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Herbicide selectivity and weed control in gladiolus cultivation

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Abstract – The objective of this work was to evaluate the selectivity of pre- and post-emergent herbicides and their efficiency in weed control, as well as the growth and quality of floral stems, in a gladiolus (*Gladiolus* x *grandiflorus*) crop in two growing seasons. The experiments were carried out in the field, where the planted gladiolus received the application of pre- and post-emergent herbicides, with and without mechanical weed control. At 7, 14, 21, and 28 days after emergence (DAE), monocotyledon and eudicotyledon control and phytotoxicity to gladiolus plants were evaluated. At 28 DAE, the shoot dry matter of weeds and gladiolus plants was also evaluated. The s-metolachlor and diuron pre-emergent herbicides and the haloxyfop-p-methyl post-emergent herbicide are selective to gladiolus plants in both seasons, which allows of the production of floral stems with commercial quality. The s-metolachlor and haloxyfop-p-methyl herbicides also promote an efficient control of monocotyledons regardless of the growing season. Although, when applied, saflufenacil and 2,4-D cause phytotoxicity in the vegetative phase of gladiolus, they do not affect the production of floral stems and control satisfactorily eudicotyledons in the second season.

Index terms: *Gladiolus* x *grandiflorus*, floriculture, phytotoxicity, post-emergence, pre-emergence, quality standard.

Seletividade de herbicidas e controle de plantas daninhas no cultivo de gladíolo

Resumo – O objetivo deste trabalho foi avaliar a seletividade de herbicidas pré e pós-emergentes e a sua eficiência no controle de plantas daninhas, bem como o crescimento e a qualidade de hastes florais, na cultura do gladíolo (*Gladiolus* x *grandiflorus*), em duas épocas de cultivo. Os experimentos foram conduzidos a campo, onde os gladíolos plantados receberam a aplicação de herbicidas pré e pós-emergentes, com e sem controle mecânico das plantas daninhas. Aos 7, 14, 21 e 28 dias após a emergência (DAE), avaliaram-se o controle de monocotiledôneas e eudicotiledôneas, além da fitotoxicidade no gladíolo. Aos 28 DAE, também foi avaliada a massa seca da parte aérea das plantas daninhas e dos gladíolos. Os herbicidas pré-emergentes s-metolacloro e diuron e o pós-emergente haloxifope-p-metílico são seletivos ao gladíolo, em ambas as épocas de cultivo, o que possibilita a produção de hastes florais com qualidade comercial. Os herbicidas s-metolacloro e haloxifope-p-metílico também promovem controle eficiente de monocotiledôneas independentemente da época de cultivo. Embora, quando aplicados, saflufenacil e 2,4-D causem fitotoxicidade na fase vegetativa do gladíolo, não afetam a produção de hastes florais e controlam satisfatoriamente as eudicotiledôneas no segundo cultivo.

Termos para indexação: *Gladiolus* x *grandiflorus*, floricultura, fitotoxicidade, pós-emergência, pré-emergência, padrão de qualidade.

Introduction

Gladiolus (*Gladiolus* x *grandiflorus* Hort.) is a plant belonging to the family Iridaceae that is propagated by corms and used as a cut flower with a high acceptance in the flower market (Schwab et al., 2015; Tomiozzo et al., 2019). The species stands out for being easy to grow, having a low production cost, and for the elegance of its florets, which present a diversity of colors and formats, good post-harvest durability, and added value, resulting in a quick financial return (Tomiozzo et al., 2018; Bosco et al., 2021). Because of these agronomic and ornamental characteristics, the gladiolus is the most important species of a project, called Flores para Todos (flowers for all), aiming to stimulate flower production and, consequently, provide income for more than 150 families of family farmers from Northern to Southern Brazil (Uhlmann et al., 2019; Streck & Uhlmann, 2021).

Gladiolus plants are usually cultivated using the conventional system, characterized by soil turning and bed preparation (Bosco et al., 2021). However, according to these same authors, the soil is continuously exposed throughout cultivation because of the high frequency of soil mobilization and the low population density and lanceolate leaves of this crop, creating favorable conditions for the germination and emergence of weeds, which can negatively interfere with plant development and floral stem quality due to the low weed control in gladiolus (Forte et al., 2018; Martins et al., 2019). In that system, soil turning also causes alterations in the environment that can lead to propagule dispersal and the increase in weed germination (Schneider, 2007).

Even under conditions considered unfavorable for most cultivated plants, weeds show a high competitive ability, attributed to their rapid growth and initial development, efficient reproduction and dispersion mechanisms, and adaptability, which increase their potential to access limited resources of the environment, such as nutrients, light, and water (Fahad et al., 2015; Caratti et al., 2016). This competition negatively affects the growth and development of ornamental plants, reducing the quality and final yield of floral stems or corms, which are the propagation material of gladiolus plants (Manuja et al., 2005; Martins et al., 2019).

In ornamental crops, weed control is commonly carried out using the mechanical method, through weeding or uprooting, whose required labor increases production costs and may cause quality loss in the final product due to physical damage (Queiroz et al., 2016). The chemical method is an alternative for that type of production system, being one of the most applied in agriculture because it is easy to use and has a fast action on the target (Harker & O'Donovan, 2013).

Up to date, only two active ingredients are registered for weed control in gladiolus: sethoxydim, an acetyl-coenzyme A carboxylase inhibitor herbicide, indicated to be applied post-emergence for the control of monocotyledon weeds; and trifluralin, a microtubule assembly inhibitor to be applied pre-emergence for the control of mono- and eudicotyledon weeds (Agrofit, 2022). Therefore, studies are still necessary to determine the efficiency and selectivity of herbicides and to recommend possible chemical alternatives for weed management in this crop.

The objective of this work was to evaluate the selectivity of pre- and post-emergent herbicides and their efficiency in weed control, as well as the growth and quality of floral stems, in a gladiolus crop in two growing seasons.

Materials and Methods

Two field experiments were carried out in 2018 and 2019, in the winter-spring and summer-autumn growing seasons, respectively, in the experimental area of the Department of Phytosanitary Defense of Universidade Federal de Santa Maria, located in the municipality of Santa Maria, in the state of Rio Grande do Sul, Brazil (29°42'S, 53°43'W, at an altitude of 96 m). According to Köppen-Geiger's classification, the climate is Cfa, warm and wet subtropical, with no defined dry season. The values registered for the main climatic variables are: 1,830 mm average annual precipitation; 14.7 and 25.2°C minimum and maximum average temperatures, respectively; 77% relative humidity; and 16.4 MJ m^{-1} per day solar radiation (Wrege et al., 2012). The soil of the experimental area is classified as an Argissolo Vermelho distrófico arênico (Santos et al., 2018), i.e., a Paleaudalf (Soil Survey Staff, 2014).

According to Instituto Nacional de Meteorologia (INMET, 2022), specifically during the experimental period, in the first growing season, total precipitation was 499.6 mm and average temperature was 17.1°C, with minimum and maximum temperatures of 1.0 and 35.1°C, respectively (Figure 1 A). In the second season, total precipitation was 572.8 mm and average temperature was

20.5°C, with minimum and maximum temperatures of 7.9 and 36.3°C, respectively (Figure 1 B).

Gladiolus corms of the Jester cultivar were planted on July 18 in the winter-spring of 2018 and on February 22 in the summer-autumn of 2019, in beds with paired rows spaced at 0.40 m, with 0.20 m between plants in the row, at a depth of 10 to 15 cm, totaling 40 corms per plot. The experimental design was randomized complete blocks with four replicates, in which the experimental units consisted of the plots with 4.0 m of length and 1.0 m of width (4.0 m^2).

After planting, the average date of emergence was determined by monitoring plant emergence, considered when 50% of the plants in the plots were visible above soil surface. As plant emergence stabilized, thinning was carried out weekly, maintaining one seedling per corm aiming at a standardized production of a single stem. When gladiolus plants were between the V3 and V4 stages (three and four leaves, respectively), 350 kg ha^{-1} urea (45% N) were applied as topdressing in all experimental plots. The other management practices were planned using the PhenoGlad model (Uhlmann et al., 2017), which calculates the phenology of gladiolus plants based on meteorological temperature data. The phenological stages of the gladiolus plants were observed according to the scale proposed by Schwab et al. (2015).

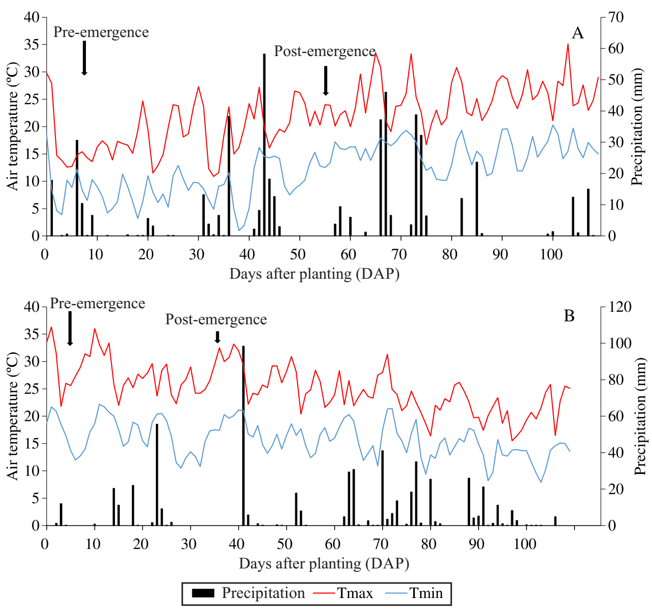

Figure 1. Meteorological data of minimum temperature, maximum temperature, and precipitation during the experimental periods in the winter-spring (A) and summer-autumn (B) growing seasons of 2018 and 2019, respectively, in the municipality of Santa Maria, in the state of Rio Grande do Sul, Brazil. The arrows represent the time of application of the pre- and post-emergent herbicides.

After the application of the treatments, the number of leaves of six gladiolus plants from the center of each plot was counted up to the final leaf number (FLN). The daily thermal time (STd, °C day) from emergence to FLN, corresponding to the vegetative phase, was calculated using the following equation: $STd = [(Tmax + Tmin)/2 - Tb]$, where Tmax and Tmin are the daily maximum and minimum air temperatures (°C), respectively, measured at the main climatological station of INMET, located approximately 1.5 km from the experimental area; and Tb is the base temperature of the crop, which is 2°C (Arnold, 1960; Uhlmann et al., 2017). The accumulated thermal time (STa, °C day) was calculated by the equation: $STa = \Sigma\, STd$. The phyllochron in each plant, defined as the time interval between the appearance of two successive leaves (°C day per leaf), was calculated by the inverse of the slope of the linear regression between leaf number and STa (Xue et al., 2004).

Both experiments were composed of ten treatments (T1 to T10) each. T1–T3 and T4–T8, respectively, consisted of the following pre- and post-emergent herbicides: T1, diclosulam (42 g a.i. ha^{-1}); T2, s-metolachlor (1,440 g a.i. ha^{-1}); T3, diuron (200 g a.i. ha^{-1}); T4, glyphosate (1,350 g a.i. ha^{-1}); T5, haloxyfop-p-methyl (120 g a.i. ha^{-1}); T6, saflufenacil (49 g a.i. ha^{-1}); T7, 2,4-D (1,005 g a.i. ha^{-1}); and T8, imazapyer + imazapic (70.5 + 24.5 g a.i. ha^{-1}). T9 and T10 were the control treatments without herbicide application, with (weeded check) and without (untreated check) mechanical weed control, respectively.

In the winter-spring and summer-autumn growing seasons, the pre-emergent herbicides were applied seven and five days after planting, respectively, and the post-emergent herbicides when the plants were in the V3 stage, which is the recommended time for the application of N topdressing (Schwab et al., 2015). Herbicides were applied using a CO_2-pressurized backpack sprayer equipped with six TeeJet XR 110.015 flat fan nozzles (TeeJet Technologies, Glendale Heights, IL, USA), spaced at 0.5 m, which was also the height of the target, and calibrated to provide an application volume of 150 L ha^{-1}. The time of application was under the climatic conditions recommended by the manufacturer. For the plots corresponding to the treatment with mechanical weed control, weeding was carried out approximately every 15 days with the aid of a hoe, maintaining the crop free from the negative interference of weeds.

The control of monocotyledons and eudicotyledons and their phytotoxicity to gladiolus plants were evaluated at 7, 14, 21, and 28 days after emergence (DAE) for pre-emergent herbicides and after the application of treatments (DAT) for post-emergent herbicides. For this, a visual scale ranging from 0 to 100% was used, representing the absence of injuries and the complete death of the plants, respectively (Frans et al., 1986). In 2018, there was no emergence of eudicotyledon weeds in the area treated with pre-emergent herbicides; therefore, only the control of monocotyledons was evaluated. To determine the predominant weeds, sampling was carried out using a 0.25 m^2 quadrat frame placed in two locations per plot.

In addition, the shoot dry matter (DM) of the weeds and gladiolus crop was evaluated, respectively, using weed plant material from within a 0.25 m^2 frame and two plants per plot collected at 28 DAE for pre-emergent herbicides and at 28 DAT for post-emergent herbicides. The weeds and gladiolus plants were placed, separately, in a forced-air circulation oven, at 60ºC, for 72 hours until reaching constant mass, and then weighed; the obtained value was converted to 1.0 m^2 for weeds and to gram per plant for gladiolus.

For gladiolus, maximum leaf area (LA) was determined at the R2 stage (harvesting point of the flower stem) by measuring the length and width of each leaf of the two plants collected per plot. The leaf area index (LAI) was calculated by dividing the sum of the LA of all leaves of the plant by the soil area occupied by each plant (800 cm^2), using the equation described by Schwab et al. (2014): LA = 0.644 (L.W), where L and W correspond to the length and width of the leaves, respectively. Furthermore, the quantitative parameters indicative of floral stem quality – such as stem length, spike length, stem diameter, and number of florets – were measured. However, the LAI and the quality parameters of the floral stem were not determined for the treatments with 2,4-D and imazapyr+imazapic in 2018 and with glyphosate in 2018 and 2019 since these herbicides caused the death of gladiolus plants and/or damaged the floral stems after being applied.

Variable data for all treatments were analyzed together, except those for the DM of weeds and gladiolus because they were collected at different times. The data were subjected to the analysis of variance using the F-test, at 5% probability, and, when statistical significance was observed, means were compared by the Scott-Knott test, also at 5% probability, using the R software (R Core Team, 2020). Data without statistical significance by the F-test was not considered.

Results and Discussion

The analysis of variance showed statistical significance for phytotoxicity (Table 1) and the control

Table 1. Phytotoxicity to gladiolus (*Gladiolus* x *grandiflorus*) plants at 7, 14, 21, and 28 days after crop emergence when pre-emergent herbicides were applied or after the application of post-emergent herbicides in the winter-spring and summer-autumn growing seasons of 2018 and 2019, respectively, in the municipality of Santa Maria, in the state of Rio Grande do Sul, Brazil[(1)].

Treatment	Phytotoxicity (%) to gladiolus			
	7 days[(2)]	14 days	21 days	28 days
	Winter-spring			
Weeded check	0d	0f	0e	0e
Untreated check	0d	0f	0e	0e
Diclosulam	19c	17d	18d	5e
S-metolachlor	15c	11e	3e	0e
Diuron	12c	24d	6e	5e
Saflufenacil	83a	86a	94a	95a
2,4-D	53b	55b	52b	50c
Glyphosate	18c	35c	55b	70b
Imazapyr+imazapic	18c	22d	31c	35d
Haloxyfop-p-methyl	3d	4f	2e	1e
CV[(3)] (%)	22.21	19.37	18.84	20.35
	Summer-autumn			
Weeded check	0d	0d	0c	0d
Untreated check	0d	0d	0c	0d
Diclosulam	31b	45a	51b	51b
S-metolachlor	18c	8c	1c	5d
Diuron	13c	10c	18c	1d
Saflufenacil	41a	35b	33b	34c
2,4-D	36a	41a	49b	38c
Glyphosate	31b	46a	74a	84a
Imazapyr+imazapic	23b	26b	44b	46b
Haloxyfop-p-methyl	6d	0d	0c	0d
CV (%)	33.49	29.22	48.05	18.82

[(1)]Means followed by equal letters, in the columns, do not differ by the Scott-Knott test, at 5% probability. [(2)]Number of days after gladiolus emergence when the diclosulam, s-metolachlor, and diuron pre-emergent herbicides were applied at pre-emergence or after the application of the saflufenacil, 2,4-D, glyphosate, imazapyr+imazapic, and haloxyfop-p-methyl post-emergent herbicides. [(3)]Coefficient of variation.

(Table 2) at 7, 14, 21, and 28 DAE or DAT, as well as for the stem length, phyllochron, and FLN growth variables in the two growing seasons (Table 3). However, the LAI and floral stem quality were significant only in the second season for pre- and post-emergent herbicides. Regarding the DM of weeds and gladiolus plants, significance was observed only in the treatments with post-emergent herbicides in the first season and both in the treatments with pre- and post-emergent herbicides in the second (Table 4). The results are presented separately according to the growing season.

Table 2. Control of monocotyledon weeds in gladiolus (*Gladiolus* x *grandiflorus*) at 7, 14, 21, and 28 days after crop emergence when pre-emergent herbicides were applied or after the application of post-emergent herbicides in the winter-spring and summer-autumn growing seasons of 2018 and 2019, respectively, in the municipality of Santa Maria, in the state of Rio Grande do Sul, Brazil[(1)].

Treatment	Control (%) of monocotyledon weeds			
	7 days[(2)]	14 days	21 days	28 days
	Winter-spring			
Weeded check	100a	100a	100a	100a
Untreated check	0f	0e	0d	0d
Diclosulam	93a	94a	92b	91a
S-metolachlor	93a	98a	94b	97a
Diuron	89a	88b	90b	85b
Saflufenacil	56d	28c	12c	7c
2,4-D	13e	10d	0d	0d
Glyphosate	80b	86b	87b	81b
Imazapyr+imazapic	53d	85b	97a	96a
Haloxyfop-p-methyl	67c	91b	99a	100a
CV[(3)] (%)	10.39	8.60	6.59	6.25
	Summer-autumn			
Weeded check	100a	100a	100a	100a
Untreated check	0e	0e	0c	0c
Diclosulam	92b	97a	97a	94a
S-metolachlor	95a	96a	97a	90a
Diuron	86b	80c	69a	53b
Saflufenacil	14d	15d	8c	5c
2,4-D	0e	0e	0c	3c
Glyphosate	91b	93a	86a	90a
Imazapyr+imazapic	74c	89b	93a	93a
Haloxyfop-p-methyl	89b	95a	91a	83a
CV (%)	8.53	6.02	21.72	11.26

[(1)]Means followed by equal letters, in the columns, do not differ by the Scott-Knott test, at 5% probability. [(2)]Number of days after gladiolus emergence when the diclosulam, s-metolachlor, and diuron pre-emergent herbicides were applied or after the application of the saflufenacil, 2,4-D, glyphosate, imazapyr+imazapic, and haloxyfop-p-methyl post-emergent herbicides. [(3)]Coefficient of variation.

In the first season, the haloxyfop-p-methyl herbicide presented the lowest phytotoxicity to the crop at 7 and 14 DAT, with values lower than 5% throughout the experimental period (Table 1). This herbicide is among those that inhibit the enzyme acetyl-coenzyme A carboxylase, promoting the destruction of the meristems of species of the family Poaceae; however, species from other families are frequently tolerant to it (Oliveira Júnior, 2011; Leal et al., 2020), which may explain the selectivity to gladiolus of the family Iridaceae. Queiroz et al. (2016) also found phytotoxicity values lower than 5% due to the application of fluazifop-p-butyl, quizalofop-p-ethyl, and sethoxidim at 28 DAT when evaluating the selectivity of different herbicides to the *Alpinia purpurata* (Vieill.) K.Schum.,

Table 3. Final leaf number (FLN), phyllochron (PHYL), leaf area index (LAI), and stem length (SL) of gladiolus (*Gladiolus* x *grandiflorus*) as a function of pre- and post-emergent herbicide application in the winter-spring and summer-autumn growing seasons of 2018 and 2019, respectively, in the municipality of Santa Maria, in the state of Rio Grande do Sul, Brazil[(1)].

Treatment	FLN	PHYL (°C day per leaf)	LAI	SL (cm)
		Winter-spring		
Weeded check	8.17a	151.55b	ns	94.03a
Untreated check	7.67a	160.59b	-	99.18a
Diclosulam	7.71a	157.65 b	-	89.30a
S-metolachlor	7.83a	151.10b	-	98.63a
Diuron	8.00a	155.45b	-	68.98b
Saflufenacil	3.68b	220.33b	-	-
2,4-D	4.45b	374.40a	-	-
Glyphosate	3.75b	332.06a	-	-
Imazapyr+imazapic	4.58b	357.62a	-	-
Haloxyfop-p-methyl	8.04a	152.25b	-	95.13a
CV[(2)] (%)	10.94	46.71	-	11.56
		Summer-autumn		
Weeded check	9.04a	138.57b	0.68a	90.87a
Untreated check	8.87a	137.58b	0.62b	77.78b
Diclosulam	7.13b	209.35a	0.32c	63.10b
S-metolachlor	8.96a	141.88b	0.72a	88.02a
Diuron	8.90a	129.62b	0.67a	92.11a
Saflufenacil	8.79a	132.27b	0.59b	83.81b
2,4-D	8.75a	134.48b	0.57b	75.23c
Glyphosate	4.08c	173.77a	-	-
Imazapyr+imazapic	4.74c	196.77a	0.30c	43.49e
Haloxyfop-p-methyl	8.70a	145.97b	0.77a	81.82b
CV (%)	6.28	15.30	12.64	9.31

[(1)]Means followed by equal letters, in the columns, do not differ by the Scott-Knott test, at 5% probability. [(2)]Coefficient of variation. [ns]Nonsignificant by the analysis of variance, at 5% probability.

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Strelitzia reginae Aiton, and *Heliconia psittacorum* L.f. ornamental monocotyledons. In general, the s-metolachlor, diuron, and diclosulam pre-emergent herbicides resulted in a low phytotoxicity to gladiolus, with values at 28 DAE similar to those of haloxyfop-p-methyl after 28 DAT and of the controls without herbicides (Table 1). Therefore, these pre-emergent herbicides could be considered selective to the gladiolus crop.

In the second season, the saflufenacil herbicide caused a phytotoxicity above 80% throughout the experimental period, whereas glyphosate, imazapyr+imazapic, and 2,4-D led to an intermediate phytotoxicity above 30% at 21 and 28 DAT (Table 1). Since the commercially acceptable phytotoxicity limit for gladiolus is 10%, the application of these herbicides is not recommended in this growing season (Richardson & Zandstra, 2006).

The control of monocotyledon weeds was above 90% at 28 DAT or DAE with the application of the haloxyfop-p-methyl, diclosulam, and s-metolachlor herbicides, but was slightly lower, 80% at 28 DAE, with that of diuron (Table 2). The DM obtained with the post-emergence application of glyphosate, imazapyr+imazapic, and haloxyfop-p-methyl did not differ in relation to that of the weeded check and was even similar to that of gladiolus plants when the latter herbicide was used (Table 4).

The predominant weed species were *Lolium multiflorum* Lam., *Anagallis arvensis* L., and *Ipomoea triloba* L. in the first season and *I. triloba* and *Raphanus sativus* L. in the second. In the untreated check in the second season, the DM of the monocotyledon species, mainly of *L. multiflorum*, was higher than that of the eudicotyledons (Table 4). Therefore, knowing the weed flora in each growing season is important for the production of floral stems, especially for All Souls' Day, one of their main peaks of demand in Brazil (Becker et al., 2020). In this scenario, farmers should decide on the use of pre- and post-emergence herbicides that are selective to gladiolus, registered, and that exert control over this weed class.

In general, the tested post-emergent herbicides, except haloxyfop-p-methyl, promoted a superior control of eudicotyledon species compared with the weeded check (Table 5). This result confirms that found for the DM of eudicotyledons, whose lowest values were obtained with the application of saflufenacil, 2,4-D, glyphosate, and imapazyr+imazapic, which did not differ from each other and from the weeded check (Table 4). Freitas et al. (2007) concluded that oxyfluorfen showed an effective control of 90% of the target species *Pilea microphylla* L., being selective to two orchid species – *Epidendrum ibaguense* Kunth and *Dendrobium* sp. This result is an indicative that, in addition to saflufenacil, other protoporphyrinogen oxidase inhibitors should be tested in gladiolus plants cultivated under Brazilian conditions in order to better understand the selectivity of these herbicides to the crop.

Table 4. Dry matter (DM) of eudicotyledon and monocotyledon weeds and of gladiolus (*Gladiolus* x *grandiflorus*) at 28 days after crop emergence when pre-emergent herbicides were applied or after the application of post-emergent herbicides in the winter-spring and summer-autumn growing seasons of 2018 and 2019, respectively, in the municipality of Santa Maria, in the state of Rio Grande do Sul, Brazil[(1)].

Treatment	Weed DM (g m^{-2})		Gladiolus DM (g per plant)
	Eudicotyledon	Monocotyledon	
	Winter-spring / Post-emergent herbicides		
Weeded check	0.10c	0.14b	11.82a
Untreated check	23.62b	175.89a	9.06a
Saflufenacil	0.13c	292.90a	2.82b
2,4-D	1.19c	245.60a	3.60b
Glyphosate	0.22c	8.12b	2.01b
Imazapyr+imazapic	2.17c	5.65b	4.40b
Haloxyfop-p-methyl	31.47a	8.67b	10.27a
CV[(2)] (%)	30.06	86.78	23.61
	Summer-autumn / Pre-emergent herbicides		
Weeded check	0.05b	0.18c	5.62a
Untreated check	28.17a	0.92a	8.34a
Diclosulam	0.04b	0.11c	2.65b
S-metolachlor	7.20b	0.07c	7.71a
Diuron	20.74a	0.62b	7.40a
CV (%)	51.60	47.98	37.45
	Summer-autumn / Post-emergent herbicides		
Weeded check	0.15b	0.19b	20.39a
Untreated check	29.87a	13.94a	23.71a
Saflufenacil	0.59b	12.01a	19.01a
2,4-D	1.63b	15.55a	10.87b
Glyphosate	1.36b	6.71b	5.63b
Imazapyr+imazapic	1.27b	0.78b	7.94b
Haloxyfop-p-methyl	31.12a	1.39b	17.42a
CV (%)	32.71	85.09	42.12

[(1)]Means followed by equal letters, in the columns, do not differ by the Scott-Knott test, at 5% probability. [(2)]Coefficient of variation.

In addition to their low phytotoxicity (Table 1), haloxyfop-p-methyl and the pre-emergent herbicides did not interfere with the growth and development of gladiolus plants, since no differences were observed between these treatments and the controls without herbicide application for FLN, phyllochron, and stem length (Table 3). However, further studies should be carried out using different rates and sites to confirm the results obtained both for phytotoxicity to gladiolus and the DM of the crop, important indicators of plant growth and development.

Contrastingly, the glyphosate, imazapyr+imazapic, and 2,4-D herbicides paralyzed the growth of gladiolus plants, stabilizing the FLN at approximately four leaves (Table 3) and, consequently, leading to higher phyllochron values, i.e., a longer interval between the appearance of sequential leaves on the stem. Moreover, the application of saflufenacil and glyphosate caused plant death and that of 2,4-D and imazapyr+imazapic, the deformation of leaves and floral stems, which made it impossible to evaluate the LAI and quality of floral stems at the R2 stage. These results are an indicative that these herbicides cannot be used in the management of weeds in the gladiolus crop.

Table 5. Control of eudicotyledon weeds in gladiolus (*Gladiolus* x *grandiflorus*) at 7, 14, 21, and 28 days after crop emergence when pre-emergent herbicides were applied or after the application of post-emergent herbicides in the winter-spring and summer-autumn growing seasons of 2018 and 2019, respectively, in the municipality of Santa Maria, in the state of Rio Grande do Sul, Brazil(1).

Treatment	Control (%) of eudicotyledon weeds			
	7 days(2)	14 days	21 days	28 days
	Winter-spring			
Weeded check	100a	100a	100a	100a
Untreated check	0d	0c	0b	0c
Saflufenacil	98a	98a	96a	94b
2,4-D	86b	94b	98a	93b
Glyphosate	71c	96b	98a	90b
Imazapyr+imazapic	73c	95b	98a	97a
Haloxyfop-p-methyl	0d	0c	0b	0c
CV(3) (%)	9.14	3.43	2.49	4.13
	Summer-autumn			
Weeded check	100a	100a	100a	100a
Untreated check	0d	0d	0d	0d
Diclosulam	92a	99a	98a	96a
S-metolachlor	78b	84b	81b	68b
Diuron	51c	66c	54c	34c
Saflufenacil	97a	97a	91a	89a
2,4-D	71b	92b	96a	94a
Glyphosate	79b	99a	96a	98a
Imazapyr+imazapic	61c	89b	97a	97a
Haloxyfop-p-methyl	0d	0d	0d	0d
CV (%)	17.72	6.52	7.12	15.52

(1)Means followed by equal letters, in the columns, do not differ by the Scott-Knott test, at 5% probability. (2)Number of days after gladiolus emergence when the diclosulam, s-metolachlor, and diuron pre-emergent herbicides were applied or after the application of the saflufenacil, 2,4-D, glyphosate, imazapyr+imazapic, and haloxyfop-p-methyl post-emergent herbicides. (3)Coefficient of variation.

Haloxyfop-p-methyl caused the lowest phytotoxicity to gladiolus at 7 and 14 DAT, with total plant recovery from this period onwards, not differing from the controls without herbicide application (Table 1). The diuron and s-metolachlor pre-emergent herbicides were also highly selective to gladiolus, showing a phytotoxicity of less than 5% at 28 DAE (Table 1), whereas glyphosate was not, causing a phytotoxicity above 80% at 28 DAT. Manuja et al. (2005), however, found that *Gladiolus* spp. plants with chlorotic spots at 7 DAT due to the application of glyphosate completely recovered from this phytotoxic effect at 21 DAT. These different results could be attributed to the time of application of glyphosate, which was at 90 days after planting in Manuja et al. (2005), when plants were more developed than at 50 days after planting in the present study.

The diclosulam and s-metolachlor pre-emergent herbicides and the glyphosate, imazapyr+imazapic, and haloxyfop-p-methyl post-emergent herbicides showed a control of monocotyledon weeds above 80% at 21 and 28 DAT or DAE, in both growing seasons (Table 2). For eudicotyledons, diclosulam, saflufenacil, 2,4-D, glyphosate, and imazapyr+imazapic stood out at 21 and 28 DAT, showing a control above 85% for this weed spectrum and not differing from the weeded check (Table 5). Of the herbicides with action on eudicots, diuron exerted the weakest control, which was below 40% at 28 DAE.

In the second growing season, eudicotyledon species were predominate in the untreated check, evidenced by their higher DM values compared with those of monocotyledons (Table 4). Therefore, chemical weed management in gladiolus plants between late summer and early autumn should prioritize selective pre- or post-emergent herbicides for the control of broad-leaved weeds.

Diclosulam and s-metolachlor caused greater reductions in the DM of monocotyledon and eudicotyledon weeds, not differing from the weeded check, which is in alignment with the results obtained for the control (Table 4). Regarding the post-emergent herbicides, saflufenacil, 2,4-D, glyphosate, and imazapyr+imazapic led to a lower DM of eudicotyledon weeds, whereas glyphosate, imazapyr+imazapic, and haloxyfop-p-methyl decreased the DM of monocotyledons, also not differing from the weeded check.

The application of imazapyr+imazapic and diclosulam resulted in a slower plant vegetative growth, evidenced by a longer phyllochron, lower FLN, and shorter stem length, as well as in a worse quality of floral stems, confirmed by a shorter spike length and lower final floret number compared with the weeded check (Tables 3 and 6). Saflufenacil and 2,4-D, however, did not differ from the weeded check regarding phyllochron, FLN, stem length, final floret number, and spike length, meaning that the initial phytotoxicity observed did not cause a greater damage to the production of floral stems. Furthermore, haloxyfop-p-methyl, diuron, and s-metolachlor did not affect plant growth since the values obtained for DM, FLN, phyllochron, and the LAI did not differ from those of the weeded check, allowing of the production of floral stems with an adequate quality for commercialization (Tables 3 and 4).

Table 6. Spike length (SPL), stem diameter (SD), and final floret number (FFN) of gladiolus (*Gladiolus* x *grandiflorus*) as a function of pre- and post-emergent herbicide application in the summer-autumn growing season of 2019, in the municipality of Santa Maria, in the state of Rio Grande do Sul, Brazil[(1)].

Treatment	SPL (cm)	SD (cm)	FFN
Weeded check	46.11a	0.93a	15.88a
Untreated check	35.66b	0.78b	11.94a
Diclosulam	31.42b	0.56c	8.87b
S-metolachlor	44.25a	0.92a	10.21a
Diuron	42.87a	0.90a	13.97a
Saflufenacil	41.58a	0.90a	14.45a
2,4-D	38.38a	0.82b	13.02a
Glyphosate	25.71c	0.74b	9.25b
Imazapyr+imazapic	38.82a	0.86a	13.62a
CV[(2)] (%)	13.50	8.85	12.5

[(1)]Means followed by equal letters, in the columns, do not differ by the Scott-Knott test, at 5% probability. [(2)]Coefficient of variation.

The LAI showed a positive linear relationship with the quality parameters of gladiolus flowers. The herbicide treatments that promoted higher values of this index were those that resulted in a longer stem length, a longer spike length, and a wider stem diameter (Table 3). Therefore, the lower values obtained for the LAI with the application of diclosulam and imazapyr+imazapic were related to a shorter stem length, shorter spike length, and narrower stem diameter, evidencing the importance of maintaining the leaf area for the growth and production of gladiolus flower stems and also of choosing selective herbicides that do not interfere negatively in this characteristic (Table 6). According to Silva et al. (2016) and Trachta et al. (2020), larger leaf areas allow of a greater interception of solar radiation, favoring the production, through photosynthesis, of photoassimilates that are, then, allocated to the vegetative and reproductive organs of the plants, enabling their growth and development. Therefore, any factor that interferes with leaf area can affect plant yield, whether in the form of grains as commodities or floral stems as ornamental plants.

In addition to the plant protection products registered for gladiolus, the obtained results are an indicative that there are other active ingredients selective to the species and with a good efficiency in weed management. Although the active ingredients tested in the present study are not recommended specifically for gladiolus, these findings may support future work aiming to include this crop in the label of other products. However, further research needs to be carried out to confirm the behavior of the evaluated herbicides.

Conclusions

1. The s-metolachlor and diuron herbicides applied at pre-emergence and haloxyfop-p-methyl at post-emergence are selective to gladiolus (*Gladiolus* x *grandiflorus*) regardless of the growing season and do not hinder crop growth and floral stem quality.

2. S-metolachlor and haloxyfop-p-methyl promote an efficient control of monocotyledon weeds at pre- and post-emergence, respectively, in the winter-spring and summer-autumn cultivation of gladiolus plants.

3. For cultivation in summer-autumn, the application of saflufenacil and 2,4-D causes phytotoxicity to gladiolus but does not affect the production of floral stems, controlling eudicotyledon weeds.

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