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Original Article

Selectivity of herbicides used in corn on *Crotalaria ochroleuca* G. Don

Seletividade de herbicidas utilizados em milho sobre *Crotalaria ochroleuca* G. Don

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Abstract

In the cropping systems that integrate the corn crop, the insertion of *Crotalaria ochroleuca* G. Don is predominantly intercropped. In this context, there is a need to observe herbicides that present selectivity for this sunn hemp species. The objective of this study was to evaluate the selectivity of pre and post-emergent herbicides on *C. ochroleuca*. Two field experiments were conducted in randomized blocks with four replications, involving the pre-emergence and post-emergence application of different herbicide treatments. For the pre-emergent ones, amicarbazone, atrazine and flumioxazin provided phytotoxicity higher than 90% and, consequently, low plant biomass. On the other hand, acetochlor and s-metolachlor did not cause phytotoxicity and did not affect the dry mass of crotalaria. In post-emergence, atrazine + mesotrione showed phytotoxicity >95%, followed by nicosulfuron and 2.4-D with phytotoxicity between 50-60%, whereas tembotrione did not cause injury to the plants. Thus, it was found that among the pre-emergent, acetochlor and s-metolachlor were selective, and for the emerging powders, only tembotrione was the most selective for all parameters analyzed.

Keywords: green manure, acetochlor, phytotoxicity, pre-emergent, post-emergent.

Resumo

Nos sistemas de cultivo que integram a cultura do milho, a inserção de *Crotalaria ochroleuca* G. Don é predominantemente consorciada. Nesse contexto, há a necessidade de se observar herbicidas que apresentem seletividade para esta espécie de crotalária. O objetivo deste trabalho foi avaliar a seletividade de herbicidas pré e pós-emergentes sobre *C. ochroleuca*. Dois experimentos de campo foram conduzidos em blocos casualizados com quatro repetições, envolvendo a aplicação de diferentes tratamentos herbicidas em pré-emergência e pós-emergência. Para os pré-emergentes, amicarbazone, atrazina e flumioxazin proporcionaram fitotoxicidade superior a 90% e, consequentemente, baixa biomassa vegetal. Por outro lado, o acetocloro e o s-metolacloro não causaram fitotoxicidade e não afetaram a massa seca da crotalária. Em pós-emergência, atrazina + mesotrione apresentou fitotoxicidade >95%, seguido de nicosulfuron e 2,4-D com fitotoxicidade entre 50-60%, enquanto o tembrotrione não causou danos às plantas. Assim, verificou-se que entre os pré-emergentes, o acetocloro e o s-metolacloro foram seletivos, e para os pós emergentes, apenas o tembotrione foi o mais seletivo para todos os parâmetros analisados.

Palavras-chave: adubação verde, acetocloro, fitotoxicidade, pré-emergente, pós-emergente.

1. Introduction

In maize, the search for alternative methods for sustainable agricultural production has increased significantly in recent years, especially in the Cerrado region (Costa et al., 2017). Thus, the sustainability of agricultural systems can be compromised in monocultures (Braz et al., 2016) because there is no adoption of alternative crops in the diversification of the production system (Richetti et al., 2021). As options, one can cite the cultivation of species that improve soil quality, such as green manures, which can be used in intercropping, rotation and/or succession with maize (Castro et al., 2021).

Legumes such as *Crotalaria ochroleuca* stand out among these crops, which are highly positioned in rotation and/or intercropped with agricultural crops due to their high potential for nitrogen fixation, nematode control and reduction in weed population (Silva et al., 2020). Despite these benefits,

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Table 1. C hemical and physical soil analysis conducted at the experiment site.

Chemical and physical analysis of the soil											
pH	**OM**	**Q**	**K**	**Ca**	**Mg**	**Al**	**H + Al**	**SB**	**ECEC**	**V%**	**Clay**
CaCl	**(g/dm³)**	**Mehlich (mg/dm³)**				**(cmol/dm³)**				**(%)**	**(g/kg)**
5.20	23.24	35.52	0.32	4.76	2.34	0.00	3.22	7.42	7.42	69.74	634.00

OM = Organic Matter; SB = Sum-of-bases; ECEC = Effective Cation Exchange Capacity; V = Basic saturation. Source: SGS Laboratory.

C. ochroleuca can suffer significant yield losses due to weed competition with weeds (Paula et al., 2020). This situation is exacerbated by the lack of herbicides registered in Brazil (Brasil, 2023). Thus, as *C. ochroleuca* is often inserted in grain production systems, especially in intercropping with maize, there is a need to evaluate herbicides that are selective for both crops at the same time, maize and sunn hemp (Braz et al., 2015; Garcia and Silva, 2019).

This aspect is important because the selectivity of herbicides for a particular crop is one of the main issues that needs to be studied, since the inadequate positioning of these products in the field can result in greater damage than the interference exerted by weeds (Braz et al., 2016). This aspect is even more relevant in the case of intercropping between two physiologically distinct crops, such as maize and *C. ochroleuca*. Importantly, for *C. ochroleuca,* there is a lack of information regarding the selectivity of herbicides, hindering weed management and intercropping with different crops, especially maize (Balan et al., 2017).

Given the benefits of using sunn hemp in intercropping and/or crop rotation and the scarcity of information on the use of selective herbicides, it is necessary to develop cultural practices to enable the use of *Crotalaria ochroleuca* in production systems that include corn. Thus, this study aimed to evaluate the selectivity of pre- and post-emergent herbicides recommended for maize on *Crotalaria ochroleuca*.

2. Material and Methods

2.1. Experiment location

The experiment was conducted in the field at the Experimental Farm of Agricultural Sciences (FAECA) of the Federal University of Grande Dourados - UFGD, located in the municipality of Dourados in the state of Mato Grosso do Sul (MS) (22°18'14.6"S 54°37'14.2"W). The experiment was conducted from 11/30/2020 to 03/16/2021. Figure 1 shows the weekly values of accumulated rainfall and average maximum and minimum temperatures in the municipality of Dourados, MS, Brazil. The data were collected at the Embrapa rainfall station (Embrapa, 2023).

2.2. Installation and conduct of the experiment

The experimental units consisted of 3x5 meter plots, with 6 sunn hemp rows. Soil samples were taken from the experimental area before the beginning of the experiment, which had been fallow for two years after the succession of corn and soybean. The chemical and physical parameters of the soil are shown in Table 1.

Table 2. Description of pre-emergent herbicide treatments on *Crotalaria ochroleuca*.

Treatments	Active Ingredient	Dose (g a.i. ha⁻¹)
T1	Atrazine	1500
T2	Amicarbazone	280
T3	Acetochlor	2300
T4	Flumioxazin	60
T5	S-metolachlor	1440
T6	Weeded control	----------
T7	Unweeded control	----------

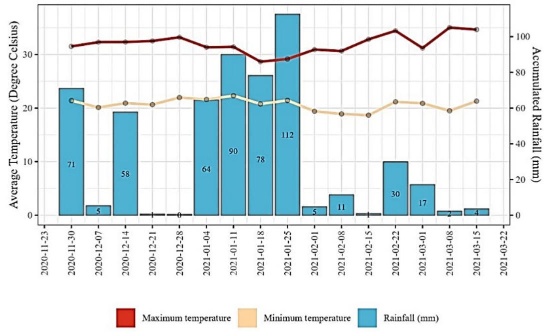

Figure 1. Historical series of accumulated rainfall and average values, both weekly, of minimum and maximum temperatures in the municipality of Dourados, Mato Grosso do Sul, Basil, for the period from November 30, 2020, to March 15, 2021. Source: Embrapa (2023).

Two experiments were performed, the first with the application of pre-emergent herbicides and the second with the application of post-emergent herbicides. The experimental design used for both experiments was randomized blocks with four replications. The experiment with pre-emergent herbicides consisted of 7 treatments, in which there were two controls without herbicide application, one weeded and the other without weeding, and 5 pre-emergent herbicides (Table 2). The treatments were applied to the *C. ochroleuca* culture in the pre-emergence experiment in the plant-and-apply system, i.e., immediately after sunn hemp sowing.

The trial involving the post-emergent herbicides consisted of 8 treatments, of which there were two controls without herbicide application, one weeded and the other without weeding, and 6 post-emergent herbicides (Table 3). The experiments were performed on 11/30/2020 for the pre-emergence experiment and on 01/04/2021 for the post-emergence experiment. At the time of application, the *C. ochroleuca* plants were up to 10 cm tall.

The treatments were applied with a backpack sprayer pressurized with CO_2, with a spray bar containing six fan nozzles (Teejet AI 110.02), spaced 0.5 m apart, covering a 3 m range. The sprayer had a flow rate of 150 L ha^{-1}. The climatic conditions at the time of application of pre-emergent herbicides in relation to humidity, temperature and wind speed were 58%, 28 °C and 0.5 ms^{-1}, respectively, while for the post-emergent herbicides, they were 65%, 25 °C and 0.2 ms^{-1}, respectively.

2.3. C. ochroleuca experimental evaluations

Phytotoxicity evaluations of sunn hemp plants were performed at 7, 14, 21, 28 and 35 days after emergence (DAE) in the pre-emergence experiment and at 7, 14, 21 and 28 days after application of the treatments (DAT) for the post-emergence experiment. These evaluations were performed using the phytotoxicity rating scale proposed by the European Weed Research Council, which correlates the percentage of visual damage with the characterization of the phytotoxicity symptom, where 0% is related to the absence of damage and 80-100% means total destruction of plants (plant death) (EWRC, 1964).

After the end of the evaluation periods, the experimental units were harvested individually and manually, removing the entire plant from the field, totaling ten plants per plot. At harvest, the three central lines of the useful area of the plots were selected, thus discarding the 0.5 m edge of the experimental units to avoid errors and standardize the harvest, allowing the estimation of the total grain weight corresponding to each plot.

The 10 *C. ochroleuca* plants were evaluated for shoot fresh mass (FFW), root fresh mass (RFM), shoot dry mass (ASM) and root dry mass (RMS) with the aid of scale analytics. For this, the sections of the plants (aerial part and root system) were packed in paper bags separately and taken to a forced-air oven at 60 °C +/- 2 °C until reaching constant weight. Fifteen beans were randomly selected from each plot, and the beans were removed for further analysis in the laboratory of the Experimental Farm of Agricultural Sciences - FAECA.

Table 3. Description of post-emergent herbicide treatments on *Crotalaria ochroleuca*.

Treatments	Active Ingredient	Dose (g a.i. ha^{-1})
T1	Atrazine	1500
T2	2,4-D	1005
T3	Mesotrione	192
T4	Nicosulfuron	60
T5	Tembotrione	84
T6	Atrazine + Mesotrione	1000 + 100
T7	Weeded control	----------
T8	Unweeded control	----------

Soon after the pods were harvested, 50 seeds of each treatment were selected in both experiments, the first related to the pre-emergent herbicides and the second inherent to the post-emergent herbicides, with 4 replicates for each experiment in each treatment, which were kept within a plastic gerbox box (11×11×3.5 cm). The seeds were placed on filter paper moistened with distilled water at 2.5 times the mass of the seeds.

The assays were conducted in a BOD (biochemical oxygen demand) incubator with a temperature of 25 °C and a 24-hour photoperiod of light, in which they were maintained for a period of fifteen days, according to the Rules of Seed Analysis (Brasil, 2009).

The number of germinated seeds was recorded daily at 1, 2, 3, 4, 5, 6 and 7 days to obtain the percentage of germination throughout the period. On the 15th day, the experiment was terminated after one week without any germinated seeds. Seeds were considered germinated when they emitted at least 2 mm from a rootlet (Borges and Rena, 1993).

2.4. Statistical analysis

In this study, to model the phytotoxicity variable (%), generalized additive location, scale and shape models (GAMLSS) with Inflated Beta family and *Logit and Logit* connection functions for the mean and variance, respectively, were used. The F statistic (D) for the post-emergence experiment and the interaction (T × D) were applied to the F statistic (D) for the pre-emergence experiment and DAT (D) for the post-emergence experiment. obtained in the *Deviance* analysis. The plot was included in the model as a random effect.

The characteristics related to dry and fresh mass of shoots and roots have been proposed to fit GAMLSS models with a ZAGA distribution (zero adjusted Gamma distribution) and log linkage function for the parameter related to the mean. The treatment factors and blocks were considered to have fixed and random effects, respectively. For germination (%), GAMLSS models with an Inflated Beta distribution were used in the modeling.

The adequacy of the model was assessed using normality (Shapiro-Wilk), homogeneity (Bartlett) and independence (Durbin-Watson) tests. To compare the levels of products, the Tukey test was used. To adjust each response variable as a function of AED or DAT, regression adjustment was performed because it was a quantitative factor. In all hypothesis tests, a 5% significance level was considered.

All statistical analyses were performed using *R software* (R Core Team, 2023). The gamlss library was used to build the *GAMLSS* models (Stasinopoulos et al., 2017). The multiple comparison tests were performed using the *emmeans* library (Lenth, 2023). The graphical presentations were conducted using the *ggplot2* library (Wickham, 2016).

3. Results

3.1. Herbicides applied pre-emergence

The *deviance* analysis identified the effect of the treatment versus AED interaction when assessing pre-emergence phytotoxicity ($F = 4.39$; $P < 0.01$). The Shapiro-Wilk normality test presented a p value of 0.683, indicating that the normal distribution adequately models the residuals produced by the GAMLSS regression. Bartlett's test resulted in a p value of 0.478, meaning that the hypothesis of homogeneity of variances is not rejected. The p value of 0.269 of the Durbin-Watson test showed independence between the residues. Once the assumptions of the model were accepted, the interaction unfolded (Figure 2).

Regarding the phytotoxicity of the significant treatments, at 7 DAE, a phytotoxicity greater than 90% was obtained for amicarbazone, atrazine and flumioxazin, which did not differ statistically from each other (Figure 2a). Acetochlor and s-metolachlor differed from the other treatments, with percentages of acceptable phytotoxicity lower than 25%. The same behavior is observed at 14, 21 and 28 DAE. At 35 DAE, the behavior of amicarbazone and atrazine followed the same pattern as the other evaluation periods and did not differ from each other in terms of statistical analysis, with percentages higher than 90%. The herbicide flumioxazin differed from the other treatments, with a phytotoxicity percentage close to 80%. S-metolachlor and acetochlor did not differ from each other, with percentages of phytotoxicity lower than 25% (Figure 2a).

The herbicides amicarbazone, acetochlor and flumioxazin showed high levels of phytotoxicity at all times, analyzed according to the evaluation dates (Figure 2b). The herbicides atrazine and s-metolachlor showed almost no variation in the percentages of control over the evaluation periods.

Regarding the variables associated with dry and fresh mass of shoots and roots (Table 4), there was a treatment effect for all traits ($P < 0.05$). Additionally, the model assumptions for normality, homogeneity and independence were met ($P > 0.05$).

In Figure 3, we show the results of the Tukey test when the traits that showed a treatment effect were evaluated according to Table 2. For all the variables related to mass, the control with hoeing stands out. This treatment showed no significant difference only in relation to acetochlor, regardless of the trait analyzed. The treatments containing amicarbazone, atrazine, s-metolachlor, flumioxazin and the control without weeding resulted in lower biomass production and did not differ statistically from each other.

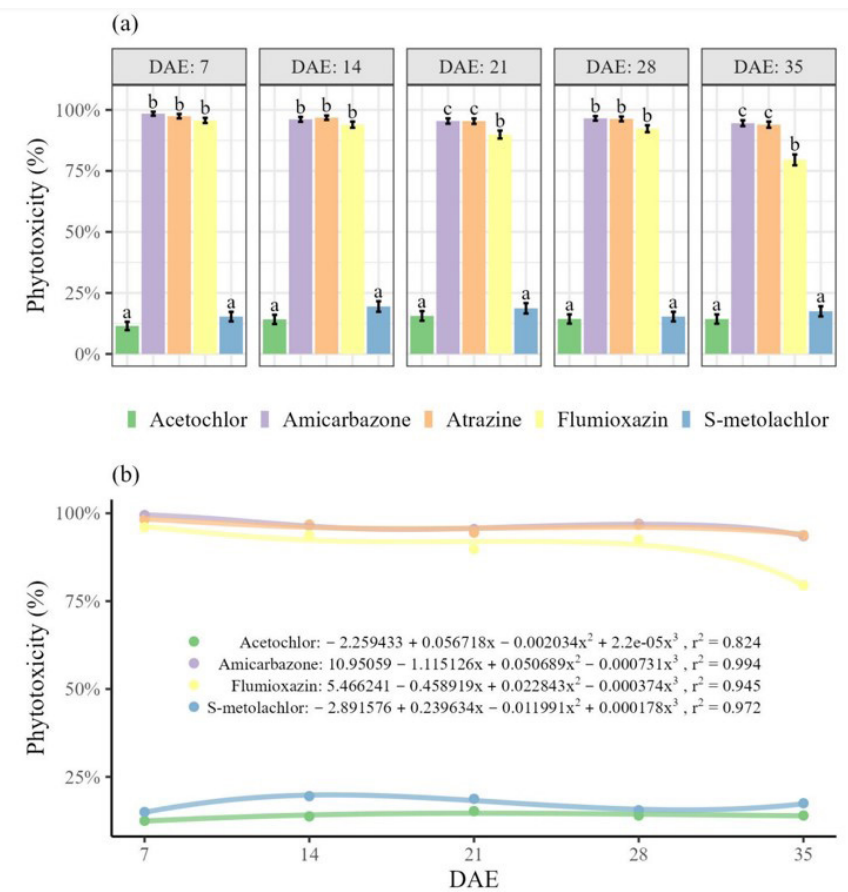

Figure 2. Comparison of the treatment levels for each AED using the Tukey test (a) and the fit of the linear predictor of the logistic function considering the phytotoxicity as a function of the AEDs for each treatment (b).

Table 4. p values of the F test of the deviance analysis and of the model assumptions for normality (Shapiro-Wilk), homogeneity (Bartlett) and independence (Durbin-Watson).

Variable	F test	Shapiro-Wilk test	Bartlett test	Durbin-Watson test
FFW*	0.0014	0.2693	0.9657	0.1465
RFM	0.0061	0.1734	0.9815	0.2195
DSM	0.0006	0.5839	0.9905	0.1665
RMS	0.0102	0.1255	0.9997	0.4001

*FFW: Fresh shoot mass; RFM: Fresh root mass; DSM: Dry shoot mass; RMS: Dry root mass.

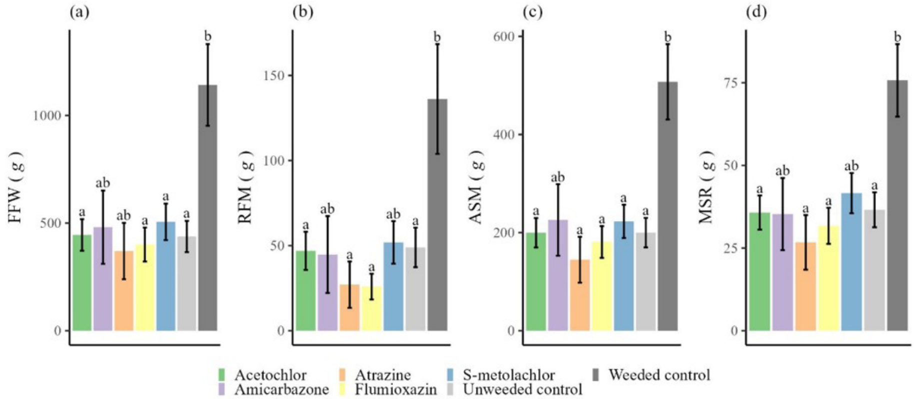

Figure 3. Comparison of treatment levels on traits related to shoot and root dry and fresh mass. FFW = shoot fresh mass; RFM = root fresh mass; DSM = shoot dry mass; RMS = root dry mass.

The germination percentage showed an effect of the treatment versus period interaction ($F = 2.184$; $P = 0.000$). The assumptions of normality ($P = 0.450$) and homogeneity ($P = 0.443$) were all met. However, the model residues showed autocorrelation, indicating that germination in the present time was influenced by the past time.

An analysis within each evaluation date (Figure 4) shows that initially, in the first and second evaluations, there was no significant difference between treatments regarding the percentage of germination (4a). From the third day onward, the highest percentage of germination was observed for the control without weeding, which did not differ statistically from acetochlor and s-metolachlor with 15 and 14.75%, respectively. did not affect the germination of *C. ochroleuca*, not differing from the controls with and without weeding for any of the periods.

Figure 4b shows the evolution of the germination percentage of *C. ochroleuca* over the evaluation periods. In this sense, it is possible to observe that as the evaluation period increases, the seeds of *C. ochroleuca* begin to have their germination more evenly distributed within the seven days of counting (Figure 4b). It was observed that atrazine and s-metolachlor provided a germination percentage lower than 20% at the end of the seven days of evaluation.

3.2. Herbicides applied post-emergence

The *deviance* analysis identified the effect of the treatment versus DAT interaction when evaluating post-emergence phytotoxicity ($F = 37.48$; $P < 0.01$). The Shapiro-Wilk normality test presented a p value of 0.375, indicating that the normal distribution adequately models the residuals produced by the GAMLSS regression (Figure 5). Bartlett's test resulted in a p value of 0.181, meaning that the hypothesis of homogeneity of variances is not rejected. The p value of 0.940 of the Durbin-Watson test showed independence between the residues.

In the analysis for each evaluation date, it was observed that at 7 DAT, the mixture of atrazine + mesotrione and the use of atrazine alone did not differ from each other in relation to the statistical analysis, with percentages close to 75% phytotoxicity. treatments differed from tembotrione, which exhibited a phytotoxicity percentage lower than 25% (Figure 5a). At 14 DAT, there was a significant difference between the atrazine and atrazine + mesotrione treatments, with percentages close to 50 and 80%, respectively. at 50%. At 21 and 28 DAT, the same phytotoxicity behavior was observed for *C. ochroleuca*, and the 2.4 D and nicosulfuron treatments did not differ from each other in terms of statistical analysis, with percentages higher than 50%, which differed from the treatment with the highest percentage of phytotoxicity, atrazine + mesotrione, with a value above 75%. It is noteworthy that tembotrione differed from all other treatments with percentages below 25%.

Figure 5b shows the phytotoxicity in *C. ochroleuca* as a function of the evaluation periods. The treatments atrazine + mesotrione and nicosulfuron showed a gradual increase in the percentages of phytotoxicity over time, and the atrazine treatment resulted in a gradual decrease over time.

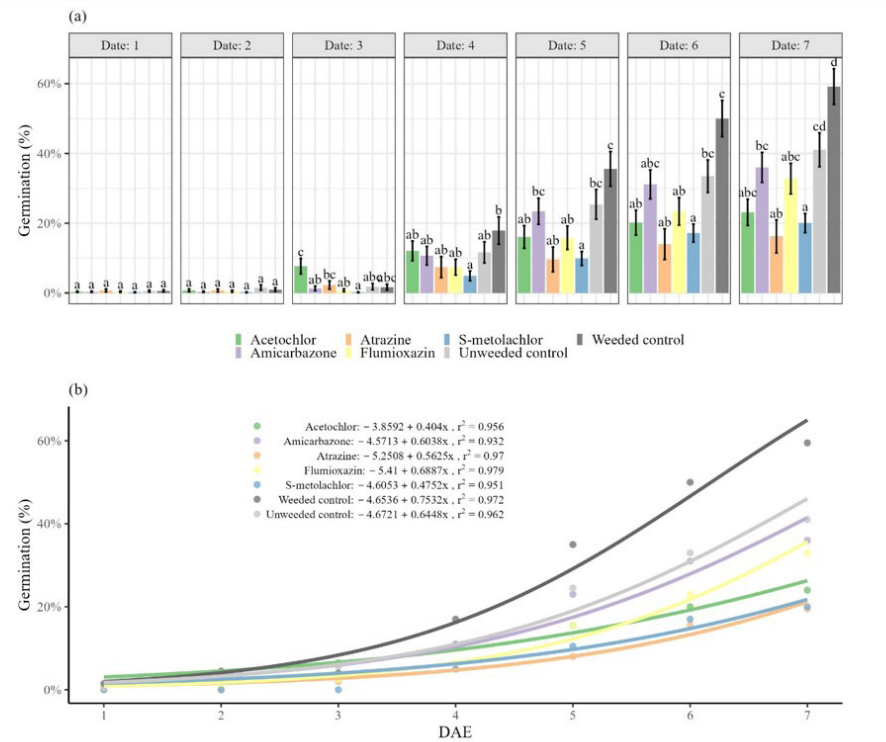

Figure 4. Comparison between the levels of the treatments on each day by the Tukey test (a) and the fit of the linear predictor of the logistic function considering germination (%) as a function of the period for each treatment (b). DAE = days after emergence.

Table 5. p values of the F test of the deviance analysis and of the model assumptions for normality (Shapiro-Wilk), homogeneity (Bartlett) and independence (Durbin-Watson).

Variable	F test	Shapiro-Wilk test	Bartlett test	Durbin-Watson test
FFW*	0.0327	0.0855	0.9904	0.5739
RFM	0.0981	0.2370	0.9980	0.2335
DSM	0.0211	0.4930	0.9992	0.5567
RMS	0.3612	0.2143	0.9997	0.2295

*FFW: Fresh shoot mass; RFM: Fresh root mass; DSM: Dry shoot mass; RMS: Dry root mass.

over time. The treatments tembotrione, mesotrione and 2.4 D showed high stability in phytotoxicity percentages, with little variation.

Regarding the variables associated with sunn hemp plant mass (Table 5), there was a treatment effect only for the traits related to shoot fresh and dry mass ($P < 0.05$). Additionally, the model assumptions for normality, homogeneity and independence were met ($P > 0.05$).

In Figure 6, we have the results of the Tukey test when the traits that showed a treatment effect were evaluated in Table 2. For the results of aerial part fresh mass, there was no significant difference between the 2,4-D and control treatments with hoeing. These treatments showed dry mass accumulation greater than 600 g and were significantly different from mesotrione, with dry mass accumulation close to 400 g. Regarding shoot dry mass, the atrazine and mesotrione treatments did not differ from each other in the statistical analysis, with 135.25 g and 122.75 g, respectively; however, they differed from the treatments with greater accumulation, such as 2.4- D and the control with weeding (Figure 6b). For this parameter, the mesotrione+atrazine mixture stands out, in which plant death and therefore absence of mass were observed.

The germination percentage showed no effect of the treatment versus period interaction ($F = 0.006$; $P = 0.900$) (Figure 7b). The assumptions of normality ($P = 0.208$), homogeneity ($P = 0.633$) and independence ($P = 0.838$) were all met. It is noteworthy that although sunn hemp produced high biomass in the treatment with 2.4-D, seed production was inhibited. Thus, the treatments atrazine and nicosulfuron did not differ from each other in relation to the statistical analysis, but they differed from mesotrione, which showed a

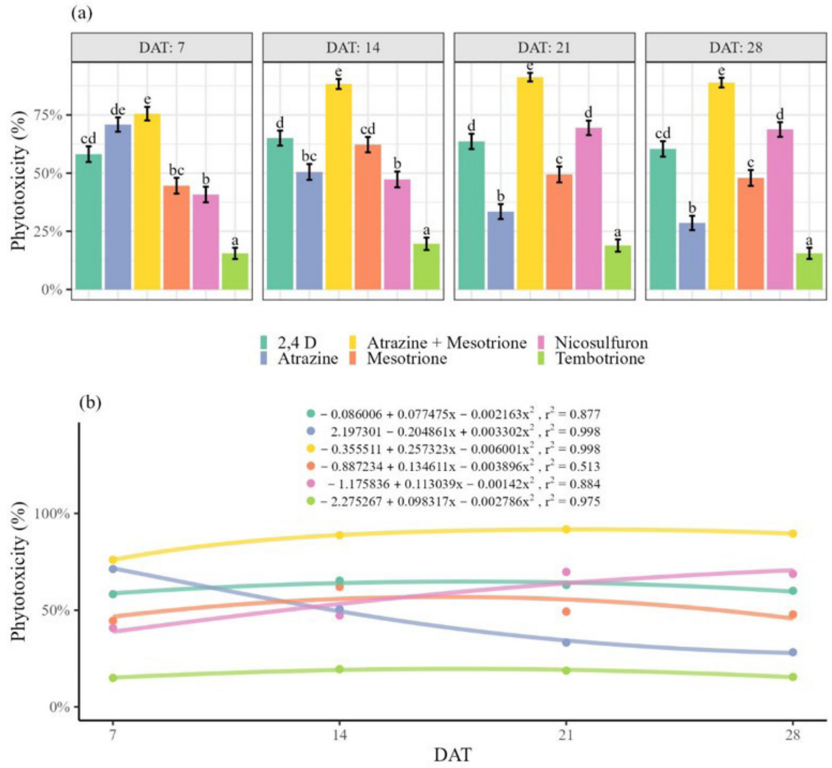

Figure 5. Comparison between the levels of the treatments at each DAT by the Tukey test (a) and the fit of the linear predictor of the logistic function considering the phytotoxicity as a function of the DAT for each treatment (b). DAT = days after application of the treatments.

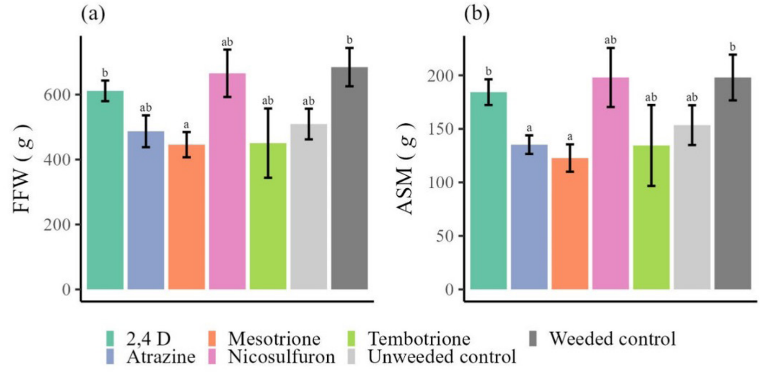

Figure 6. Comparison between the levels of treatments on the traits related to fresh and dry mass of the aerial part. FFW = shoot fresh mass; RFM = root fresh mass.

higher percentage of germination (17%), statistically differing from all treatments. Figure 4b shows the evolution of the germination percentage, where the values showed a gradual increase as the evaluation days progressed.

4. Discussion

Regarding the application of herbicides in pre-emergence of *C. ochroleuca,* it was observed that amicarbazone, flumioxazin and atrazine *were* not selective, while s-metolachlor and acetochlor showed little damage, being considered selective due to the low reduction of biomass of green manure plants.

The high selectivity of acetochlor observed in this experiment may be related to the absence of a control spectrum for weeds of the Fabaceae family and a greater control spectrum for monocotyledonous weeds (Brasil, 2023). In this sense, acetochlor is normally positioned in the control of annual species of the Poaceae family,

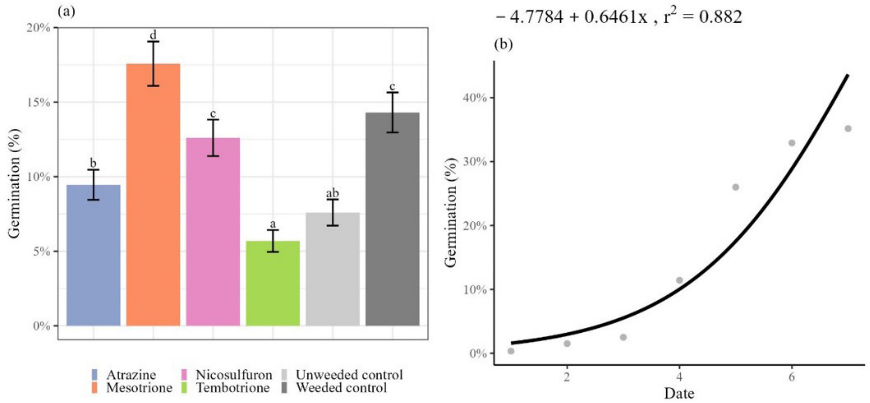

Figure 7. Comparison between the levels of the treatments by the Tukey test (a) and the fit of the linear predictor of the logistic function considering germination (%) as a function of date (b).

comelinaceae and a smaller number of eudicots. This herbicide controls pre-emergence weeds in large crops such as maize, soybean, rice and wheat (Götz and Böger, 2004; Busi, 2014), reinforcing the selectivity potential for broadleaf species.

Another factor worth mentioning is the physicochemical characteristics of acetochlor, which is rapidly degraded at the surface and subsurface (Ma et al., 2000) with a half-life of 2-63 days (Ma et al., 2004; Dictor et al., 2008; Oliveira-Junior et al., 2013) depending on the particular agro environmental conditions (for example, organic carbon content and soil moisture, pH and temperature) and initial concentration of acetochlor in the soil. It is not highly mobile in soils, showing solubility in water (Ma et al., 2000; Jursik et al., 2013). Furthermore, soil sorption for acetochlor increases with increasing soil organic carbon content, while other soil characteristics are less important (Kholodov et al., 2005; Wang et al., 1999). In this sense, the soil used in the present experiment had a high clay content in its composition and organic matter content, a fact that may have favored the greater adsorption of this herbicide and consequently decreased its mobility and availability in soil solution for contact with pre-emergence of *C. ochroleuca* seeds, suggesting a position selectivity.

The s-metolaochlor was also selective in the pre-emergence positioning of *C. ochroleuca,* showing low percentages of phytotoxicity for the crop. Similar results were obtained by Malardo et al. (2017), who found that s-metolachlor had low toxicity to *C. juncea* and *C. ochroleuca*, which did not differ from the control regarding the accumulation of dry mass. S-metolachlor also showed potential for use in *C. breviflora*. *C. spectabilis* was the species most susceptible to the herbicide, with 37% dry mass accumulation compared to the control without herbicide at the commercial dose. The authors explain that this behavior may be associated with the mechanism of s-metolachlor metabolism, which detoxified part of the herbicide molecules, whose limit was extrapolated at the highest doses.

Regarding the herbicides of action in the inhibition of the enzyme protoporphyrinogen oxidase (PROTOX), together with the inhibitors of photosystem II (PSII), in the case of amicarbazone, flumioxazin and atrazine positioned in the pre-emergence of *C. ochroleuca,* were nonselective because all showed high phytotoxicity to the crop. These results were expected because, according to Braz et al. (2015), the herbicides amicarbazone and atrazine are recommended for the control of voluntary *C. spectabilis* in corn and sugarcane crops, both in clayey and sandy soils. Flumioxazin is also recommended for weed control in sandy soil and in cotton, sugarcane, beans and soybean crops. The same authors emphasize that amicarbazone, fluimioxazin and atrazine do not represent potential uses for weed control in *C. spectabilis* culture, but s-metallochlorine was selective.

Regarding the dry and fresh mass of the root and part area, all pre-emergent herbicides showed no significant difference. These results can be explained by the climatic conditions because at the time of application, the soil had high moisture, and the days following applications were an association of high temperatures and greater rainfall, a fact that may have favored the transport of these herbicides abroad. of the root system positioning zone and its biological degradation, reducing the availability of these herbicides in soil solution (Jursík et al., 2020). In addition to these aspects, the soil used in this experiment presented adequate chemical and physical conditions for the development of *C. ochroleuca* plants (Table 1), an important aspect because the reduction of the herbicide concentration in soil solution over time results in lower residuals and consequently better conditions for the vegetative development of the crop.

Braz et al. (2015) reinforce that the better development of *C. spectabilis* is associated with the texture and chemical properties of the soil, and the higher organic carbon content and more appropriate pH favor the vegetative development of these plants. Furthermore, the lower penetration resistance and higher water retention capacity favor the availability of O_2, culminating in better root development of sunn hemp.

Regarding the percentage of germination of the seeds, the values increased over the evaluation periods because even the control without weeding and without application of pre-emergent herbicides showed a low germination percentage (less than 60%). This fact is adequate for many seeds of this species, in which a maximum of 70% germination was found on filter paper at 25 °C (Peixoto, 2007). Acetochlor stands out because although it showed low phytotoxicity, it influenced other stages of vegetative development. With the application of atrazine, there was no recovery of sunn hemp plants, resulting in low seed production.

It was found that the application of post-emergent herbicides, such as 2,4 D, atrazine + mesotrione and nicosulfuron, was not selective, presenting phytotoxicity percentages higher than 50% in the last evaluation period, and the damage was classified according to the crop. such as severe injuries and/or nonrecoverable growth reductions and/or stand reductions. These intense effects were sufficient to promote drastic reductions in the dry and fresh mass of the plants.

The *C. ochroleuca* plants showed symptoms of phytotoxicity after the application of 2,4-D, such as yellowing, wilting, wilting and epinasty, resulting in inexpressive vegetative development. These results were expected because the mechanism of action of 2,4D is to mimic synthetic auxins, with a high spectrum of control of broadleaf weeds and non selectivity for eudicots (Bester et al., 2020). Paula et al. (2020) observed a phytotoxicity of 75% in *C. ochroleuca* 35 days after the application of 2,4-D, which resulted in low or no growth during the evaluations and, consequently, low production of shoot dry mass, negative interference in the stand and no flower formation.

The post-emergence application of atrazine and mesotrione in combination or alone resulted in higher phytotoxicity and consequently lower dry and fresh mass of *C. ochroleuca* plants. Dias et al. (2017) highlighted that the greatest post-emergence phytotoxic effects of *Crotalaria spectabilis* were through the application of atrazine at doses of 500 and 1000 g ha^{-1}, with 95 and 99%, respectively, and mesotrione with 56% phytotoxicity. The authors also report that due to these characteristics, atrazine and mesotrione should not be placed in the crotalaria culture because they were not selective.

Nogueira et al. (2019) concluded that a dose of 48 g ha^{-1} of nicosulfuron resulted in high weed control in *C. spectabilis*; however, this dose resulted in a phytotoxic effect of 81.3% at 42 DAA, significantly reducing its biomass. In this sense, the authors emphasize that *C. spectabilis* is a plant with C3 photosynthetic metabolism, with slow initial growth and that the application of nicosulfuron slows down this vegetative development even more, a fact that can significantly reduce the biomass of this crop in competition with maize and/or weeds. Therefore, in comparison with the present experiment, the phytotoxicity in *C. ochroleuca* was considered high, above 70%, a fact that may have deleterious effects on the vegetative development of this species and make the effects of dry mass accumulation more impactful due to weed competition.

Braz et al. (2015), in the positioning of tembotrione in *C. spectabilis,* obtained high levels of phytotoxicity because its positioning leads to a level of inhibition in plant development that would compromise the exploitation of this legume. but did not lead to the death of the plants. Unlike in this experiment, the phytotoxic effects were considered insignificant, and tembotrione can be classified as selective for *C. ochroleuca*, although it showed a low percentage of germination.

Thus, due to the scarcity of information in the literature on the use of herbicides for *C. ochroleuca*, especially under tropical conditions, the present study highlighted the importance of planning and correct positioning of herbicides in the field, especially those with a long residual, considering the implantation of crotalaria in intercropping or succession with maize.

5. Conclusion

There was a difference in the selectivity of pre- and post-emergent herbicides for *C. ochroleuca*. Among the pre-emergent, acetochlor and s-metolachlor were selective, not causing significant injuries and reduction of dry mass for the species. While the post-emergent was used, only tembotrione was the most selective for all parameters analyzed.

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