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Article

Phytoremediation of Contaminated Soil with Sulfentrazone by Different Density of *Crotalaria juncea*

Fitorremediação de Solo Contaminado com Sulfentrazone por Diferentes Densidades de ***Crotalaria juncea***

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ABSTRACT - In phytoremediation programs of contaminated soil with herbicides, it is necessary to determine the appropriate density of phytoremediation species, since this practice will contribute to the efficiency of the process. The aim of this study, therefore, was to evaluate the influence of density in *Crotalaria juncea* on the phytoremediation of contaminated soils with the sulfentrazone herbicide. The experiment was conducted in a greenhouse using plastics pots. The treatments were the combination of density of *C. juncea*, (0, 60, 120 and 240 plants m^{-2}) and doses of sulfentrazone (0, 200 and 400 g i.a. ha^{-1}). The herbicide was applied on the pots and then the species used for phytoremediation were sown. At 75 days after emergence, the plants were cut close to the ground and discarded. Posteriorly, the bioindicator species for sulfentrazone, *Pennisetum glaucum*, was planted in each pot. In the absence of previous cultivation of *C. juncea,* the fresh mass and dry mass of shoot and root of *P. glaucum* were lower than those obtained with the previous cultivation. As the density of *C. juncea* increased, there was an increase in fresh mass and dry mass, regardless of the sulfentrazone dose applied to the soil. The earlier cultivation of *C. juncea* led to the remediation of the soil contaminated with sulfentrazone. The minimum density of *C. juncea* which allows *P. glaucum* to develop is 120 plants m^{-2}.

Keywords: soil decontamination, green manure, *Pennisetum glaucum*.

RESUMO - Em programas de fitorremediação de solo contaminado com herbicidas, faz-se necessário determinar a densidade adequada da espécie fitorremediadora, uma vez que essa prática irá contribuir para a eficiência do processo. Com isso, objetivou-se neste trabalho avaliar a influência da densidade de ***Crotalaria juncea*** *sobre a fitorremediação de solo contaminado com o herbicida sulfentrazone. O experimento foi conduzido em vasos plásticos em casa de vegetação. Os tratamentos foram compostos pela combinação de densidades da espécie fitorremediadora* ***C. juncea*** *(0, 60, 120 e 240 plantas* m^{-2}*) e doses de sulfentrazone (0, 200 e 400 g i.a.* ha^{-1}*). O herbicida foi aplicado nos vasos e, em seguida, procedeu-se à semeadura da espécie utilizada como fitorremediadora. Aos 75 dias após a emergência, as plantas foram seccionadas rente ao solo e descartadas. Posteriormente, efetuou-se no próprio vaso a semeadura da espécie bioindicadora da presença ou não de sulfentrazone no solo:* ***Pennisetum glaucum****. Na ausência de cultivo prévio de* ***C. juncea****, a massa fresca e a massa seca da parte aérea e da raiz de* ***P. glaucum*** *foram inferiores àquelas obtidas com cultivo prévio. À medida que aumentou a densidade de* ***C. juncea****, houve incremento na massa fresca e massa seca, independentemente da dose de sulfentrazone aplicada no solo. O*

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*cultivo prévio de **C. juncea** promoveu a remediação do solo contaminado com sulfentrazone. A densidade mínima de **C. juncea** que possibilita o desenvolvimento do **P. glaucum** é de 120 plantas m^{-2}.*

Palavras-chave: descontaminação de solo, adubo verde, *Pennisetum glaucum*.

INTRODUCTION

Herbicides are compounds with a critical role in agriculture, due to their efficiency to control weeds. Some of these molecules, however, present concerning characteristics, due to their persistence in the soil and the water (Coutinho and Barbosa, 2007).

Herbicides that belong to the chemical group of triazolinones are examples of compounds with high soil persistence, and they may affect susceptible crops sown in rotation/succession. Among them is sulfentrazone, which is known to be used for soybean, sugarcane, eucalyptus, citrus, and coffee crops and non-agricultural areas, controlling a broad spectrum of broadleaves and grassy weeds. A period of 18 months after the application of sulfentrazone is required for rotation of sensitive crops, such as (Rodrigues and Almeida, 2011).

The behavior of the sulfentrazone herbicide in soils with sugarcane crops was evaluated by bioassays using beet as the test plant, determining that, for the lowest evaluated dose (0.6 kg ha^{-1}), the herbicide persisted up to 601 days after treatment (DAT). For the 1.2 kg ha^{-1} dose, up to the end of the assay, at 704 DAT, the herbicide still lingered, evidencing that sulfentrazone stays on the soil for a long time, proportionally to the applied dose (Blanco et al., 2010).

Arruda et al. (2001), evaluating the effect of doses of sulfentrazone on the nitrogen nodulation and fixation on soybean crops, observed that this herbicide reduces both the formulation of nodules and the fixation of N_2, and such effects are accentuated as the herbicide doses increase. According to Lourenço and Carvalho (2015), the phytotoxic activity of sulfentrazone was identified up to 182 days after application, and its average dissipation rate was 2.15 g ha^{-1} day^{-1}, and half-life of over 182 days.

Several factors influence the persistence of sulfentrazone molecules. Reddy and Locke (1998), evaluating the sulfentrazone sorption in two types of soil and management, observed that, regardless of the management type, the sorption rate was higher in clay soil. On the other hand, Grey et al. (1997) observed that the sulfentrazone sorption is strongly influenced by the pH, that is, sorption is usually reduced in response to the pH increase, especially when this increase exceeds the pKa of the herbicide (6.56).

Considering the environmental problems caused by herbicides that remain for a long residual time in the soil, however, in relation to the toxicity of sensitive crops subsequently sown in the soil treated with these herbicides (carryover), phytoremediation is an alternative to overcome and/or minimize their environmental impacts. This is a bioremediation strategy, which involves using plants and their associated microbiota and soil amendments, in addition to agronomical practices that, if applied in combination, remove, immobilize or make the contaminants harmless or less toxic to the ecosystem (Cunningham et al., 1996).

The faster the decontamination conducted by a certain phytoremediation species, the faster the area will be released for a crop of a species known to be sensitive to the previously used xenobiotic. In addition, the less likely this compound will be to be leached out in the soil and reach the water sources in the underground (Carmo et al., 2008). Considering that, actions that may intensify the decontamination process of the soil are of great interest in phytoremediation programs. One of these practices consists of increasing the density of remediating plants in a certain area, up to a certain limit, in order to increase the phytoremediation.

The density of the phytoremediation species, for example, may influence the action of the physiological mechanisms responsible for phytoremediation, phytoextraction and phytostimulation. The increase in the exploration volume of the root system and the transpiration of plants by area may result in greater absorption of xenobiotics, in addition to stimulating the population of rhizodegrading microorganisms associated to their roots (Santos et al., 2007).

The adequate density will depend mainly on the species used, however, according to Schnoor and Dee (1997), who work with tree species as phytoremediation agents, the high density as the plants start to get established ensures a significant evapotranspiration rate, which is desirable up to a certain point, since, with the excessive increase of the density, intraspecific competition may damage the growth and development of plants.

Santos et al. (2006) observed that the minimal density of the phytoremediation species *Canavalia ensiformis* that allowed the best development and maximal productivity of the bean plant grown in the soil contaminated with the trifloxysulfuron-sodium herbicide was 20 plants m^{-2}, corresponding to 2.5 times to that recommended for green fertilization. Procópio et al. (2005) also evaluated the remediation of the trifloxysulfuron-sodium herbicide by *Stizolobium aterrimum* and concluded that the minimal density of the green manure that allowed the greatest grain yield to the bean culture was 25 plants m^{-2}. Similarly, the densities that optimized the action of the *Eleusine coracana* and *Panicum maximum* species (Tanzania cultivar) were 172 and 122 plants m^{-2}, respectively, for the picloram + 2,4-D herbicide (Procópio et al., 2008, 2009).

In a study made by Ferraço et al. (2017), the efficiency of *Canavalia ensiformis* to decontaminate the soil contaminated with sulfentrazone increased due to the increase in the plant density, which may be due to the greater number of roots absorbing the herbicide from the soil, as well as to the greater number of plants in association to the microbiota of the soil, degrading sulfentrazone. This herbicide shows low mobility on the soil and low adsorption (Rodrigues and Almeida, 2011), and its solubility increases as the pH increases, being found mainly in the soil solution in the non-ionized form (FMC,1995), making it easier for the plants to absorb it.

Considering the long persistence of sulfentrazone (Grey et al., 2000; Polubesova et al., 2003) and the problems caused by its carryover effect in crop rotation (Main et al., 2004), as well as the higher capacity by *C. juncea* to remediate soils contaminated with sulfentrazone (Madalão et al., 2012), the objective of this study was to evaluate the phytoremediation of the soil contaminated with sulfentrazone, conducted by *C. juncea* plants grown at different densities.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse in the municipality of São Mateus, ES, which is located at a south latitude of 18°42’50" and west longitude of 39°50’53". The experiment consisted of a 4 x 3 factorial, with a completely randomized design with four replicates. The first factor was constituted by the combination of densities of the phytoremediation species *Crotalaria juncea*, and the second one, by sulfentrazone doses (0, 200 and 400 g i.a. ha^{-1}), in a total of 12 treatments.

The *C. juncea* densities used were 0, 3, 6 and 12 plants per vase, corresponding to 0, 60, 120 and 240 plants m^{-2}, equivalent to zero, 1x, 2x and 4x the recommended density for green fertilization.

As substrate for plant growth, samples of the soil classified as Cohesive Yellow Argisol with Sandy texture, according to the classification by Embrapa (2013), collected in an area without a history of application of herbicides at a depth of 0.00-0.20 m, sieved on a 4 mm mesh and then characterized as to their texture and fertility (Table 1). This characterization worked as a basis

Table 1 - Chemical and texture composition of the soil used on the experiment

Granulometric analysis (g kg^{-1})			
Clay	Silt	Sand	Texture classification
120	104	776	Sandy loam

Chemical aqnalysis									
pH (H_2O)	P	K^+	Ca^{2+}	Mg^{2+}	H+Al	Al^{3+}	CTC	V	MO
	(mg dm^{-3})		(cmol$_c$ dm^{-3})					(%)	(dag kg^{-1})
5.2	90	17	0.6	0.2	2.4	0.4	3.2	26.0	2.0

Substrate analysis conducted by Fullin – Laboratory of Agronomic Analysis, Linhares - ES.

for the correction and fertilization of the vases, aiming at the proper development of the evaluated species for phytoremediation, conducted based on the recommendation by Prezotti et al. (2007) for the bean plant crop.

The following fertilizer dose was used per vase: 6.54 g of dolomitic limestone (mixed to the soil one week before the vases were filled); 2.22 g of nitrogen; 11.11 g of phosphorus; 2.5 g of potassium; 0.046 g of boric acid; 0.052 g of copper sulphate; 0.077 g of ferrous sulphate; 0.112 g of manganese sulphate; and 0.019 g of ammonium molybdate.

After the soil was prepared, it was distributed in vases with an area of 0.046 m^2 and 24 cm of height, coated with polyethylene film, in order to keep them in a closed system. A total of 10.0 kg of the substrate was used per vase, individually weighted after filling. They were irrigated adjusting the humidity of the soil with a value close to 80% of the field capacity, and sulfentrazone was then applied with the help of a pressurized sprayer with CO_2, equipped with two TT 110.02 nozzles, with a space of 0.5 m, calibrated for the application of 200 L ha^{-1} of each herbicide.

The phytoremediation species *C. juncea* was sown eight days after the application of sulfentrazone. Usually, the sowing would be conducted at the end of the main crop cycle, to avoid the intoxication of the succession crop. However, in this study, a short interval between the application and sowing was chosen, with the purpose of exposing the phytoremediation species to readily available doses, without adsorption effects resulting from the longer time the molecule remained in the soil. In addition, the 200 g i.a. ha^{-1} dose corresponds, approximately, to half the dose expected to be available at the end of the cycle of an annual crop (Ferraço et al., 2017).

Seven days after the emergence (DAE) of the phytoremediation species *C. juncea*, thinning was conducted, and the number of plants per vase corresponded to each treatment. Irrigations were conducted three times a day, in order to maintain the soil humidity at 60% of the field capacity (CC). The CC value was determined by a test before the implantation of the experiment, using the methodology suggested by Casaroli and Jong van Lier (2008), considering a reduction rate of the water content of $|d\theta/dt| = 0.001\ d^{-1}$.

At 75 DAE, the *C. juncea* plants were cut close to the soil and discarded. During that same period, the soil samples were collected (one sample per vase), resulting in one sample per treatment. From these samples, the pH, macro and micronutrients were analyzed. After interpreting the results, the specific fertilization demanded for each treatment was conducted. This was conducted in order to make the nutrient availability uniform in each experimental unit, preventing the soil fertility to be constituted by a source of variation, that is, that differences in the development of the bioindicator crop (sequentially sown) resulted from the lack of uniformity of the soil fertility in the vases.

After this stage, the bioindicator species that indicated the presence of sulfentrazone in the soil, *Pennisetum glaucum* var. ADR7010, was sown, distributing 15 seeds per vase. *P. glaucum* was used based on its high susceptibility to sulfentrazone, evidenced by previous experiments (Madalão et al., 2012). After the emergence of the bioindicator plant, thinning was conducted, leaving two *P. glaucum* plants per vase, which were daily irrigated, as previously described.

At 25 and 42 DAE of *P. glaucum*, the phytotoxicity was visually evaluated, using a percentage scale, in which 0 (zero) means lack of symptoms (reduction of the height of plants, chlorosis and necrosis of the leaves) and 100%, death of all plants (SBCPD, 1995), as well as the height of the plants, using a graduated scale, with the apical meristem as the reference.

At 42 DAE, *P. glaucum* was cut close to the soil, and the vegetable material was immediately weighted in an analytical scale, determining the fresh mass of the shoot. The same was conducted for the roots, after being carefully removed from the vases and washed. Then, the vegetable material (shoot and root) was placed in a forced air circulation drying oven (70 ± 2 °C), until a constant weight was reached, and thein it was weighted again using an analytical scale, determining the dry mas of the shoot and root.

After the collection and tabulation of the data, they were submitted to an analysis of variance by the F test ($p<0.05$), with the help of the GENES program (Cruz, 2006). The significant effects of the density of the phytoremediation species within each herbicide dose were analyzed by a regression analysis, and the coefficients of the equations were tested by the t test (p<0.05), whose equations were adjusted according to the relevant variable and its respective biological behavior. The significant effects of the sulfentrazone doses, at each density, were verified using Tukey's test (p<0.05), due to the insufficient number of levels to adjust the regression equations.

RESULTS AND DISCUSSION

There was a significant interaction between the sulfentrazone doses and the *C. juncea* densities, for all analyzed variables.

When evaluating the growth and development of *P. glaucum*, it was observed that, when *C. juncea* had not been previously planted, the height of the plants did not increase due to the sulfentrazone doses at 25 and 42 DAE (Table 2). It was also observed that with the application of the highest dose of the herbicide (400 g i.a. ha^{-1}). *P. glaucum* did not develop, due to the high toxicity of sulfentrazone (Table 2). The high sensitivity of *P. glaucum* to the residual activity of sulfentrazone was also evidenced by a study conducted by Dan et al. (2011).

Table 2 - Height and phytotoxicity in *Pennisetum glaucum* plants at 25 and 42 days after emergence (DAE), sown after the previous cultivation of *Crotalaria juncea*, due to the densities and application of doses of the sulfentrazone herbicide

Sulfentrazone dose (g i.a. ha^{-1})	*C. juncea* (plants m^{-2})			
	0	60	120	240
	Height (cm) at 25 DAE*			
0	18.32 a	18.52 a	19.77 a	23.38 a
200	12.76 b	13.93 a	15.82 ab	18.45 b
400	0.00 c	8.92 b	11.92 b	13.80 c
CV (%)	18.09			
	Height (cm) at 42 DAE			
0	100.50 a	101.93 a	100.62 a	111.31 a
200	58.37 b	76.87 b	77.56 b	87.81 b
400	0.00 c	35.00 c	55.30 c	65.12 c
CV (%)	16.92			
	Phytotoxicity (%) at 25 DAE			
0	0.00 c	0.00 c	0.00 c	0.00 c
200	60.00 b	46.25 b	41.25 b	37.50 b
400	100.00 a	83.75 a	77.50 a	58.75 a
CV (%)	18.32			
	Phytotoxicity (%) at 42 DAE			
0	0.00 c	0.00 c	0.00 b	0.00 b
200	53.75 b	25.00 b	15.00 b	12.50 b
400	100.00 a	70.00 a	58.75 a	43.75 a
CV (%)	28.39			

* Averages followed by the same letter in the column are not different from each other according to Tukey's test (p<0.05).

Among the treatments that received the previous cultivation of the phytoremediation species (*C. juncea*), it was observed that the increase of the sulfentrazone dose in the soil allowed a reduction on the height of *P. glaucum* at 42 DAE. The same occurred when *P. glaucum* was grown in succession to the *C. juncea* crop at the density of 240 plants m^{-2} at 25 DAE (Table 2). That also occurred at other densities, although it was only significant at the highest dose.

At 25 DAE, there was an Evolution of the phytotoxicity symptoms on *P. glaucum* plants for the treatments with 200 and 400 g i.a. ha^{-1} of the herbicide; without the previous cultivation of the phytoremediation species, the *P. glaucum* plants showed 100% of phytotoxicity, and did not survive to the action of the herbicide in the soil (Table 2). This fact shows the importance of the previous cultivation of *C. juncea* in soils that have been previously treated with sulfentrazone.

Madalão et al. (2012) observed a significant effect of the sulfentrazone doses evaluated on the height, fresh mass and dry mass of the shoot, as well as on the percentage of the toxicity degree of this herbicide on the indicator plant (*P. glaucum*), when in succession to different phytoremediation species (*C. juncea*, *Canavalia ensiformis*, *Cajanus cajan* and *C. cajan* dwarf) and to the controls with no previous cultivation. The height of the plants and the fresh and dry mass of the shoot of *P. glaucum* reduced as the sulfentrazone doses increased, on the four evaluated species. The visual toxicity, across all evaluated species, increased as the sulfentrazone doses also increased.

The previous cultivation of *C. juncea* at densities of 120 and 240 plants m^{-2} contributed for the decontamination of the soil contaminated with 200 g i.a. ha^{-1} of sulfentrazone, since the phytotoxicity presented on the *P. glaucum* plants at 42 DAE was not statistically different from the phytotoxicity of the plants grown without the herbicide. At those same densities, the beneficial effect of the soil decontamination promoted by *C. juncea* is also observed, since at the highest dose of sulfentrazone (400 g i.a. ha^{-1}), there was a reduction of approximately 50% in the phytotoxicity of *P. glaucum*, in relation to the treatment with no phytoremediation, at 42 DAE (Table 2). This result shows that the increase in the density of *C. juncea* contributes to a greater efficiency in the remediation process. Similar results for different species, in which greater densities increased the phytoremediation effect, were obtained by Procópio et al. (2005, 2008, 2009), Santos et al. (2006) and Ferraço et al. (2017).

Increases on the density of remediating species in a certain area, up to a certain limit, may offer a greater root and explored soil volume, and it may lead to an increase in the absorption/degradation of the contaminant and/or rhizosphere degradation (Santos et al., 2006; Ferraço et al., 2017). In addition, since the herbicide studied here shows moderate soil mobility and low adsorption (Rodrigues and Almeida, 2011), it is believed that it is found in the solution of the soil available for the remediating plants. Another factor that contributes to the greater availability of sulfentrazone in the soil solution is the fact that the studied soil is a sandy soil.

Pennisetum glaucum plants, when grown in succession to *C. juncea*, showed lower phytotoxicity at 25 and 42 DAE, when compared to the treatment without a previous crop, regardless of the sulfentrazone dose evaluated. At 42 DAE, the percentage of the toxicity degree on *P. glaucum* plants was lower than the one presented at 25 DAE, that is, the *P. glaucum* plants showed a considerable recovery ability (Figure 1). It is known that the microbiological activity is the initial mechanism for the degradation of sulfentrazone (FMC, 1995). Therefore, a justification for the lower toxicity degree to *P. glaucum* at 42 DAE is that the herbicide molecules, still present in the soil, may have been degraded by the microorganisms, thus reducing their availability to be absorbed by the plants. This behavior was also observed by Belo et al. (2011) when using sorghum as the species to indicate residues of sulfentrazone in the soil, after the phytoremediation by *Helianthus annus*.

The previous cultivation of *C. juncea* in the soil contaminated with sulfentrazone contributed to increase the height of *P. glaucum* at 25 and 42 DAE, regardless of the evaluated density, although this increase is lower when compared to the height of *P. glaucum* grown without the herbicide (Figure 1).

All *C. juncea* densities (60, 120 and 240 plants m^{-2}) were able to assure the accumulation of the fresh and dry mass of the shoot and root of the bioindicator plant, when it was grown in the soil contaminated with sulfentrazone. At a density of 60 plants m^{-2}, the fresh and dry mass of the shoot of *P. glaucum*, grown in contaminated soil with 200 g i.a. ha^{-1} of sulfentrazone, did not differ from the treatment without the application of the herbicide, showing that the density of *C. juncea* is adequate to decontaminate the soil with the application of up to 200 g i.a. ha^{-1} of sulfentrazone (Table 3).

When grown in succession to *C. juncea* (60, 120 and 240 plants m^{-2}), *P. glaucum* showed a reduction of the fresh and dry mass of the root with the increase of the sulfentrazone dose in the soil (200 and 400 g i.a. ha^{-1}), except at the density of 240 plants m^{-2} of *C. juncea*, for which both with the absence and the application of 200 g i.a. ha^{-1} of sulfentrazone the dry mass of the root was not statistically different (Table 3).

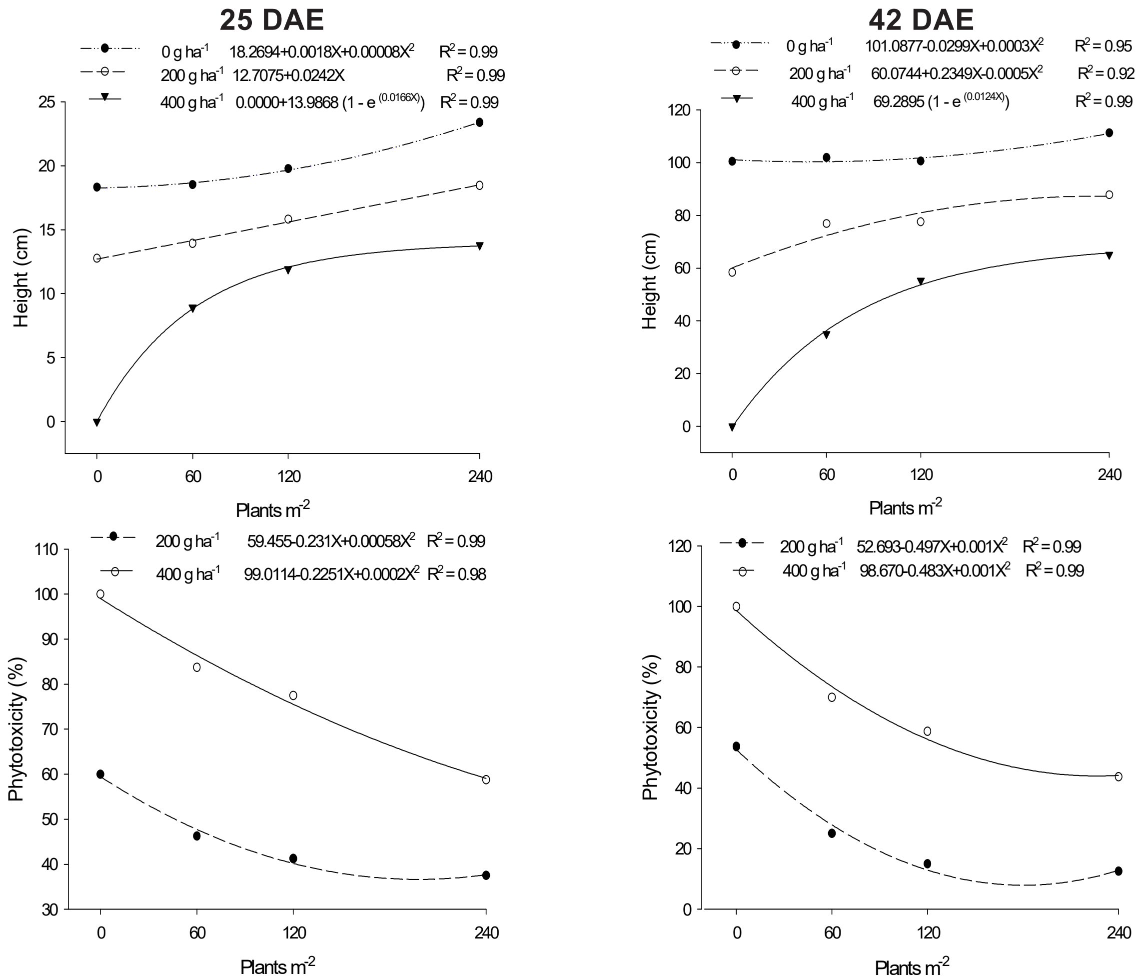

Figure 1 - Height and phytotoxicity in *Pennisetum glaucum* plants at 25 and 42 days after emergence (DAE), sown after a previous *Crotalaria juncea* crop, due to the density and application of doses of the sulfentrazone herbicide.

Table 3 - Fresh and dry mass of the shoot and the root of *Pennisetum glaucum* at 42 days after emergence, shown after the previous cultivation of *Crotalaria juncea*, due to the densities and application of doses of the sulfentrazone herbicide

Sulfentrazone dose (g i.a. ha^{-1})	*C. juncea* (*plants m^{-2})			
	0	60	120	240
	Shoot fresh mass (g)			
0	326.75 a	341.50 a	358.50 a	384.75 a
200	144.25 b	301.00 a	316.25 b	325.25 b
400	0.00 c	102.87 b	152.25 c	191.00 c
CV (%)	9.64			
	Shoot dry mass (g)			
0	52.39 a	53.43 a	54.84 a	58.28 a
200	20.00 b	50.30 a	50.38 a	52.50 a
400	0.00 c	9.68 b	21.30 b	28.72 b
CV (%)	18.65			
	Root fresh mass (g)			
0	61.25 a	96.00 a	95.50 a	102.00 a
200	18.50 b	74.25 b	70.00 b	77.50 b
400	0.00 c	21.75 c	40.00 c	41.00 c
CV (%)	17.59			
	Root dry mass (g)			
0	28.17 a	44.49 a	45.93 a	50.97 a
200	13.05 b	34.06 b	35.02 b	40.99 a
400	0.00 c	9.38 c	20.65 c	21.30 b
CV (%)	20.88			

* Averages followed by the same letter in the column are not different from each other according to Tukey's test ($p<0.05$).

In the absence of a previous *C. juncea* crop, the fresh and dray mass of the shoot and root were lower than those obtained with a previous crop. As the density of *C. juncea* increased, there was an increase in the fresh and dry mass, regardless of the sulfentrazone dose applied in the soil (Figure 2).

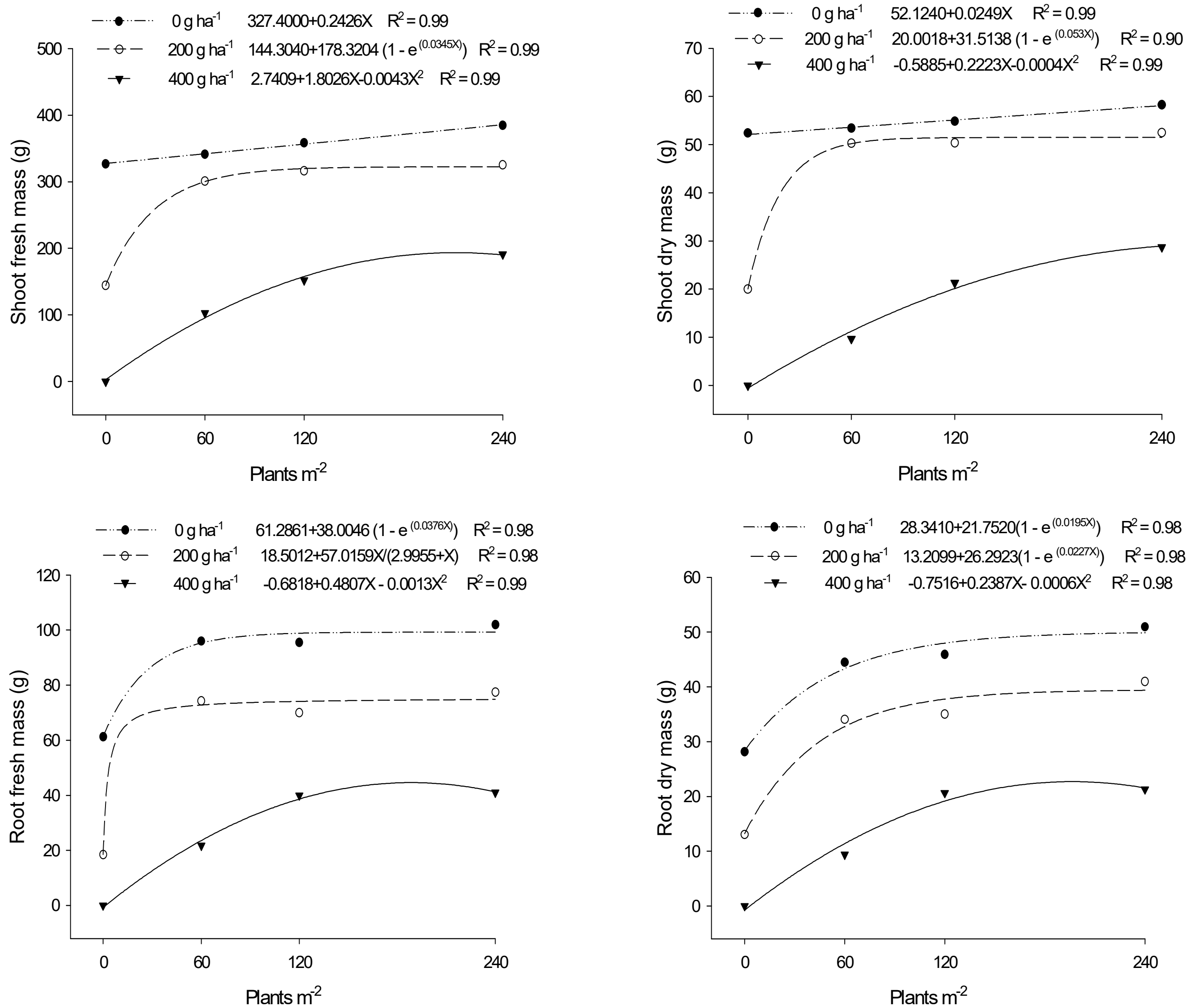

Figure 2 - Fresh and dry mass of the shoot and the root of *Pennisetum glaucum* at 42 days after emergence (DAE), sown after the previous cultivation of *Crotalaria juncea*, due to the density and application of doses of the sulfentrazone herbicide.

The adequate density of a phytoremediation species varies. For example, the minimal density of *C. ensiformis* that promotes the remediation of trifloxysulfuron-sodium and allows the development and productivity of the bean plant is 20 plants m^{-2} (Santos et al., 2006). The density of 172 plants m^{-2} is the most indicated one for the phytoremediation species *E. coracana* to offer a reduction in the carryover of picloram on the soybean crop sown in succession (Procópio et al., 2008). On the other hand, the minimal density of *C. ensiformis* that allows the remediation of the soil treated with sulfentrazone and allows the development of *P. glaucum* if 10 plants m^{-2} (Ferraço et al., 2017). For *Stizolobium aterrimum*, the minimal efficient density for the remediation of trifloxysulfuron-sodium in the soil is 25 plants m^{-2} (Procópio et al., 2005). For *Panicum maximum* cv. Tanzania, among the evaluated densities, 122 plants m^{-2} was the most efficient one to decontaminate the soil treated with picloram (Procópio et al., 2009).

Considering the results, it is concluded that the previous cultivation of *C. juncea* promotes the remediation of sulfentrazone, and the minimal density of this species that allows the development of *P. glaucum* is 120 plants m^{-2}.

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