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Weed Control and Selectivity of Four Herbicides Applied in Pre-Emergence on Two Sunflower Cultivars

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Abstract: The sunflower (*Helianthus annuus* L.) is an oleaginous plant that shows high suitability for cultivation in Brazil. However, the performance of the crop is influenced by factors such as weed interference, mainly because of the few selective herbicide options. Thus, the objective of this study was to evaluate weed control and selectivity of four pre-emergent herbicides applied to two sunflower cultivars in sandy and clayey soils. Two field experiments were conducted in a randomized block design with a 2 × 6 factorial scheme, two cultivars (CF 101 and M 734) and six treatments with S-metolachlor (1920 g a.i. ha^{-1}), sulfentrazone (150 g a.i. ha^{-1}), flumioxazin (40 g a.i. ha^{-1}), and trifluralin (1780 g a.i. ha^{-1}) and two controls, one with weeding and the other without weeding and without herbicide application, in soils with contrasting textures (sandy and clayey). No injury symptoms were observed in both cultivars, regardless of soil texture. The cultivar M 734 exhibited the highest values of the agronomic parameters evaluated. The treatment with flumioxazin provided control of more than 90% of the weeds in clayey soil and more than 64% in sandy soil. The yield of both cultivars was lower in the sandy soil. Thus, all herbicide treatments were selective for both cultivars tested, since they did not interfere with sunflower grain yield.

Keywords: *Helianthus annuus* L.; injury level; chemical control; soil type

Citation: dos Santos, E.G.; Inoue, M.H.; Guimarães, A.C.D.; Bastos, J.S.Q.; Mendes, K.F. Weed Control and Selectivity of Four Herbicides Applied in Pre-Emergence on Two Sunflower Cultivars. *Crops* **2023**, *3*, 139–147. https://doi.org/10.3390/crops3020014

Academic Editor: Kenneth J. Moore

Received: 9 March 2023
Revised: 13 April 2023
Accepted: 19 April 2023
Published: 4 May 2023

1. Introduction

Sunflower (*Helianthus annuus* L.) stands out as a crop with products and byproducts used in human and animal food and the production of biofuels [1]. In addition, sunflower presents importance as an alternative for second-crop cultivation due to its agroeconomic advantages for production systems. In the 2019/20 harvest, it presented a production of 74.9 thousand tons, with emphasis on the Brazilian Midwest region, considered the main sunflower-producing region [2].

Although it is a crop with great agroeconomic potential, there is little information about plant health management, mainly because sunflower is a species very susceptible to interference imposed by weeds [3]. This is further compounded by the limited information available on effective weed management strategies for sunflower cultivation [4]. Weed competition can cause substantial damage to sunflower crops, leading to reductions in plant size, leaf area, stem diameter, and capitulum diameter [5]. It is, therefore, imperative to develop effective weed management strategies to mitigate the impact of weeds on sunflower yield and quality.

Effective weed control is crucial in sunflower cultivation since the crop has slow initial growth, which provides little soil coverage and favors weed growth [4]. According to Alves et al. [6], the critical period of weed competition in sunflower cultivation is the first 30 days after plant emergence. During this period, weed interference can cause significant yield losses in sunflowers, with losses of up to 2.5 kg ha^{-1} reported by Brighenti et al. [7] depending on the weed species.

However, there is little information available regarding herbicide selectivity for sunflowers. Additionally, the options for herbicides registered for sunflowers in Brazil are limited, especially for the control of dicotyledonous weeds. Sunflower is a highly sensitive crop to many herbicides, which is why post-emergence herbicides such as lactofen, fomesafen, and chlorimuron-ethyl are typically applied to minimize the risk of crop damage [8]. As a result, pre-emergent herbicides are less commonly used in sunflower cultivation. On the other hand, it is important to note that there can be significant differences in herbicide sensitivity and yield interference among sunflower cultivars (hybrids). Therefore, it is crucial to assess the specific characteristics of each variety before implementing weed control practices in order to maximize efficiency and minimize adverse impacts.

The control efficiency of pre-emergent herbicides is influenced by several factors, including soil texture. In general, herbicides tend to bind more strongly to fine-textured soils, such as clay soils, compared to coarse-textured soils, such as sandy soils. This can result in reduced herbicide availability for absorption by weeds present in the seed bank, and hence, reduced control efficiency. Furthermore, soil texture also affects herbicide movement in the soil profile, with greater leaching potential in coarse-textured soils, which can lead to off-target movement and potential environmental risks [9]. Therefore, the choice and application of pre-emergent herbicides should take into account the soil texture and other relevant soil properties to optimize weed control and minimize environmental risks.

S-metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-((1S)-2-methoxy-1-methylethyl) acetamid) is a selective herbicide, absorbed through roots and shoots, pre-emergent, and belongs to the chloroacetamide chemical family and causes inhibition of synthesis of very long-chain fatty acids (VLCFA). Sulfentrazone (N-[2,4-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide) is a herbicide of the triazinone chemical family, absorbed by roots and foliage and translocated, and acts by inhibiting the enzyme protoporphyrinogen oxidase (PPO). Trifluralin (2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine) is a selective pre-emergent herbicide that belongs to the dinitroaniline chemical family, with inhibition of mitosis and cell division (microtubule assembly inhibition). Flumioxazin (2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3(2H)-dione) is a pre-emergent herbicide that belongs to the pyridazinone chemical family, and it works by inhibiting the enzyme PPO, similar to sulfentrazone [10].

Studies on herbicides used in sunflower crops, especially pre-emergent herbicides, are essential since the crop's early growth is the most susceptible stage. Thus, the objective of this study was to evaluate the weed control and selectivity of S-metolachlor, sulfentrazone, trifluralin, and flumioxazin herbicides applied in pre-emergence on two sunflower cultivars grown in sandy and clayey soils, since the behavior of herbicides is affected by soil characteristics.

2. Materials and Methods

The study was conducted in two experimental areas in the Parecis region, belonging to the municipality of Nova Marilândia, MT, Brazil (Area 1: latitude 14°12′14.39″ S, longitude 57°33′24.51″ W, and altitude of 644 m; Area 2: latitude 14°15′11.63″ S, longitude 57°33′36.48″ W, and altitude of 590 m).

These areas presented distinct soil types, characterized as two Oxisols (*Latossolo Vermelho* and *Latossolo Amarelo*), and their physical and chemical characteristics are described in Table 1.

The experimental design used was a randomized block design with a 2 × 6 factorial scheme with four repetitions, analyzing two cultivars (M 734 and CF 101) and six control methods (four chemicals and two controls, one without application and the other with weeding), in two soils with different textures (clayey and sandy), with independent experiments in each soil type. In the chemical treatments, the herbicides used were: S-metolachlor

(1920 g a.i. ha^{-1}), sulfentrazone (150 g a.i. ha^{-1}), flumioxazin (40 g a.i. ha^{-1}), and trifluralin (1780 g a.i. ha^{-1}), with the same treatments and doses in both soil types.

Table 1. Chemical and physical characteristics of soil samples in the experimental areas (0–20 cm depth) in Nova Marilândia, MT, Brazil, 2021.

Area	pH	Al^{3+} + H^+	Ca^{2+} + Mg^{2+}	K^+	P	OM	BS	Sand	Silt	Clay
	(H_2O)	(cmolc dm^{-3})	(mg dm^{-3})	(g dm^{-3})			(%)		(%)	
1	5.80	2.10	4.20	0.20	6.20	2.34	67.40	35	7	58
2	4.90	2.91	3.70	0.18	6.30	1.98	56.20	74	14	12

pH: the potential of hydrogen, Al^{3+} + H^+: exchangeable acidity, Ca^{2+}: calcium, Mg^{2+}: magnesium, K^+: potassium, P: phosphorus, OM: organic matter, BS: base saturation. Source: Plante Certo Laboratory, Várzea Grande, MT, Brazil.

The experiment was arranged in 3 $\times$ 5 m plots, totaling 720 m^2 of usable area. Sowing in both areas (conventional system) occurred on 15 March 2020, mechanically with the aid of a seeder with a vacuum distribution system, regulated to distribute 2.1 seeds per linear meter and a spacing of 0.45 m between rows, totaling 46,666 thousand seeds ha^{-1}.

Fertilization was applied using NPK (30-10-10 formulation) at 200 kg ha^{-1}. As the predecessor crop was soybean, desiccation of weed and volunteer soybean was performed 7 days before planting with 2,4-D + glyphosate (201 + 1017 g a.e. ha^{-1}). The other chemical treatments on sunflowers followed the standard of the farm according to the needs throughout the crop cycle, such as nutritional management and pest and disease management.

The herbicides were applied on the same day as sowing using a CO_2 backpack sprayer equipped with six XR 110.02 fan spray tips with a syrup volume of 120 L ha^{-1} and a pressure of 200 kPa. At the time of application, the average temperature was around 26.8 °C, with wind varying between 0.3 and 0.9 m s^{-1} and relative humidity around 82%. There was sufficient rainfall in the first week following the herbicide application to activate the products present in the soil.

The visual evaluations of weed control and injury level of the crop by herbicides were performed at 7, 14, 21, and 28 days after the application (DAA) of treatments, using a scale of 0 to 100%, where 0 corresponds to no damage to plants and 100 corresponds to the death of all plants.

Besides the weed control and selectivity evaluations, agronomic characteristics such as capitulum insertion height, stem diameter, capitulum diameter, the weight of 1000 achenes, and sunflower yield were evaluated only middle four rows.

The sunflower capitulum (head) insertion height was measured from ground level to the capitulum insertion, and the stem diameter was 5 cm above the ground. Both variables were analyzed at flowering (R5.5) by averaging 20% of the plants in the sampled area (middle two rows) of each experiment plot. Capitulum diameter was assessed at the point of physiological maturity by the average of 20% of the plants in the area, using a tape measure.

The weight of one thousand achenes (seed) was obtained, in grams, by weighing it on a high precision scale. The yield was obtained after the harvest of the entire sunflower sampled area, extrapolated to kilograms per hectare. These variables had their values corrected to 13% humidity.

The climatic data during the period of the experiment were obtained from the INMET [11] since some climatic factors directly influence the behavior of herbicides in the soil. The areas studied are close to this rain station.

All data obtained met the assumptions and were subjected to analysis of variance (ANOVA) to verify the interaction between the factors analyzed by the F test, and when significant, the means were compared by the Tukey test ($p < 0.05$).

3. Results

No differences were observed for the level of injury to plants in all the seasons evaluated, and the results were similar to those of the control (no injury). The non-occurrence of injury can be attributed to the low rainfall volume in the study areas, as presented in Figure 1, which affects the behavior of these herbicides in the soil.

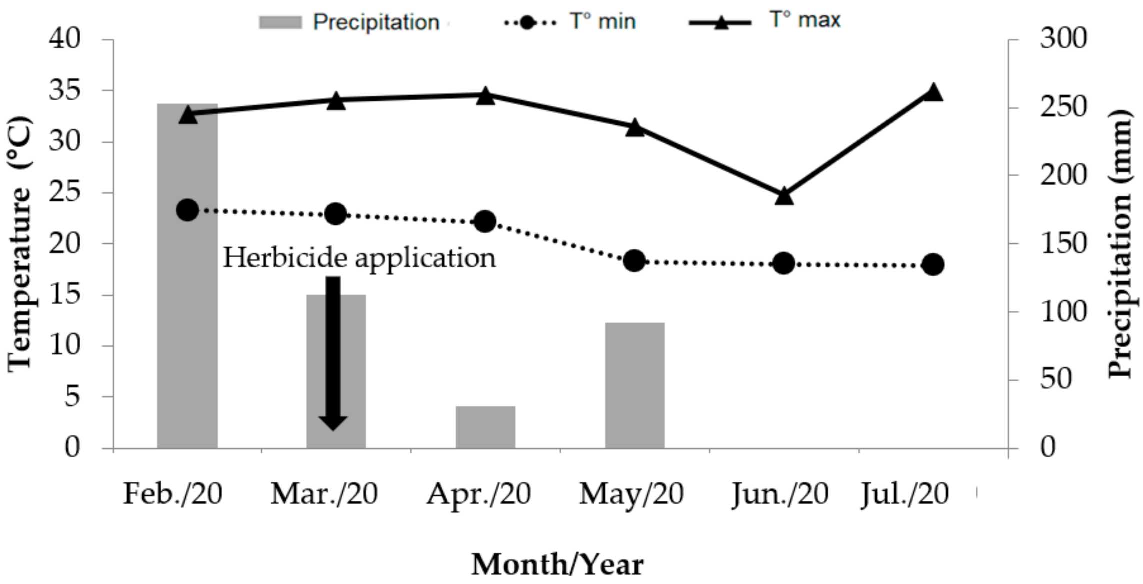

Figure 1. Monthly averages of precipitation and air temperatures (maximum and minimum) for the municipality of Nova Marilândia, MT, Brazil, between February and July 2020. Source: Data from the INMET [11].

There was no interaction (F = 0.55, $p > 0.05$) among the weed control for factors (cultivars and treatments) at 21 and 28 DAA. Regarding weed control, the evaluations carried out at 7 and 14 DAA, with the exception of the control without weeding, maintained 100% control levels. In the evaluations conducted at 21 and 28 DAA, differences were observed in comparison to the control, but there were no differences between chemical treatments in sandy soil for the cultivars M734 and CF101. In clayey soil, despite the low variation, it was possible to observe differences between chemical treatments as of the evaluation at 21 and 28 DAA: the treatments to which the plants were submitted, trifluralin and flumioxazin, presented control levels above 89% in cultivar CF101. In cultivar M 734, S-metolachlor also showed high control levels, above 88%, not differing from the weeded witness. In contrast, the sulfentrazone treatment showed the lowest levels of control in both cultivars, close to 79 and 76% at 21 and 28 DAA, respectively (Table 2).

Regarding agronomic parameters, with respect to capitulum insertion height, there was no interaction (F = 0.41, $p > 0.05$) among the factors (cultivars and treatments). The cultivar CF101 did not differ between treatments in clayey and sandy soils (Table 3). On the other hand, the mean insertion height of the capitulum of cultivar M734 differed between the control and trifluralin treatments in sandy soil, in which the plants subjected to the latter showed the highest mean height of 110.75 cm (Table 3), which may be related to better weed control in the plots subjected to trifluralin treatment in sandy soil (Table 2).

Regarding stem diameter, there was no interaction (F = 0.92, $p > 0.05$) among the factors (cultivars and treatments). Plants subjected to chemical treatments did not differ from the controls in the cultivar CF 101, with its highest average in plants that received treatment with S-metolachlor in clayey soil with 23.50 cm (Table 4). The plants of cultivar M 734 in clayey soil showed a larger stem diameter in the treatment with weeding compared to the chemical treatments (S-metolachlor, sulfentrazone, and trifluralin). In sandy soil, despite the relatively smaller stem diameter, no differences were observed between the chemical treatments, differing only when compared to the control without weeding (Table 4).

Table 2. Weed control in sunflower cultivars CF 101 and M 734 in sandy and clayey soils at 21 and 28 days after application (DAA) of four pre-emergent herbicides.

Time	Herbicide	Clayey		Sandy	
		CF 101	M 734	CF 101	M 734
21 DAA	Control without weeding	0.00 d	0.00 c	0.00 c	0.00 c
	Control with weeding	100.00 a	100.00 a	100.00 a	100.00 a
	S-metolachlor	80.00 bc	91.00 ab	75.25 b	78.75 b
	Sulfentrazone	79.00 c	78.75 b	71.75 b	65.75 b
	Trifluralin	91.75 ab	85.50 b	82.50 b	77.75 b
	Flumioxazin	96.50 a	91.50 ab	72.00 b	73.25 b
	CV (%)	6.99	7.54	9.89	13.71
28 DAA	Control without weeding	0.00 d	0.00 d	0.00 c	0.00 c
	Control with weeding	100.00 a	100.00 a	100.00 a	100.00 a
	S-metolachlor	78.25 bc	88.75 abc	72.75 b	74.75 b
	Sulfentrazone	76.25 c	76.25 c	62.00 b	62.00 b
	Trifluralin	89.00 ab	82.25 bc	78.25 b	74.50 b
	Flumioxazin	94.75 a	91.50 ab	64.75 b	64.25 b
	CV (%)	7.14	8.25	11.37	13.81

Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$). CV: Coefficient of Variation.

Table 3. Capitulum insertion height (cm) at the flowering stage of sunflower (R5.5) of cultivars CF 101 and M 734, after application of four herbicides in the pre-emergence of the crop in sandy and clayey soil.

Herbicide	Clayey		Sandy	
	CF 101	M 734	CF 101	M 734
Control without weeding	141.25 a	155.00 a	92.50 a	96.25 b
Control with weeding	143.25 a	163.75 a	93.00 a	103.00 ab
S-metolachlor	146.75 a	163.50 a	89.00 a	104.50 ab
Sulfentrazone	144.25 a	159.25 a	92.50 a	101.00 ab
Trifluralin	140.75 a	161.00 a	89.75 a	110.75 a
Flumioxazin	143.50 a	161.75 a	88.75 a	102.75 ab
CV (%)	3.36	2.77	7.44	4.61

Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$). CV: Coefficient of Variation.

Table 4. Stem diameter (cm) in sunflower plants of cultivars CF 101 and M 734 after application of four herbicides in pre-emergence of the crop in sandy and clayey soil.

Herbicide	Clayey		Sandy	
	CF 101	M 734	CF 101	M 734
Control without weeding	22.70 a	30.05 ab	14.77 b	16.05 b
Control with weeding	23.12 a	31.12 a	17.22 a	19.40 a
S-metolachlor	23.50 a	28.97 b	15.70 ab	19.15 a
Sulfentrazone	23.05 a	29.30 b	15.20 ab	19.62 a
Trifluralin	22.72 a	28.87 b	15.65 ab	20.07 a
Flumioxazin	24.55 a	30.22 ab	15.12 ab	19.82 a
CV(%)	8.31	2.15	6.74	6.15

Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$). CV: Coefficient of Variation.

For capitulum diameter, there was no interaction (F = 0.80, $p > 0.05$) among factors (cultivars and treatments). Differences were observed in the cultivar M734 in the soil of clayey texture, in which the plants submitted to treatment with sulfentrazone stood out with 21.12 cm, not differing from the control with weeding (21.35 cm), both being superior to the control without weeding (20.12 cm) (Table 5).

Table 5. Diameter of the capitulum (cm) in sunflower plants of cultivars CF 101 and M 734 after application of four herbicides in pre-emergence of the crop in sandy and clayey soil.

Herbicide	Clayey		Sandy	
	CF 101	**M 734**	**CF 101**	**M 734**
Control without weeding	17.34 a	20.12 b	11.17 a	16.05 a
Control with weeding	17.52 a	21.35 a	11.80 a	16.75 a
S-metolachlor	17.36 a	20.90 ab	11.75 a	16.47 a
Sulfentrazone	17.44 a	21.12 a	11.60 a	16.77 a
Trifluralin	17.74 a	20.70 ab	11.47 a	16.47 a
Flumioxazin	17.35 a	20.80 ab	11.35 a	16.47 a
CV (%)	5.04	1.77	2.55	2.54

Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$). CV: Coefficient of Variation.

Regarding the weight of 1000 achenes, there was no interaction (F = 0.12, $p > 0.05$) among the factors (cultivars and treatments). There was also no difference between chemical treatments, differing only compared to the witness without weeding in cultivar M 734 in both soils (Table 6).

Table 6. Weight of 1000 achenes (g) in sunflower plants of cultivars CF 101 and M 734 after application of four herbicides in the pre-emergence of the crop in sandy and clayey soil.

Herbicide	Clayey		Sandy	
	CF 101	**M 734**	**CF 101**	**M 734**
Control without weeding	58.50 a	88.50 b	26.75 a	51.00 b
Control with weeding	55.00 a	92.75 a	29.25 a	55.25 ab
S-metolachlor	56.50 a	92.00 ab	29.75 a	55.75 a
Sulfentrazone	57.00 a	92.25 a	27.75 a	55.75 a
Trifluralin	59.00 a	93.25 a	26.75 a	58.25 a
Flumioxazin	57.50 a	91.00 ab	27.00 a	56.00 a
CV (%)	5.32	1.69	5.68	3.49

Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$). CV: Coefficient of Variation.

Regarding grain yield, there was no difference between the treatments in clayey soil in both cultivars, with the exception of cultivar M 734, in which the plants from the control without weeding differed from the other treatments with the lowest yield (2469 kg ha^{-1}). This fact can be attributed to the genetic characteristics of the cultivar, which has a longer cycle and slow initial growth, thus being more affected by weed interference. In sandy soil, there was a difference only in relation to the cultivar M 734 in plants submitted to treatment with S-metolachlor, which stood out with the highest average (1291 kg ha^{-1}), different from plants from the control without weeding, which had the lowest average yield (1246 kg ha^{-1}) with no interaction between the factors (cultivars and treatments) (F = 0.98, $p > 0.05$) (Table 7).

Table 7. Grain yield (kg ha^{-1}) in sunflower plants of cultivars CF 101 and M 734 after application of four pre-emergent herbicides in sandy and clayey soil.

	Clayey		Sandy	
Herbicide	**CF 101**	**M 734**	**CF 101**	**M 734**
Control without weeding	2597.00 a	2469.00 b	846.00 a	1246.00 b
Control with weeding	2896.00 a	2604.00 a	867.00 a	1285.00 ab
S-metolachlor	2845.00 a	2574.00 a	866.00 a	1291.00 a
Sulfentrazone	2712.00 a	2550.00 a	853.00 a	1268.00 ab
Trifluralin	2870.00 a	2564.00 a	859.00 a	1273.00 ab
Flumioxazin	2910.00 a	2572.00 a	865.00 a	1282.00 ab
CV (%)	10.91	1.36	2.23	1.42

Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$). CV: Coefficient of Variation.

4. Discussion

In sunflowers, no injury was observed with the application of the herbicides, and these results diverge from the evaluation performed by Brighenti et al. [7], who observed plant injury at 30 DAA in the treatment submitted with sulfentrazone (350 g a.i. ha^{-1}) in pre-emergence of the cultivar CF 101 sunflower in Oxisol. In other cultivars, Inoue et al. [12] also observed plant injury levels at 7 DAA with S-metolachlor (1920 g a.i. ha^{-1}) and sulfentrazone (600 g a.i. ha^{-1}). On the other hand, Pannacci et al. [13] found that a mixture of S-metolachlor and acetochlor applied pre-emergence, followed by a post-emergence application of nicosulfuron and dicamba, provided the most effective control of both grass and broadleaf weeds in sunflower crops.

The use of pre-emergent herbicides is usually influenced by several factors, among them climatic and soil conditions. Temperature and soil moisture both directly affect the behavior of these herbicides, influencing the leaching and degradation of the product. For example, despite the Arenic Hapludult soil being relatively sandy, which often results in poorer herbicide sorption and increases its molecular biotransformation and leaching, the time half-life degradation (DT_{50}) value for sulfentrazone found in the present study's laboratory was 172.4 days at 27 °C and 70% of water holding capacity [14]. Environmental conditions also affected soil microbial activity and consequently of the persistence of S-metolachlor in the soil [15]. At 70% moisture content and 30 °C incubation, trifluralin rapidly degraded, with a half-life of 5.80 days and a dissipation time of 182.01 days [16]. The authors found over the measured temperature range, the DT_{50} of this herbicide tended to double with every 10 °C drop in temperature; trifluralin has the capacity to linger in clay loam soil for several years at temperatures below 20 °C, which may have an impact on subsequent crops in a rotation. Flumioxazin stability in solution and field dissipation indicate that, with the input of thermal energy, degradation can be rapid; and even at the lowest levels of solar radiation and soil temperature, the energy from these environmental measures exceeded the activation energy needed for flumioxazin degradation [17].

Therefore, after the application of pre-emergent herbicides, many of these products require rain or irrigation for their activation. For most of these products, precipitation is required within 7–14 DAA so that they can exert weed control after germination [18,19], a condition that did not occur after the application of treatments, precipitation volumes being recorded only 6 days after application, and still in low volumes, totaling only 74.3 mm in the accumulated 15 days after application (Figure 1).

This information justifies the few variations observed between chemical treatments since the efficiency of pre-emergent herbicides was affected by the climatic conditions during the harvest. Under low-soil-moisture conditions, their effectiveness decreases considerably, as does the phytosociological composition of the weed communities that depend on soil moisture to trigger the germination process. This is especially evident in sandy soil, where all chemical treatments showed inferior control when compared to those obtained in clayey soil (Table 2).

According to Jursík et al. [20] the herbicides used in sunflower pre-emergence, linuron, prosulfocarb, and pethoxamid had their efficiency influenced by soil moisture, not being recommended for dry regions or in dry conditions after sowing. This information corroborates the results observed by Steckel et al. [21] for S-metolachlor in corn crops. The results found that this crop requires precipitation within 7 to 10 DAA for adequate movement into the active weed seed zone and that they are generally up to 5 cm deep.

The results found in this study for sunflower plant height are in agreement with Mascarenhas et al. [3], who obtained higher mean heights in treatments with trifluralin application, which did not differ from fenoxaprop-p-ethyl, sethoxydim, and alachlor. Furthermore, the sunflower stem diameter data in this study are in disagreement with the results obtained by Brighenti et al. [7], who concluded that the values of stem and capitulum diameters were similar to the control when sulfentrazone was tested at doses of 350 and 600 g a.i. ha^{-1}.

Silva et al. [22], studying periods of weed interference for hybrid M 734, reported a decrease of 9.56% in the average value of capitulum diameter when comparing treatments in the absence and presence of weeds throughout the cycle.

The data observed in this study corroborate with the study conducted by Queiroz [23], in which flumioxazin (50 g a.i. ha^{-1}) and sulfentrazone (400 g a.i. ha^{-1}) did not cause different values from the witness for the sunflower capitulum diameter characteristic.

The negative impact of weeds on sunflower yields was most pronounced during the early growth stages of the crop. In this phase, climatic conditions can also affect weed emergence, resulting in less competition during the most critical period of interference. However, if left uncontrolled, weeds can quickly become a significant problem and severely impact sunflower yields later in the season. Therefore, effective weed management strategies that address both pre- and post-emergent control measures are crucial for maintaining optimal sunflower growth and yield.

5. Conclusions

The present study investigated the selectivity and weed control efficiency of the herbicides S-metolachlor, sulfentrazone, trifluralin, and flumioxazin when applied to two cultivars of sunflower. Results demonstrated that all herbicides were selective to the sunflower crop and did not interfere with grain yield, regardless of soil texture. Pre-emergence application of S-metolachlor, trifluralin, and flumioxazin exhibited potential for use in sunflower crops. However, in sandy soil, the efficacy of the herbicides was significantly reduced, likely due to low soil moisture levels. These findings suggest that soil type should be taken into account when selecting herbicides for sunflower crop management.

Author Contributions: Conceptualization, E.G.d.S., M.H.I., A.C.D.G. and K.F.M.; methodology, E.G.d.S., M.H.I. and A.C.D.G.; software, A.C.D.G. and K.F.M.; validation, E.G.d.S., M.H.I., A.C.D.G., J.S.Q.B. and K.F.M.; formal analysis, A.C.D.G. and K.F.M.; investigation, E.G.d.S., M.H.I. and J.S.Q.B.; resources, E.G.d.S. and M.H.I.; data curation, A.C.D.G. and K.F.M.; writing—original draft preparation, E.G.d.S., M.H.I., A.C.D.G., J.S.Q.B. and K.F.M.; writing—review and editing, K.F.M.; visualization, E.G.d.S.; supervision, M.H.I. and A.C.D.G.; project administration, E.G.d.S.; funding acquisition, M.H.I. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank the "Programa de Pós-Graduação em Ambiente e Sistema de Produção Agrícola" (UNEMAT, Tangará da Serra, MT, Brazil).

Conflicts of Interest: The authors declare no conflict of interest.

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