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Herbicide selectivity on forage cactus (*Nopalea cochenillifera*) (L.) Salm - Dick cv miúda

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ABSTRACT: The objective of this work was to evaluate the herbicide selectivity and efficiency on weed control in forage cactus. The treatments were composed of oxyfluorfen, sulfentrazone, ametrine, hexazinone and the weeded control, with 4 replications. The potential quantum yield of photosystem II (Fv/Fm) was evaluated; phytotoxicity levels; productivity of green and dry mass of the aerial part and efficiency of the products in the control of the weeds. It was observed that there was no change in the potential yield of photosynthesis (Fv/Fm) of forage cactus, the values were between 0.76 and 0.83 quantum-1 electrons, the plants did not show phytotoxicity, only those that received oxyfluorfen with later recovery. The average productivity of plants that received herbicides was similar to the weeded control. The herbicides oxyfluorfen and ametrine were efficient in the first 45 days after application (DAA), hexazinone showed moderate control until 45 DAA, sulfentrazone obtained low control of weeds that appeared in the experimental period. The herbicides were selective for forage cactus, oxyfluorfen, hexazinone and ametrine are efficient in controlling weeds up to 45 DAA.

Key words: cactus; chemical control; xerophytes; weeds

Seletividade de herbicidas na palma forrageira (*Nopalea cochenillifera*) (L.) Salm - Dick cv miúda

RESUMO: O trabalho teve como objetivo avaliar a seletividade de herbicidas e a eficiência sobre o controle de plantas daninhas na palma forrageira. Os tratamentos foram compostos por oxyfluorfen, sulfentrazone, ametrina, hexazinone e a testemunha capinada, com 4 repetições. Foram avaliados o rendimento quântico potencial do fotossistema II (Fv/Fm); níveis de fitotoxicidade; produtividade de massa verde e seca da parte aérea e eficiência dos produtos no controle das plantas daninhas. Observou-se que não houve alteração no rendimento potencial da fotossíntese (Fv/Fm) da palma forrageira, os valores situaram-se entre 0,76 e 0,83 elétrons quantum^{-1}, as plantas não apresentaram fitotoxicidade, apenas as que receberam oxyfluorfen com recuperação posterior. A produtividade média das plantas que receberam herbicidas foi semelhante à testemunha capinada. Os herbicidas oxyfluorfen e ametrina foram eficientes nos primeiros 45 dias após a aplicação (DAA), hexazinona apresentou controle moderado até os 45 DAA, sulfentrazone obteve baixo controle das plantas daninhas que surgiram no período experimental. Os herbicidas foram seletivos para palma forrageira, oxyfluorfen, hexazinona e ametrina são eficientes no controle das plantas daninhas até os 45 DAA.

Palavras-chave: cactáceas; controle químico; xerófitas; plantas daninhas

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Introduction

The forage cactus is a plant of Mexican origin, however, it is currently dispersed on several continents, except in the polar regions (Marques et al., 2017). In Brazil, especially in the Northeast region, it is considered one of the main sources of fodder for ruminants during the dry period of the year. This forage presents adaptation characteristics to the semi-arid climate due to its high water use efficiency and drought tolerance (Castro et al., 2020).

In Northeast Brazil, two species of forage cactus *Opuntia ficus-indica* Mill are mainly cultivated, with the cultivars gigante and round, clone IPA-20 and *Napalea cochenillifera* Salm - Dyck, whose cultivar is the ‘palma miúda’ or sweet palm, in the state of Alagoas, Brazil, the cultivar ‘miúda’ is planted on a large scale (Silva, 2019).

Among the main problems affecting the cultivation of this cactacea are those related to weed interference. In addition to competition for productivity factors, weeds have their negative effect intensified in forage cactus crops, mainly due to the slow growth of this plant (Carvalho et al., 2016). In addition, the shallow root system of the forage cactus makes it very sensitive to mechanical control which, depending on the size of the property, becomes a costly practice for the producer (Castro et al., 2021).

For a better performance of the crop, the chemical management of weeds in palm groves becomes a viable alternative, provided it is adopted correctly, with products that do not cause a reduction in crop productivity. The objective of this work was to evaluate the selectivity of herbicides, as well as their efficiency in weed control in the cultivation of forage cactus (*N. cochenillifera*) (L.) Salm Dick cv miúda.

Materials and Methods

The experiment was conducted at the Campus of Engineering and Agricultural Sciences of the Universidade Federal de Alagoas - CECA/UFAL (latitude 09°28’03” S; longitude 35°49’50” W; altitude 127 m). The soil of the region is classified as cohesive yellow argissolic latossolo of medium-clayey texture, the climate is classified as As’ (tropical megathermal with rains in the autumn - winter) (SEMARH, 2020).

The planting of the experimental area was done manually, using cladodes of the ‘miúda’ forage cactus (*N. cochenillifera*) previously dehydrated for ten days and free of pests and diseases. The experimental plots consisted of 3 rows of plants, each 2 m long, with spacing of 1.20 m between rows and 0.20 m between plants, totaling a population of 41,666 plants ha^{-1}. The useful area was composed of the central row of each plot, leaving out two plants on each side of the row, totaling 8 plants. Before receiving the treatments, the experimental plots were kept free of weeds by manual weeding.

At 390 days after planting (DAP), when the plants presented cladodes of various orders and sizes and ages, the experimental plots received the treatments, which consisted of 4 herbicides (ametrin 4,000 g ha^{-1}, hexazinone 375 g ha^{-1}, oxyfluorfen 1,240 g ha^{-1}, and sulfentrazone 600 g ha^{-1}) and the control (manual weeding). The doses used were based on the manufacturer’s recommendation, using the highest dose recommended for the sugar cane crop, enabling a broad spectrum of weed species control. For the application of the products a CO_2 pressurized knapsack sprayer was used, coupled with a boom with two 110.02 flat fan spray tips, spaced at 0.50 m apart with a constant pressure of 2.0 kgf cm^{-2}, providing a spray volume of 200 L ha^{-1}. The application was directed on top of the row of plants corresponding to the useful area (central row). During the application the other plants were protected with a plastic tarp structure to make sure that the product reached the desired target and to protect the other plants in the plot.

The variables analyzed during the experimental period were: potential quantum yield of photosystem II photochemical activity (Fv/Fm); phytotoxicity in the crop; efficiency of products in the control of weeds and productivity of green and dry mass of the aerial part of the palm ‘miúda’.

The potential quantum yield of photosystem II (Fv/Fm) was evaluated using a portable frequency-modulated fluorometer model PAM 2500, Walz - Germany. The evaluations were made at 2, 4, 8, 16, 32, and 64 days after application (DAA) of the herbicides. Before the measurements, the cladodes were kept in the dark for 30 minutes to deactivate the electron transport chain of the photosystem (Bolhar-Nordenkampf & Oquist, 1993). To do this, we used clamps adapted and made from thin aluminum plate, black rubberized material, and glue. The cocks were placed in three different cladodes, 1st, 2nd, and 3rd order on one plant in each plot, and for the statistical analysis the average obtained from the reading of the three cladodes was considered.

The classification of the cladodes was done as follows: the first order ones are those that originated from the planted cladode, or mother cladode; second-order ones originate from the first-order ones; and, the third-order ones are those that come from the second-order ones, and so on.

The evaluation of phytotoxicity caused by herbicides on the forage cactus occurred concomitantly with the readings of the potential quantum yield of photosystem II (Fv/Fm), for which we used the visual rating scale (Table 1) for phytotoxicity evaluation (ERWC, 1964).

The scales were given based on visual observations, analyzing all the plants in the useful area of the plot.

The evaluation of the weed control efficiency occurred at 30, 45, and 90 DAA of the products. Before the application, manual weeding was performed in the plots, removing all weeds. In each plot, after the application of the treatments, weed emergence was evaluated using a 0.25 m² square. The weeds were collected, separated, counted, and identified. With the results, the percentage of control was calculated based on the number of plants that emerged in the control (without herbicide use) for which Equation 1 was used:

Table 1. Visual rating scale for phytotoxicity evaluation (ERWC, 1964). Where: "scale 1" means absence of symptoms and "scale 9" means death of 100% of the plants.

Scale	Description of damage
9	Total loss
8	Very heavy damage
7	Heavy damage to the harvest
6	Clear damage
5	Dubious
4	Heavy damage with no effect on yield
3	Light damage
2	Very mild symptom
1	Absence of damage

$$\text{Control}(\%) = \frac{(\text{NPte} - \text{NPtr})}{\text{NPte}} \times 100 \quad (1)$$

where:

NPte - total number of plants that appeared in the control group; and,

NPtr - total number of plants that appeared in the treatment.

To calculate the percentage of control per species, we considered the species that appeared most frequently in the control treatment and used Equation 2:

$$\text{Control}(\%) = \frac{(\text{NEte} - \text{NEtr})}{\text{NEte}} \times 100 \quad (2)$$

where:

NEte - number of plants of the same species that have appeared in the control; and,

NEtr - number of plants of the same species that appeared in the treatment.

Green mass yield was obtained at harvest at 90 DAA of the products and 480 DAP. All the cladodes from the useful area of each plot were harvested and weighed while still in the field. To obtain the yield in t ha^{-1} the total weight of the plot was divided by the number of plants harvested, thus obtaining the average weight of each plant and the result was multiplied by 41,666, which corresponds to the number of plants ha^{-1}.

Dry mass yield was obtained by multiplying the green mass yield by the dry mass content of each treatment. To obtain the dry mass content, a 500 g sample was taken from each treatment, and then dried in an oven with forced ventilation at 65 °C to remove all the water and obtain constant mass.

The data collected in the experiment were submitted to variance analysis and the means were compared using Tukey test (p = 0.05), using the Sisvar software version 5.7.

Results and Discussion

The quantum yield power of photosystem II of millet palm was not affected by the herbicides ($p \geq 0.05$), regardless of the evaluation season (Table 2). The values were between 0.76 and 0.83 electron quantum^{-1}. Brito et al. (2018) observed similar values in forage cactus (*Opuntia ficus-indica* Mill) cv gigante under optimal growing conditions, with values ranging from 0.75 to 0.82 electrons quantum^{-1}.

The value of this variable can range from 0.75 (minimum limit) to 0.85 (maximum limit) in most plant species when kept under normal, unstressed growing conditions. Values lower than these indicate impairment in the maximum quantum efficiency of photosystem II and, consequently, the photosynthetic potential of the plant when they are, among others, subjected to herbicide application (Silveira et al., 2017).

Throughout the evaluation period, the Fv/Fm values were maintained with low variation, regardless of the order of the cladodes (1st, 2nd, and 3rd), indicating the absence of photoinhibitory effect caused by the herbicides used. Morphological characteristics of this cactacea such as the reduced amount of stomata and cladodes with thick cuticles influence the absorption of herbicides by the cladodes and may explain the low penetration of the molecules in the plant, preventing the product from reaching the site of action in the target cell, this being one of the factors responsible for the low sensitivity of the forage cactus cv miúda to the application of these herbicides (Salvador et al., 2021).

Another determining factor for the selectivity of oil palm to herbicides is related to its low transpiration due to the lower frequency of stomatal opening, which directly influences the uptake of photosystem II inhibitor products, since they are efficiently transcollected via xylem and depend on the transpiratory flow of the plant to be absorbed via the root and

Table 2. Photosystem II potential quantum yield (Fv/Fm) of forage cactus (*N. cochenillifera*) cv miúda submitted to different herbicide applications.

Herbicides	Days after application (DAA)					
	2	4	8	16	32	64
Oxyfluorfen	0.81 aA	0.79 aA	0.82 aA	0.76 aA	0.79 aA	0.79 aA
Sulfentrazone	0.81 aA	0.79 aA	0.76 aA	0.75 aA	0.79 aA	0.77 aA
Ametryn	0.76 aA	0.76 aA	0.83 aA	0.79 aA	0.80 aA	0.80 aA
Hexazinone	0.77 aA	0.79 aA	0.78 aA	0.76 aA	0.81 aA	0.80 aA
Control	0.79 aA	0.79 aA	0.80 aA	0.79 aA	0.79 aA	0.82 aA
Average	0.78	0.78	0.80	0.77	0.80	0.80
CV (%)	6.63	3.21	5.32	3.71	2.56	2.81

* Averages followed by the same lower case letter in the row and capital letter in the column are not statistically different by Tukey test at 5% probability.

Table 3. Phytotoxicity in millet forage cactus (*N. cochelinifera*) after herbicide application at different evaluation periods. Average data refers to scales, ranging from 1 (no injury) to 9 (total loss).

Herbicides	Days after application (DAA)					
	2	4	8	16	32	64
Oxifluorfem	1.00 aA	2.25 bA	3.80 bA	4.00 bA	3.00 bA	2.25 bA
Sulfentrazone	1.00 aA	1.00 aB	1.00 aB	1.00 aB	1.00 aB	1.00 aB
Ametryn	1.00 aA	1.00 aB	1.00 aB	1.00 aB	1.00 aB	1.00 aB
Hexazinone	1.00 aA	1.00 aB	1.00 aB	1.00 aB	1.00 aB	1.00 aB
Control	1.00 aA	1.00 aB	1.00 aB	1.00 aB	1.00 aB	1.00 aB
CV (%)	10.25	10.33	26.08	20.46	19.86	15.4

* Averages followed by the same lower case letter in the row and capital letter in the column are not statistically different by Tukey test at 5% probability.

transcollected to the leaves where they will act on the active site of enzymes (Scalisi et al., 2016).

The levels of injury caused in the cladodes of the date palm after application of the herbicides showed significant difference by Tukey test ($p < 0.05$). Only oxyfluorfen treated plants show phytotoxic reaction from the fourth day after application (DAA), the damage progressed from very light (scale 2) to heavy with no effect on yield (scale 4) at 16 DAA. From this point on, the plants started to recover progressively until the disappearance of the symptoms that occurred after 64 DAA (Table 3).

Injury consisted of reddish-brown spots at the contact points between the herbicide and the crop and over time they did not coalesce, this occurred because oxyfluorfen is a herbicide of non-systemic action and does not translocate in plant tissue, requiring a good coverage of the plants when it is applied post-emergence (Assunção et al., 2017). The greatest damage was observed in the youngest cladodes (Figure 1), recently sprouted, precisely because they have more meristematic tissues and less cuticle, facilitating the penetration of the product applied.

PROTOX inhibitor herbicides, when in contact with plants, show little selectivity, however many crops have the ability to recover the affected leaf area due to specific mechanisms capable of interfering with the absorption translocation and metabolism of herbicide compounds in the tissues of treated plants (Brusamarello et al., 2021). This was observed in the present study, where the plants showed a certain level of injury when treated with oxyfluorfen, with subsequent recovery.

In assessing the damage caused by PROTOX inhibitor herbicides in soybean (*Glycine max* L.), Gallon et al. (2016) observed that lactofen application caused injury to the crop that recovered 20 DAA without yield reduction. Costa et al. (2019), on the other hand, found that the application of oxyfluorfen to the sunflower crop caused injury that disappeared over time.

Figure 1. Cladodes of millet palm with injuries caused by oxyfluorfen. Older cladodes with low penetration of the product (A), young, newly sprouted cladodes with high levels of injury due to increased penetration of the product (B, C).

Regarding the efficiency of herbicides in controlling weeds, there was a significant difference depending on the product used. The experimental area showed heterogeneity of monocot and dicot infestation. The main plants observed during the evaluation period were: *Euphorbia hyssopifolia* ('burra-leiteira'), *Richardia brasiliensis* ('poaia-branca'), *Digitaria* spp. ('capim-colchão'), *Acanthospermum australe* ('carrapicho-rasteiro'), *Blainvillea rhomboidea* ('erva-de-palha'), *Marsypianthes chamaedrys* ('hortelã-do-campo'), *Spigelia anthelmia* ('erva-lombrigueira'), *Emilia* spp. ('falsa serralha'), and *Mimosa* spp.

The percentage of weed control varied for each molecule used (Table 4). At 30 DAA all products were efficient and showed control greater than 85%, except sulfentrazone that showed control less than 70%, but did not differ statistically from the others. At 45 DAA there was a small decrease in the control percentage of all products and ametryn showed the highest control (92.22%), but did not differ from oxyfluorfen (90.24%) and hexazinone (85.71%).

The reduction in the efficiency of some herbicides in controlling weeds over time can be explained by the decrease in the residual amount of these products in the soil. The large amount of water available (400 mm) during the evaluation period and during the experiment contributed to the leaching of some products, such as sulfentrazone and hexazinone, which have greater solubility, removing them from the superficial layer of the soil and taking them below the growth zone of the plants.

In evaluating the degradation of herbicide molecules, Trovato & Scorza Junior (2019), observed that increasing soil temperature and moisture decreased the persistence of hexazinone characterizing a faster degradation and reducing the half-life time. According to Ribeiro (2016), soil moisture

Table 4. Average weed control values at 30, 45, and 90 DAA.

Treatments	Dose (g i.a ha^{-1})	Weed control (%) - DAA		
		30	45	90
Oxyfluorfen	1,240.00	93.14 b	90.24 c	73.98 b
Sulfentrazone	600.00	69.82 b	69.28 b	47.41 ab
Ametryn	4,000.00	92.44 b	92.22 c	32.78 ab
Hexazinone	375.00	86.30 b	85.71 c	9.10 a
Control	-------	0.00 a	0.00 a	0.00 a
CV (%)		14.85	7.78	49.68

* Averages followed by the same letter in the column are not statistically different by Tukey test at 5% probability.

is an important factor in maintaining microbial activity (sulfentrazones main degradation pathway), so in moist soils herbicides will naturally have less residual effect and persistence decreasing the interval between applications for weed control.

The low efficiency of sulfentrazone in weed control may also be associated with the species that emerged in the experimental area, since, this herbicide shows better control of cyperaceae such as 'Tiririca' (*Cyperus rotundus*) and some monocotyledons (Simplício et al., 2018).

At 90 DAA there was a marked decrease in the control of the main weeds for all herbicides, possibly due to residual reduction of the products in the soil, in this period only oxyfluorfen showed control greater than 70%, but did not differ from sulfentrazone and ametrine, which in turn showed similar control to hexazinone, both were equal to the control. Guerra et al. (2016) when evaluating the leaching potential of herbicides in sugarcane with the use of irrigation slides, found that oxyfluorfen has greater persistence in the soil when compared to other herbicides due to its lower solubility, while hexazinone was the herbicide that showed the lowest persistence in wet soil due to greater leaching, corroborating the results found in the present study.

The 'burra-leiteira' (*E. hyssopifolia*) was the species with the highest frequency during the evaluations, and the herbicides oxyfluorfen and hexazinone showed the highest control efficiency on this plant species when compared to the control (Table 5). *Richardia brasiliensis* ('poaia-branca'), was well controlled in the treatments with ametryn and hexazinone (100%), followed by oxyfluorfen (85.71%), and sulfentrazone (57.14%). For *Digitaria* spp. all herbicides showed control above 75%, with oxyfluorfen and ametryn showing the best control followed by hexazinone and sulfentrazone.

Acanthospermum australe ('carrapicho-rasteiro') was well controlled by all herbicides except for sulfentrazone (63.64%). *Blainvillea rhomboidea* ('erva-de-palha') and *Marsypianthes chamaedrys* ('hortelã-do-campo') were effectively controlled (100%) by all herbicides used.

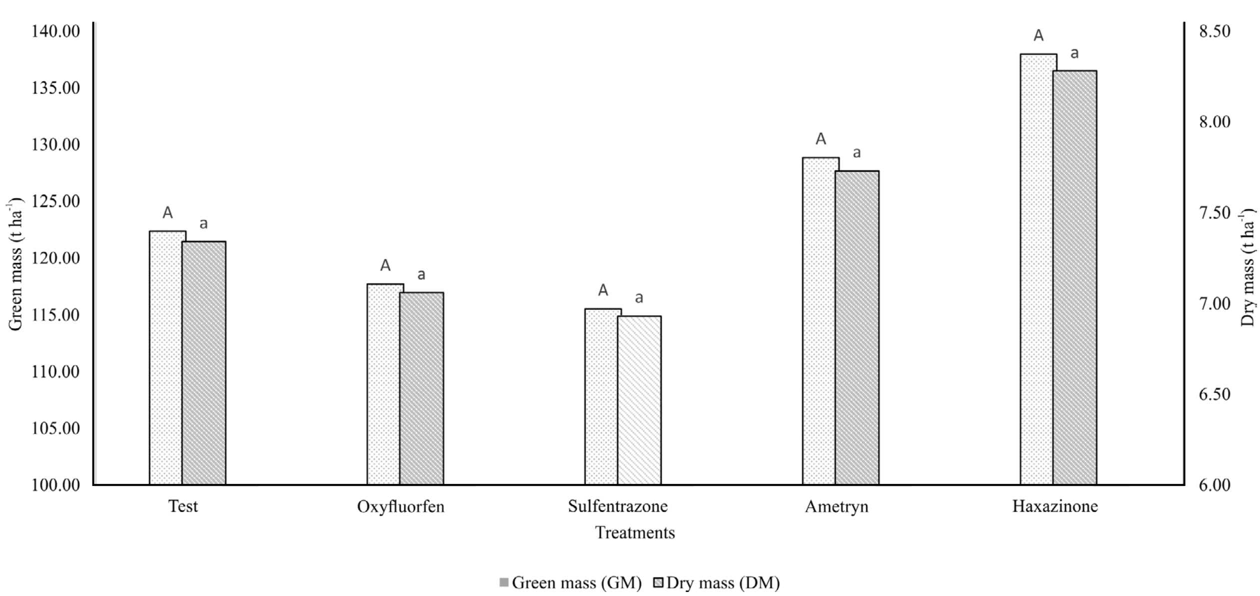
In the evaluation of photosystem II inhibitor herbicides (ametryn and hexazinone), Tropaldi et al. (2017) obtained control greater than 95% at 30 DAA for 'capim-colchão', corroborating with the results found in the present work. Ribeiro (2016), on the other hand, obtained control ranging from 89.0 to 90.3 % for doses of 400 to 800 g ha^{-1} of sulfentrazone in the eucalyptus crop at 45 DAA, as well as a reduction in the percentage of control over time, with reduced efficiency at 115 DAA.

The variables green and dry mass productivity of the aerial part of the forage cactus (*N. cochenillifera*) cv miúda showed no significant difference ($p > 0.05$) by the Tukey test, indicating that the herbicides did not negatively affect the productive yield of the crop (Figure 2). However, in the treatment with hexazinone the highest yields were obtained: 137.96 and 8.38 t ha^{-1} of green

Table 5. Percentage of control of main weeds at 30 DAA of the herbicide based on the control treatment.

Treatments	Most frequent weeds in the experimental area					
	Euphorbia hyssopifolia	*Richardia brasiliensis*	*Digitaria* spp.	*Acanthospermum australe*	*Blainvillea rhomboidea*	*Marsypianthes chamaedrys*
Oxyfluorfen	80.0 d	85.71 c	98.48 c	90.91 c	100.0 b	100.0 b
Sulfentrazone	25.0 b	57.14 b	77.27 b	63.64 b	100.0 b	100.0 b
Ametryn	55.0 c	100.0 d	98.48 c	100.0 c	100.0 b	100.0 b
Hexazinone	80.0 d	100.0 d	86.36 b	100.0 c	100.0 b	100.0 b
Control	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a

* Averages followed by the same letter in the column are not statistically different by Tukey test at 5% probability.



* Averages followed by the same letter, upper case for GM and lower case for DM do not differ statistically by the Tukey test at 5% probability.

Figure 2. Productivity of green mass (GM) and dry mass (DM) of millet palm submitted to application of different herbicides.

mass (GM) and dry mass (DM), respectively, which represents an increase of 12.70% in productive yield when compared with the control, which showed values of 122.37 and 7.35 t ha^{-1} of GM and DM, respectively. The treatments with sulfentrazone and oxyfluorfen showed lower yields than the control, but did not differ statistically from the control.

When using herbicides that inhibit photosystem II in the forage cactus, Suassuna (2013) observed a significant reduction in weed infestation without harming the palm, leading to a decrease in the production costs of this crop. Gallon et al. (2016), on the other hand, when evaluating the action of PROTOX inhibitor herbicides on soybean development, found no reduction in grain yield.

Conclusions

The herbicides sulfentrazone, ametryn, hexazinone and oxyfluorfen are selective for the forage cactus (*N. cochenillifera*) (L.) Salm Dyck cv miúda.

The herbicides tested neither alter the potential quantum yield of photosynthesis (Fv/Fm) nor cause injury to the chickweed palm, except oxyfluorfen which causes phytotoxicity in newly sprouted cladodes.

The herbicides oxyfluorfen, hexazinone, and ametryn are efficient in controlling weeds until 45 DAA, while sulfentrazone showed low control throughout the evaluated period.

The productivity of millet forage cactus is not affected by postemergence application of the herbicides sulfentrazone, ametryn, hexazinone and oxyfluorfen.

Compliance with Ethical Standards

Author contributions: Conceptualization: JLXLC, RCS; Data curation: GNR, LARL, MASS, EFS; Formal analysis: GNR, LARL, MASS. EFS; Investigation: GNR, LARL, MASS. EFS; Methodology: GNR, LARL, MASS. EFS; Supervision: JLXLC, RCS; Validation: GNR, LARL, MASS. EFS; Visualization: GNR, LARL, MASS. EFS; Writing - original draft: GNR, LARL, MASS, EFS; Writing - review & editing: JLXLC, RCS.

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Literature Cited

Assunção, N. S.; Garcia, H. A.; Santos, L. P. D.; Dias, R. C.; Melo, C. A. D.; Fernandes, F. L.; Reis, M. R. Flumioxazin selectivity to wheat. Revista Brasileira de Herbicidas, v. 16, n. 2, p. 122-129, 2017. https://doi.org/10.7824/rbh.v16i2.514.

Bolhar-Nordenkampf, H. Oquist, G. Chlorophyll fluorescence as a tool in photosynthesis research. In: Hall, D. O.; Scurlock, J. M. O.; Bolhàr-Nordenkampf, H. R.; Leegood, R. C.; Long, S. P. (Eds.). Photosynthesis and production in a changing environment. Dordrecht: Springer, 1993. Chap. 12, p. 193-205. https://doi.org/10.1007/978-94-011-1566-7_12.

Brito, C. F. B.; Donato, S. L. R.; Arantes, A. M de.; Donato, P. E. R.; Silva, J. A. Photochemical efficiency in cladodes of 'Gigante' cactus pear cultivated under different spacings and organic fertilization. Revista Brasileira de Engenharia Agrícola e Ambiental. v.22, n.5, p.338-343, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n5p338-343.

Brusamarello, A. P.; Trezzi, M. M.; Pagnoncelli Junior, F. B.; Oliveira, P. H.; Finatto, T.; Barancelli, M. V. J.; Schmalz, B. A. H.; Pereira, P. B. Tolerance of Brazilian bean cultivars to protoporphyrinogen oxidase inhibiting-herbicides. Journal of Plant Protection Research, v. 61, n.2, p. 117-126, 2021. https://doi.org/10.24425/jppr.2021.137018.

Carvalho, I. D. E.; Santos, J. R. T.; Ferreira, P. V.; Cunha, J. L.X.L.; Gomes-Filho, J. Avaliação de doses do herbicida Hexaron® no controle de plantas daninhas e seu efeito fitotóxico no cultivo de palma miúda. Magistra, v.28, n.3/4, p.317-325, 2016.

Castro, I. N.; Santos, S. R.; Kondo, M. K.; Maia, V. M.; Santos, C. C. R. Agronomic performance and water use efficiency of irrigated cactus pear cultivars. Revista Caatinga, v. 33, n. 2, p. 529-540, 2020. https://doi.org/10.1590/1983-21252020v33n225rc.

Castro, I. N.; Santos, S. R.; Kondo, M. K.; Santos, M. R.; Oliveira, P. M.; Aspiazú, I.; Godinho, F. L. Root distribution of cactus pear genotypes under different soil water replacement levels, Brazilian Journal of Agricultural and Environmental Engineering, v.25, n.12, p.819-825, 2021. https://doi.org/10.1590/1807-1929/agriambi.v25n12p819-825.

Costa, E. M.; Correia, E. V.; Pereira, L. S.; Guimarães, L. D. D. Seletividade de sulfentrazone na cultura do girassol. Colloquium Agrariae, v. 15, n. 6, p. 73-79, 2019. https://doi.org/10.5747/ca.2019.v15.n6.a338.

EWRC - European Weed Research Council. Report of the third and fourth meetings of the European Weed Research Council Committee on Methods. Weed Research, v.4, n.1, p.88, 1964. https://doi.org/10.1111/j.1365-3180.1964.tb00271.x.

Gallon, M.; Buzelli, G. L.; Trezzi, M. M.; Diesel, F.; Silva, H. L. Ação de herbicidas inibidores da PROTOX sobre o desenvolvimento, acamamento e produtividade da soja. Revista Brasileira de Herbicidas, v. 15, n. 3, p. 232-240, 2016. https://doi.org/10.7824/rbh.v15i3.471.

Guerra, N.; Oliveira Júnior, R. S.; Constantin, J.; Oliveira Neto, A. M.; Gemelli, T. M. C. J.; Guerra, A. Potencial de lixiviação de herbicidas utilizados na cultura da cana-de-açúcar. Revista Campo Digital, v. 11, n. 1, p. 42-53, 2016. https://revista2.grupointegrado.br/revista/index.php/campodigital/article/view/1980/794. 18 Jan. 2022.

Marques, O. F. C.; Gomes, L. S. P.; Mourthe, M. H. F.; Braz, T. G. S.; Pires-Neto, O. S. P. Palma forrageira: cultivo e utilização na alimentação de bovinos. Caderno de Ciências Agrárias, v. 9, n. 1, p. 75-93, 2017. https://periodicos.ufmg.br/index.php/ccaufmg/article/view/2940/1778. 17 Feb. 2022.

Ribeiro, J. R. D. Sulfentrazone no controle de plantas daninhas na fase inicial da cultura do eucalipto. São Mateus: Universidade Federal do Espírito Santo, 2016. 72p. Thesis Master. http://repositorio.ufes.br/handle/10/8211. 19 Jan. 2022.

Salvador, K. R. S.; Jardim, A. M. R. F.; Araújo Júnior, G. N.; Alves, C. P.; Pinheiro, A. G.; Pereira, R. C. G.; Souza, L. S. B.; Silva, T. G. F. Intensificação de sistemas de produção de palma forrageira por meio de consorciação rotativa com gramíneas, leguminosas e oleaginosas: uma revisão. Revista Brasileira de Geografia Física v.14, n.4, p.2322-2343, 2021. https://doi.org/10.26848/rbgf.v14.4.p2322-2343.

Scalisi, A.; Morandi, B.; Inglese, P.; Bianco, R. L. Cladode growth dynamics in *Opuntia ficus-indica* under drought. Environmental and Experimental Botany, v. 122, p. 158-167, 2016. https://doi.org/10.1016/j.envexpbot.2015.10.003.

SEMARH - Secretaria de Estado do Meio Ambiente e dos Recursos Hídricos. Municipio de Maceió. Maceió: Semarh, 2020. (Semarh. Boletim, Janeiro 2020).

Silva, M. S. Caracterização físico-química de diferentes comprimentos de cladódios das palmas *Opuntia tuna* (L.) Mill. e *Nopalea cochenillifera* (L.) salm-dyck, sob níveis de biofertilizante. Pombal: Universidade Federal de Campina Grande, 2019. 70p. Thesis Master. http://dspace.sti.ufcg.edu.br:8080/jspui/handle/riufcg/10334. 19 Jan. 2022.

Silveira, R. R.; Santos, M. V.; Ferreira, E. A.; Santos, J. B.; Silva, L. D. Chlorophyll fluorescence in brachiaria decumbens and brachiaria ruziziensis submitted to herbicides. Planta Daninha, v. 35, e017165099, 2017. https://doi.org/10.1590/s0100-83582017350100042.

Simplício, F. J. T.; Esposti, C. D.; Toffoli, C. R. de; Silva, D. G. da; Kuva, M. A. Herbicida sulfentrazone no controle de plantas daninhas em pós-emergência inicial na cultura da cana-de-açúcar. Pesquisa Aplicada & Agrotecnologia, v.11, n.1, p.99-103, 2018. https://doi.org/10.5935/PAeT.V11.N1.12.

Suassuna, P. Tecnologia do cultivo intensivo da palma - TCIP. Cactusnet Newsletter, n. 13, p. 51-63, 2013.

Tropaldi, L.; Araldi, R.; Brito I. P. F. S.; Silva, I. P. F.; Carbonari, C. A.; Velini, E. D. Herbicidas inibidores do fotossistema II em pré-emergência no controle de espécies de capim-colchão. Revista Brasileira de Herbicidas, v. 16, n. 1, p. 30-37, 2017. https://doi.org/10.7824/rbh.v16i1.528.

Trovato, V. W.; Scorza Júnior, R. P. Degradação de moléculas herbicidas no solo sob diferentes temperaturas. Agrarian Academic Journal, v.2, n.2, p. 105-117, 2019. https://doi.org/10.32406/v2n22019/105-117/agrariacad.