
indaziflam	100	100 Aa	100 Aa	100 Aa	92.7 Aa	96.0 Aa	97.8
clomazone	1080	23.2 Bb	59.8 Ab	14.3 Bb	28.4 ABb	47.3 ABb	34.6
Mean		74.4	69.2	71.4	55.4	78.9	
$F_{(Herb \times Sp)}$ = 6.3** $F_{(Herb)}$ = 102.4** $F_{(Sp)}$ = 3.3* $LSD_{(Herb)}$ = 28.5 $LSD_{(Sp)}$ = 34.5 $CV_{(Herb)}$ = 20.4 $CV_{(Sp)}$ = 24.4							

^{NS}Not significant; *Significant at 5%; **Significant at 1%. Means followed by equal letters, uppercase letters (lines) and lowercase letters (columns) do not differ by Tukey's test at 5% probability.

4. Discussion

In general, both herbicides showed more-effective residual weed control in the clayey soil than in the sandy-loam soil. This may be related in part to the physicochemical properties of the soils, with expressive differences in the levels of sand, clay and soil organic matter (SOM). As such, losses from leached herbicide were considered, especially in the sandy loam soil, a result of the high sand content and the lower levels of clay and SOM.

However, the control-score data confirm that the residual action of indaziflam (75 and 100 g ai ha^{-1}) was less affected in the sandy-loam soil than that of clomazone. It is therefore believed that leaching of the indaziflam may be limited due to the previously reported poor molecular mobility of the soil (Alonso et al. 2011). Experiments in a sandy soil (91.6% sand, 4.4% silt, 4.0% clay and 0.46% SOM) reinforce the smaller movement of indaziflam in the soil profile, which, even with 150 mm of precipitation, did not exceed the 30 cm layer (Jhala et al. 2012; Jhala and Singh 2012). In the same way, indaziflam concentrations decreased with increasing soil depth from 0 to 46 cm (Gonzáles-Delgado et al. 2017)

On the other hand, it is strongly suspected that much of the clomazone (1080 g ai ha^{-1}) applied to the sandy-loam soil was lost through leaching, due to 30 mm of rainfall being simulated 48 hours after application of the herbicides, with an accumulated volume of 100 mm up to 60 DAA. Clomazone (1500 g ai ha^{-1}) was found at depths of 15 to 20 and 20 to 25 cm after simulated rainfall of 60 mm, however, higher amounts of herbicide were lost through leaching when more precipitation (90 mm) was applied, and in soils with a lower clay and SOM content (Pereira et al. 2017). This satisfactorily explains why in the clayey soil, clomazone provided over 90% weed control up to 90 DAA, whereas in the sandy-loam soil the same level of control was maintained for up to 30 DAA.

In addition, Inoue et al. (2011) found a longer period of control over *U. decumbens* for clomazone (1100 g ai ha^{-1}) in a clayey soil, with over 80% control remaining until 71 DAA, while in a sandy soil, control was already unsatisfactory by 25 DAA. These data corroborate those of this study: clomazone is efficient up to 30 days in a sandy-loam soil, while it remains efficient up to 90 DAA in a clayey soil, with the level of control then decreasing significantly. The most efficiently controlled species was *P. maximum*, where levels greater than 90% were maintained until 90 DAA irrespective of soil texture, even reaching 180 DAA; acceptable control of this grass varied between 60 and 75.8% in the sandy-loam and clayey soils respectively.

Moreover, Correia et al. (2012) found that clomazone (1200 g ai ha^{-1}) was effective (>90%) in *D. horizontalis* and *P. maximum* up to 94 DAA, but not in *U. decumbens*, with a control of between 53.8 and 76% depending on the commercial area of sugarcane. Clomazone (1200 g ai ha^{-1}) also failed to control efficiently a high infestation of *R. cochinchinensis* up to 140 DAA, even in a clayey soil (Correia and Gomes 2014). In general, clomazone has excellent initial control of narrow-leaf weeds, but over time loses its efficiency. One possible explanation for this is based on its lower persistence in the soil, especially in soil of a sandy texture, where the loss of efficiency is faster than in a clayey soil (Mervosh et al. 1995; Senseman 2007).

In contrast, a long period of narrow-leaf weed control was obtained with indaziflam. Brosnan et al. (2011) found greater than 90% control of *Digitaria ischaemum* for 195 days in different locations in the United States. Indaziflam also gave effective control of *Poa annua,* ranging from 93 to 100%, for up to 196 DAA in two years of experiment (Brosnan et al. 2012). Control of *Digitaria sanguinalis* was also greater than 90%, lasting for up to 203 DAA (Perry et al. 2011). In this study, indaziflam gave better control of narrow-leaf weeds and longer residual activity than did clomazone, however, in some cases, control varied for dose, species and soil texture.

Narrow-leaf weeds were almost 100% controlled by indaziflam at 100 g ai ha^{-1} in a clayey soil for up to 240 DAA, and nearly all species were controlled in the sandy-loam soil, except for *U. decumbens*. Indeed, this species was not controlled by 75 g ai ha^{-1} in a clayey soil after 90 DAA, with the reasons for this lack of control being unclear. However, it is strongly believed that inefficient control in the clayey soil may have resulted from the lower dose of herbicide, whereas in the sandy-loam soil it appears that the species becomes less susceptible to indaziflam. The failure to control *P. maximum* and *U. plantaginea* was attributed to the lower dose of herbicide, irrespective of soil texture. *D. horinzontalis* and *R. conchinchinensis* were very sensitive to the herbicide, with more than 95% of these species being controlled, regardless of the dose or soil texture. Other studies underline the efficiency of indaziflam on narrow-leaf weeds, including the great potential for reducing the seed bank in species of family Poaceae (Amim et al. 2014; Amim et al. 2016).

The hypothesis that the two doses of indaziflam give a longer period of control of narrow-leaf weeds compared to clomazone was rejected, as species and soil texture affected the efficiency of the herbicide. First, the two doses of indaziflam (75 and 100 g ai ha^{-1}) were inefficient in controlling *U. decumbens* in a sandy-loam soil. Second, 75 g ai ha^{-1} of indaziflam provided the same level of control as did clomazone, considering the ability to suppress the growth of *P. maximum* and *U. decumbens* in a clayey soil. Based on the results of this study, it was found that indaziflam (100 g ia ha^{-1}) gives a long period of control of the weeds of family Poaceae, especially in soils of a more clayey texture; however the herbicide should not be recommended for the exclusive control of *U. decumbens* in agricultural soils with a higher sand content.

5. Conclusions

Both herbicides were more effective in a clayey soil; for indaziflam (100 g ai ha^{-1}), greater than 90% control of the weeds of family Poaceae remained after 240 DAA, with up to 90 DAA for clomazone.

The herbicide clomazone did not satisfactorily control the weeds in the sandy-loam soil. The herbicide indaziflam did not control *Urochloa decumbens* in the sandy-loam soil.

Digitaria horizontalis and *Rottboellia cochinchinensis* were the most sensitive species to the herbicide indaziflam, irrespective of soil texture.

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