PLANTA DANINHA
SOCIEDADE BRASILEIRA DA CIÊNCIA DAS PLANTAS DANINHAS
<http://www.sbcpd.org>
ISSN 0100-8358 (print)
1806-9681 (online)

Article

Residual Activity of Sulfentrazone Applied to Soybean on Cotton Crop in Succession

Atividade Residual de Sulfentrazone Aplicado na Cultura da Soja sobre o Algodoeiro em Sucessão

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ABSTRACT - Weed resistance to glyphosate in agricultural production systems has led to the need of applying herbicides with different mechanisms of action. However, the persistence of these herbicides in the soil can harm the subsequent crop. This study aimed to assess the effect of the residual activity of the herbicide sulfentrazone applied in pre-emergence of soybean on cotton in succession. The experimental design was a randomized block design with five replications, with seven doses of sulfentrazone (0, 37.5, 75, 150, 300, 600, and 1,200 g ha^{-1}). Cotton was sown at 112 days after herbicide application (DAA), with an accumulated precipitation of 637 mm during soybean cycle. Variables related to photosynthetic characteristics, phytointoxication, establishment, development, production components, and yield were assessed in both crops. The residual activity of sulfentrazone did not significantly interfere with the assessed variables in soybean but caused significant losses to cotton, which the recommended dosage (600 g ha^{-1}) of the herbicide reduced cotton yield by 30%.

Keywords: *Glycine max*, *Gossypium hirsutum*, carryover, herbicide, persistence.

RESUMO - A resistência de plantas daninhas ao glyphosate nos sistemas de produção agrícola tem gerado a necessidade de aplicação de herbicidas com diferentes mecanismos de ação. Entretanto, a persistência desses herbicidas no solo pode prejudicar a cultura subsequente. O presente trabalho teve como objetivo avaliar o efeito da atividade residual do herbicida sulfentrazone aplicado em pré-emergência da cultura da soja sobre o algodoeiro cultivado em sucessão. O delineamento experimental foi em blocos casualizados com cinco repetições, sendo utilizadas sete dosagens (0; 37,5; 75; 150; 300; 600; e 1.200 g ha^{-1}) do sulfentrazone. O algodoeiro foi semeado aos 112 dias após a aplicação (DAA) do herbicida com precipitação pluvial acumulada de 637 mm durante o ciclo da soja. Avaliaram-se variáveis relacionadas às características fotossintéticas, fitointoxicação, estabelecimento, desenvolvimento, componentes de produção e produtividade em ambas as culturas. A atividade residual do sulfentrazone não interferiu significativamente em nenhuma variável avaliada na cultura da soja, porém causou prejuízos significativos ao algodoeiro, na qual a dosagem recomendada (600 g ha^{-1}) do herbicida reduziu a produtividade de algodão em caroço em 30%.

Palavras-chave: *Glycine max*, *Gossypium hirsutum*, *carryover*, herbicida, persistência.

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Received: October 24, 2017
Approved: February 19, 2018

Planta Daninha 2019; v37:e019187015

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Doi: 10.1590/S0100-83582019370100043

INTRODUCTION

In the central-northern region of Mato Grosso, Brazil, soybean-cotton succession is common, with the State accounting for 27 and 65% of soybean and cotton Brazilian production, respectively (Conab, 2017). Weed interference can significantly affect their yield, which requires the use of effective measures to control invasive species. Although soybean-cotton succession is advantageous for producers, weed management adopted in the previous crop may reflect directly on cotton crop planted in succession, especially if the herbicide is not selective to cotton (Pekarek et al., 2010).

The most commonly used herbicide in RR soybean areas is glyphosate due to numerous advantages such as effectiveness and economic viability (Melhorança Filho et al., 2011). However, the constant application of glyphosate has contributed to select weed populations resistant to this herbicide due to selection pressure. Resistant species, such as ryegrass (*Lolium multiflorum*), horseweed (*Conyza* spp.), sourgrass (*Digitaria insularis*), tall windmill grass (*Chloris elata*) and, more recently, goosegrass (*Eleusine indica*) (Takano et al., 2017) have been selected in Brazil. Therefore, the application of herbicides with different mechanisms of action has been necessary in order to prevent and manage this resistance. Among these herbicides, sulfentrazone can be mentioned.

Sulfentrazone has an excellent pre-emergence activity in the soil for controlling dicotyledonous weeds and several monocotyledonous species, being registered for crops of great commercial importance in Brazil, such as sugarcane, soybean, and eucalyptus. It has a half-life of 60 to 116 days (Brum et al., 2013) and a high residual activity in the soil up to 150 days after application (DAA), reaching more than 280 DAA depending on local edaphoclimatic conditions (Monquero et al., 2010). In addition, it has the following characteristics: low dissociation in water, behaving as weak acid (pKa: 6.56); solubility related to pH increase (pH 6.0: 110 mg L^{-1}; pH 7.5: 1.600 mg L^{-1}); vapor pressure of 1×10^{-9} mmHg (25 °C); and partition coefficient (K_{ow} pH 7) of 9.8 (Dayan et al., 1997; Rodrigues and Almeida, 2011).

Sorption and desorption processes of sulfentrazone are dependent on pH and soil texture. Sorption decreases in response to an increased pH, particularly when above the herbicide pKa (6.56) (Grey et al., 2000). In addition, sulfentrazone sorption is higher in the no-tillage system than in the conventional system, which is related to a higher organic matter content in the former. Ohmes et al. (2000) verified that sulfentrazone dissipation was delayed under water restriction conditions, leading to a higher persistence in a clay loam textured soil (43% clay, 44% silt, 13% sand, 1.3% organic matter, and pH 6.1). In clayey soils, sulfentrazone presents a higher sorption rate, with a very slow desorption when compared to a medium textured soil (Reddy and Locke, 1998).

Sulfentrazone persistence in the soil is long and proportional to the applied dose (Blanco et al., 2010). However, sulfentrazone is more available in sandy soils than in clayey textured soils due to the binding of herbicide molecules to the negative charges of soil colloids (Carbonari et al., 2016). Sulfentrazone persistence at a dose of 600 g ha^{-1} was estimated to be 376 days in a clayey Oxisol (Blanco and Velini, 2005). The residual activity of sulfentrazone in cotton under succession was observed at doses higher than 400 g ha^{-1} applied in the previous year on different soils and textural classes (Main et al., 2004).

Little is known about the possible effects of the herbicide sulfentrazone when applied to soybean in succession to cotton. The aim of this study was to assess the effect of the residual activity of the herbicide sulfentrazone applied in the pre-emergence of soybean in succession to cotton.

MATERIAL AND METHODS

The experiment was carried out on the experimental area of the Center of Training and Technology Diffusion of the Cotton Institute of Mato Grosso (IMAmt), located in Sorriso, MT (12°45’47" S and 55°50’14" W), from November 2015 to July 2016. The precipitations and average temperature throughout the study period are shown in Figure 1. An accumulated precipitation

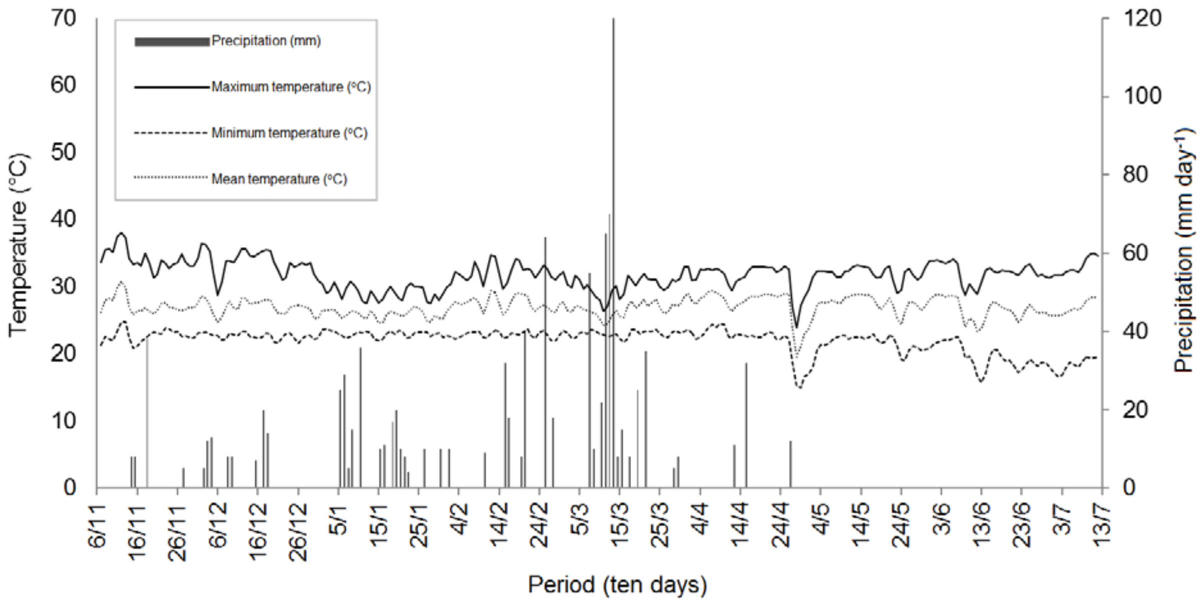

Figure 1 - Maximum, mean, and minimum temperatures (ºC) and precipitation (mm day^{-1}) registered during the experimental period in the soybean-cotton succession. Sorriso, MT, 2016.

of 637 mm was registered in the period between the day of application and cotton sowing, totaling 1,043 mm until the harvest.

The experiment was carried out in an Oxisol (Latossolo Vermelho-Amarelo Distrófico típico, LVAd, Brazilian Soil Classification System). A subsoiling operation was carried out on August 15, 2015, and then a soil correction with the application of 2,000 kg ha^{-1} of dolomitic limestone and incorporation at a depth of 0.2 m with a disc harrow. Base fertilization was carried out on September 15, 2015, by broadcast applying 1,000 kg ha^{-1} of simple superphosphate with later incorporation with a leveling harrow. The soil of experimental units presented at a depth of 0.0 to 0.2 m a pH in $CaCl_2$ of 4.9, Ca^{2+} of 2.6 $cmol_c$ dm^{-3}, Mg^{2+} of 1.0 $cmol_c$ dm^{-3}, Al^{3+} of 0.0 $cmol_c$ dm^{-3}, H^{+}+Al^{3+} of 5.2 $cmol_c$ dm^{-3}, K^{+} of 52.0 mg dm^{-3}, P of 14.6 mg dm^{-3}, CEC of 8.8 $cmol_c$ dm^{-3}, OM of 3.7%, and clay texture (sand of 140 g kg^{-1}, silt of 180 g kg^{-1}, and clay of 680 g kg^{-1}). The herbicide clethodim (100 g ha^{-1}) was applied in total area at seven days before experiment setup due to the predominance of grasses at the initial stage.

The soybean cultivar M7739 IPRO, which is resistant to glyphosate, has a semi-determined growth, and a medium-early cycle was used. Sowing occurred mechanically on November 6, 2015, at a 0.45 m row spacing, with seeder adjustment to obtain a final population of 260,000 plants ha^{-1}. Seeds were treated with the insecticide thiamethoxam at a dose of 100 g 100 kg^{-1} of seeds and with the fungicide carboxin + thiram (60 + 60 g 100 kg^{-1} of seeds). An inoculation with nitrogen-fixing bacteria (*Bradyrhizobium* 5 × 10^9 CFU mL^{-1}) in a liquid formulation was also applied at a dose of 100 mL 50 kg^{-1} of seeds. A topdressing fertilization was carried out at 30 days after soybean sowing, with a broadcast application of 150 kg ha^{-1} of KCl.

The experimental design was a randomized block design with five replications, with seven doses of the herbicide sulfentrazone (0, 37.5, 75, 150, 300, 600, and 1,200 g ha^{-1}). Plots consisted of eight soybean rows with 6 m long. Subsequently, after soybean harvest, four cotton rows were sown in these same plots at a spacing of 0.90 m. The useful plot had an area of 10.8 m^2 composed of the four central soybean rows and two central cotton rows in succession.

The application of herbicide treatments was performed in pre-emergence soon after soybean sowing by means of a backpack CO_2-pressurized sprayer equipped with a boom containing six fan type spray tips XR 110.02 spaced 0.5 m from each other and positioned at 0.5 m from soil surface, under a pressure of 2.11 kgf cm^2, delivering an application volume equivalent to 200 L ha^{-1}. Management practices were carried out following the recommendations for soybean cultivation (Embrapa, 2013). Plots were maintained without the presence of weeds during the entire experimental period by means of manual weeding.

The initial assessment of soybean stand was carried out at seven days after treatment application (DAA) by counting the number of emerged plants per linear meter in the useful area of each plot. The variables related to photosynthesis, i.e. internal CO_2 concentration in the substomatal chamber (*Ci*), photosynthetic rate (*A*), stomatal conductance (g_s), and transpiration rate (*E*), were assessed at 19, 27, and 34 DAA with an infrared gas analyzer (IRGA) (ADC BioScientific, model LC-pro SD) coupled to a 6.25 cm^2 leaf chamber equipped with a lighting and cooling system under artificial saturating light (1,500 µmol photons m^{-2} s^{-1}) and ambient CO_2 concentration. IRGA readings (gas exchange) were performed from 8:00 to 10:00 h in the plant with the most representative vegetative stage of the plot by measuring the younger fully expanded trefoil.

Soybean intoxication assessments were performed on the same days in which the photosynthesis-related variables were assessed by using 0–100% visual grades, where zero represented no injuries and 100 represented plant death (Frans and Crowley, 1986).

At 104 DAA, the pre-harvest variables plant height (measured from soil level to the last pod insertion) and first pod insertion height were assessed in ten soybean plants per experimental unit. The final plant stand (number of plants per meter) was assessed on that date. Ten plants were collected per plot for further assessments on the number of pods per plant and number of grains per pod. Moreover, soybean desiccation was also carried out at 104 DAA by applying 400 g ha^{-1} of diquat in total area.

Harvest was performed at 112 DAA. The 100 grain weight and yield were measured using a precision analytical balance and correcting the moisture to 13%, according to the Rules for Seed Testing (Brasil, 2009). Cotton was sown in succession to soybean, maintaining the same experimental design used previously.

The cotton cultivar used was the TMG 42 WS, which presents a medium-early cycle, being commonly used in the second crop in the central-northern region of Mato Grosso. Sowing was performed on February 26, 2016. Base fertilization was carried out in the sowing furrow with the application of 250 kg ha^{-1} of monoammonium phosphate. Topdressing fertilization was performed 30 days after sowing by broadcast applying 150 kg ha^{-1} of KCl. Management practices were carried out following recommendations for cotton cultivation (Belot, 2015).

After emergence, the initial stand of cotton plants was determined at seven days after sowing (DAS), which corresponded to 119 DAA. Photosynthesis-related variables and the intoxication caused by the herbicide were assessed in cotton plants at 14, 20, and 27 DAS similarly to that performed in soybean.

At 132 DAS, the pre-harvest variables plant height, measured from soil level to the top of plants, and first productive branch height, measured from soil to its insertion, were assessed in ten cotton plants aiming at representing the plot. Moreover, the number of bolls per plant was obtained by sampling ten plants per plot and the average mass of bolls was obtained by collecting at random ten bolls per plot.

Cotton defoliation was performed by applying a formulated mixture containing 60 g ha^{-1} of thidiazuron + 30 g ha^{-1} of diuron at pre-harvest (132 DAS) when more than 80% of the bolls were fully open. Cotton was manually harvested from the useful area of the plot at 7 days after defoliant application. After collection, bolls were bagged and identified in order to obtain cotton yield. Ten fiber samples were taken from each plot at harvest time and sent to the laboratory UNICOTTON, located in Primavera do Leste, MT, to assess the main characteristics of fiber quality (area of impurity, upper-half mean length, uniformity index, short fiber content, fiber strength, elongation, micronaire index, reflectance unit, degree of yellowing, spinning consistency index, and maturity).

The data were submitted to analysis of variance by the F-test by means of the statistical program SAS/STAT v. 9.1 ($p<0.05$). When significant, the regression analysis and comparison of models were performed searching for that with the best fit to the behavior of the data (Eq. 1 and 2). Subsequently, sulfentrazone doses were estimated to provide reductions of 5 and 10% in cotton yield.

Equation 1: Linear polynomial model.

$$f = a + bx \quad \text{(eq. 1)}$$

where f is the response variable, x is the sulfentrazone dose, a is the control value, and b is the linear coefficient.

Equation 2: Three-parameter sigmoidal model.

$$f = \frac{a}{\left(1 + \exp\left(-\frac{x - x0}{b}\right)\right)} \quad \text{(eq. 2)}$$

in which f is the response variable, x is the diclosulam dose, a is the amplitude or maximum value of f, $x0$ is the value of x to 50% of the amplitude, and b the constant of the sigmoidal model.

RESULTS AND DISCUSSION

Sulfentrazone application in pre-emergence did not significantly alter ($p<0.05$) the assessed variables in soybean up to a dose of 1,200 g ha^{-1} (Tables 1 and 2). On the other hand, in another study, sulfentrazone application in pre-emergence at a dose of 400 g ha^{-1} led to injuries in soybean plants at 7 DAA, but no visual symptoms of intoxication were observed at 14 DAA (López-Ovejero et al., 2013). This result may be related to the cultivar. However, sulfentrazone selectivity is variable in relation to soybean cultivars. Species or varieties whose sulfentrazone metabolism rate is higher tend to have a higher tolerance to herbicide (Merotto Jr and Vidal, 2001). In addition, a higher herbicide availability in the soil can be found under conditions of higher precipitation, lower organic matter content, low microbial activity, sandy texture, and pH above the herbicide pKa (Martinez et al., 2008; Brum et al., 2013).

Table 1 **-** Summary of analysis of variance of photosynthesis-related variables (*Ci*: internal CO_2 concentration in the substomatal chamber; *E*: transpiration rate; g_s: stomatal conductance; *A*: photosynthetic rate) and phytointoxication assessed in the soybean crop submitted to the pre-emergence application of increasing sulfentrazone doses. Sorriso, MT, 2016

Variable	19 DAA			27 DAA			34 DAA		
	Mean	CV (%)	Pr > F	Mean	CV (%)	Pr > F	Mean	CV (%)	Pr > F
C_i (μmol mol^{-1})	258.14	5.73	0.11^{ns}	219.2	9.37	0.91^{ns}	261.22	4.66	0.08^{ns}
E (mmol H_2O m^{-2} s^{-1})	5.65	9.06	0.07^{ns}	4.87	15.38	0.31^{ns}	6.24	7.31	0.28^{ns}
g_s (mol $m^{-2}s^{-1}$)	0.67	32.32	0.15^{ns}	0.21	26.81	0.27^{ns}	0.76	31.68	0.16^{ns}
A (μmol CO_2 m^{-2} s^{-1})	19.27	11.97	0.16^{ns}	13.99	21.32	0.70^{ns}	18.54	11.21	0.27^{ns}
Phytointoxication (%)	0.0	–	–	0.0	–	–	0.0	–	–

DAA: days after application; ^{ns}: not significant; CV (%): coefficient of variation.

Table 2 **-** Summary of analysis of variance of variables related to development (IS: initial stand; FS: final stand; PH: plant height; IH: first pod insertion height), production components (NP: number of pods per plant; NGP: number of grains per pod; W100: 100-grain weight), and productivity (P) assessed in the soybean crop submitted to the pre-emergence application of increasing sulfentrazone doses. Sorriso, MT, 2016

Variables related to development	Mean	CV (%)	Pr > F
IS (plants m^{-1}) – 7 DAA	10.40	9.63	0.44^{ns}
FS (plants m^{-1}) – 104 DAA	10.81	9.72	0.20^{ns}
PH (cm) – 104 DAA	66.21	18.59	0.30^{ns}
IH (cm) – 104 DAA	13.11	7.35	0.09^{ns}
Variables related to production components and productivity	–	–	–
NP (pod $plant^{-1}$)	47.24	9.61	0.89^{ns}
NGP (grain pod^{-1})	2.40	7.15	0.87^{ns}
W100 (g)	17.35	5.01	0.84^{ns}
P (kg ha^{-1})	3,370.08	13.57	0.68^{ns}

DAA: days after application; ^{ns}: not significant; CV (%): coefficient of variation.

In relation to cotton, no significant effect ($p<0.05$) of the residual activity of the herbicide was observed on the variables related to photosynthesis, plant stand, fiber yield, and fiber quality (Tables 3, 4, and 5). However, an effect was observed on the variables of visual intoxication (14, 20, and 27 DAS), plant height, first productive branch insertion height, number of bolls per plant, average weight of boll, and cotton yield.

Cotton plants had injuries during emergence, in which sulfentrazone affected the cotyledons and first leaves, causing the death of some seedlings (data not shown). However, from 14 DAS, younger leaves showed no more visible injuries.

Table 3 **-** Summary of analysis of variance of photosynthesis-related variables (*Ci*: internal CO_2 concentration in the substomatal chamber; *E*: transpiration rate; g_s: stomatal conductance; *A*: photosynthetic rate) and phytointoxication assessed in the cotton cv. TMG 42 WS cultivated in succession to the soybean cv. M7739 IPRO submitted to the pre-emergence application of increasing sulfentrazone doses. Sorriso, MT, 2016

Variable	14 DAA			20 DAA			27 DAA		
	Mean	CV (%)	Pr > F	Mean	CV (%)	Pr > F	Mean	CV (%)	Pr > F
C_i (µmol mol^{-1})	221.2	9.28	0.76^{ns}	259.7	2.89	0.81^{ns}	267.6	8.68	0.48^{ns}
E (mmol H_2O m^{-2} s^{-1})	5.07	14.77	0.21^{ns}	5.99	8.76	0.87^{ns}	4.79	12.73	0.10^{ns}
g_s (mol m^{-2}s^{-1})	0.24	23.47	0.25^{ns}	0.54	22.74	0.86^{ns}	0.56	37.05	0.12^{ns}
A (µmol CO_2 m^{-2} s^{-1})	14.29	20.87	0.56^{ns}	17.12	13.95	0.88^{ns}	16.73	31.91	0.41^{ns}
Phytointoxication (%)	8.37	45.46	0.01*	9.51	84.40	0.01*	11.17	43.54	0.01*

DAA: days after application; *: significant ($p<0.05$); ^{ns}: not significant; CV (%): coefficient of variation.

Table 4 **-** Summary of analysis of variance of variables related to development (IS: initial stand; FS: final stand; PH: plant height; PBH: first productive branch height), production components (NB: number of bolls per plant; AWB: average weight of bolls; FY: fiber yield), and cotton productivity (P) assessed in the cotton crop in succession to soybean submitted to the pre-emergence application of increasing sulfentrazone doses. Sorriso, MT, 2016

Variables related to development	Mean	CV (%)	Pr > F
IS (plants m^{-1}) – 7 DAS	7.55	7.48	0.08^{ns}
FS (plants m^{-1}) – 132 DAS	7.85	11.70	0.20^{ns}
PH (cm) – 132 DAS	46.71	12.61	0.01**
PBH (cm) – 132 DAS	21.40	9.28	0.01**
Variables related to production components and productivity	–	–	–
NB	4.04	22.49	0.01**
AWB (g)	2.90	8.19	0.01**
FY (%)	42.44	1.78	0.64^{ns}
P (kg ha^{-1})	701.80	29.64	0.01**

DAA: days after application; *: significant ($p<0.05$); **: significant ($p<0.01$); ^{ns}: not significant; CV (%): coefficient of variation.

An effect of herbicide was observed for phytointoxication assessments carried out in cotton plants at 14, 20, and 27 DAS (Table 3 and Figure 2). In all assessments, the residual activity of sulfentrazone (600 g ha^{-1}) promoted 13% of intoxication in the cotton, reaching 60% when twice the recommended dose was applied (1,200 g ha^{-1}). In addition, cotton sowing occurred at 112 DAA. The period of sulfentrazone activity (600 and 800 g ha^{-1}) in the soil observed by Monquero et al. (2010) was 150 DAA and from this period, a marked herbicide dissipation was observed under the conditions in which the study was assessed (3.6% of OM; 56% of clay; and pH ($CaCl_2$) of 4.7).

Other authors have verified the residual activity of sulfentrazone affecting cotton plants, which suggests the crop sensitivity to the herbicide. Pekarek et al. (2010) observed an 18% intoxication for cotton at 352 DAA (28 days after crop emergence) at a dose of 210 g ha^{-1} of sulfentrazone applied in pre-emergence in the soybean crop (loamy sand textured soil, 0.32% of OM, and pH of 5.6). In addition, the symptoms worsened at higher doses. The authors reported a minimum of 50% of intoxication in cotton plants when an herbicide dose of 840 g ha^{-1} was applied.

Cotton intoxication may be related to herbicide availability in the soil solution, which is dependent on the environmental conditions (precipitation and temperature), microbial activity, pH, texture, and organic matter, which influence bonds with mineral and organic colloids (Monquero et al., 2010). Soil pH presents a great influence on the availability of sulfentrazone molecules in the soil solution and its persistence. The soil of our experiment had a pH ($CaCl_2$: 4.9) lower than the herbicide pKa (6.56), which causes more than 50% of the sulfentrazone to be present in the molecular form and not available in the soil solution, favoring its persistence and hence the ability to injure sensitive crops (Ferrell et al., 2003).

Water availability in the environment is also a factor to be considered. The higher water availability in the soil favors the dissipative and leaching processes of sulfentrazone (Monquero et al., 2010). No water restriction was observed during the soybean cycle, but precipitation indices were not as marked when compared to those of the regional history (Figure 1), which favors herbicide permanence in the soil.

Table 5 **-** Summary of analysis of variance of fiber quality characteristics (TR: thrash content; A: area of impurity; UHM: upper-half mean length; UI: uniformity index; SFC: short fiber content; STR: fiber strength; ELONG: elongation; MIC: micronaire index; RD: reflectance unit; +B: degree of yellowing; SCI: spinning consistency index; MAT: maturity) assessed in cotton cv. TMG 42 WS cultivated in succession to soybean submitted to sulfentrazone application in pre-emergence. Sorriso, MT, 2016

Fiber quality characteristics	Mean	CV (%)	Pr > F
A (%)	0.43	6.17	0.34^{ns}
UHM (in)	1.13	2.09	0.06^{ns}
UI (%)	82.20	1.28	0.21^{ns}
SFC (%)	9.37	5.38	0.11^{ns}
STR (gf tex^{-1})	28.88	5.29	0.49^{ns}
ELONG (%)	6.29	6.39	0.31^{ns}
MIC (μg in^{-1})	3.95	4.17	0.15^{ns}
RD (%)	83.29	1.08	0.14^{ns}
+B	8.01	3.89	7.95^{ns}
SCI (lbf)	134.70	6.23	0.33^{ns}
MAT (%)	85.20	0.52	0.44^{ns}

^{ns}: not significant; CV (%): coefficient of variation.

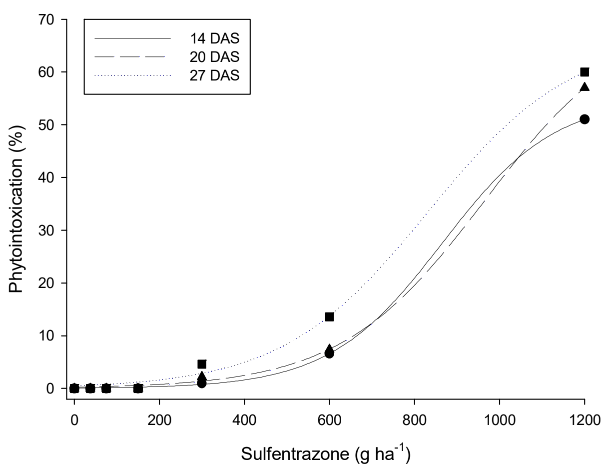

Figure 2 **-** Phytointoxication of cotton plants in succession to soybean submitted to sulfentrazone application in pre-emergence at three assessments periods (14, 20, and 27 DAS). Sorriso, MT, 2016.

The sulfentrazone doses necessary to result in a 5 and 10% intoxication (D_5 and D_{10}) in cotton can be estimated by means of regression analysis (Table 6). The application of 600 g ha^{-1} led to a phytotoxic effect, which could compromise the development and yield of the cotton cultivated in succession. However, in practice, producers have used doses below those recommended (150 to 300 g ha^{-1}), mainly in association with other herbicides (Dirks et al., 2000), which can minimize this effect.

The variables first productive branch height and plant height, assessed at 132 DAS (Figures 3A and B), were affected with increasing sulfentrazone doses. Other studies also have reported a lower plant growth in response to sulfentrazone (Main et al., 2004; Pekarek et al., 2010).

Because the residual activity of sulfentrazone has affected cotton plants since the beginning of development, it is suggested that the residual activity of the herbicide has been potentiated by water stress. Doses below that recommended for soybean cultivation provided a reduction of at least 10% in the variables plant height and first productive branch height. Sulfentrazone doses required to reduce cotton development characteristics by 5 and 10% are shown in Table 7. If a reduction of up to 5% in the residual activity of the herbicide under the observed conditions is tolerated, sulfentrazone doses below 242 g ha^{-1} could be used in the soybean-cotton succession without adversely affecting these variables. Because the dose is considered low, the herbicide is more easily degraded and/or leached, reducing the period of persistence and the concentration in the soil.

Table 6 **-** Models fitted to estimate the sulfentrazone dose (g ha^{-1}) required to result in a phytointoxication of 5 and 10% (D_5 and D_{10}) in cotton cultivated in succession to soybean submitted to sulfentrazone application in pre-emergence. Regression parameters were estimated using Eq. 2. Sorriso-MT, 2016

Phytointoxication	Regression parameters			R^2	D_5	D_{10}
	a	*B*	*x0*			
14 DAS	55.1236	133.1	865.3	0.999	558.5	664.8
20 DAS	71.5380	170.7	966.8	0.999	525.0	656.5
27 DAS	66.9835	171.4	831.5	0.998	365.5	506.0

DAS: days after sown; R^2: coefficient of determination.

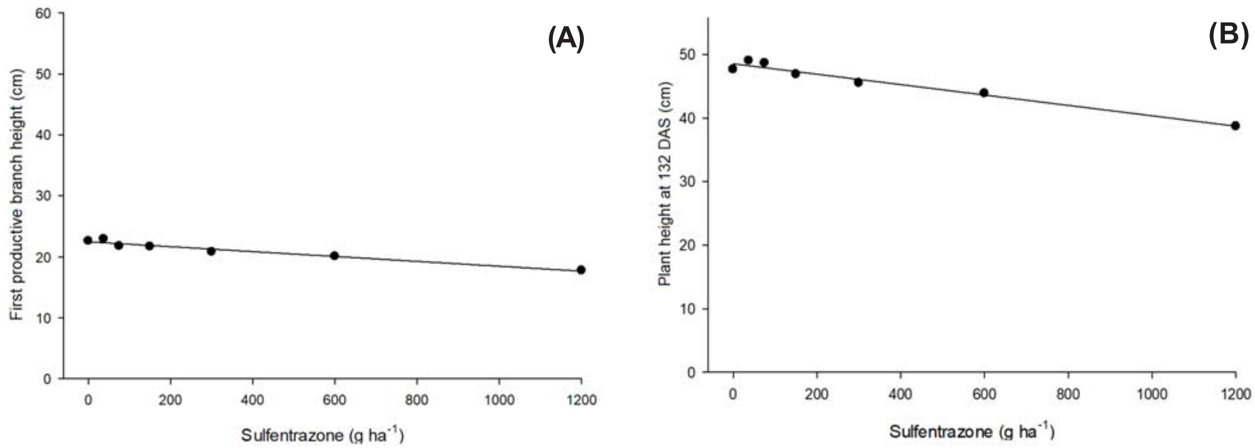

Figure 3 **-** Variables related to development (A: first productive branch height; B: plant height at 132 DAS) assessed in cotton in succession to soybean submitted to the pre-emergence application of increasing sulfentrazone doses. Sorriso, MT, 2016.

Table 7 **-** Sulfentrazone dose (g ha^{-1}) required to reduce by 5 and 10% (D_5 and D_{10}) the variables related to development, production components, and productivity of cotton in succession to soybean submitted to sulfentrazone application in pre-emergence. Regression parameters were estimated using Eq. (1). Sorriso, MT, 2016

Variable	Regression parameters		R^2	D_5	D_{10}
	a	*b*			
PH	48.5138	-0.0082	0.967	397.0	687.5
PBH	22.5152	-0.004	0.958	242.3	525.8
AWB	3.1041	-0.0006	0.856	373.8	626.4
NB	4.8418	-0.0017	0.939	255.2	391.6
P	836.187	-0.4063	0.896	217.5	314.4

PH: plant height at 132 DAS (cm); PBH: first productive branch height at 132 DAS (cm); AWB: average weight of bolls (g); NB: number of bolls per plant (boll per plant); P: cotton productivity (kg ha^{-1}).

A sulfentrazone dose of 373 g ha^{-1} led to a 5% reduction in the average weight of bolls (Figure 4A) in relation to the control, reaching a 10% reduction when a dose of 600 g ha^{-1} was applied. A dose of 391 g ha^{-1} reduced the number of bolls per plant by up to 10% (Figure 4B). Both the number of bolls per plant and the average weight of bolls are directly related to the production potential of cotton plants. When these characteristics are reduced, crop yield presents a reduction.

Cotton yield (Figure 4C) was reduced by 30% due to the residual activity of sulfentrazone applied in the soybean crop at a dose of 600 g ha^{-1}. In spite of the low yield of the experiment due to the water deficit, a 10% reduction can be estimated in crop yield caused by the residual activity with a sulfentrazone application of 314 g ha^{-1}. On the other hand, Pekarek et al. (2010) reported a reduction of 32% in the yield of cotton in succession to soybean with a sulfentrazone application of 210 g ha^{-1}. These authors reported that this reduction in yield ranged from 36 to 100% at doses of 840 g ha^{-1} or higher.

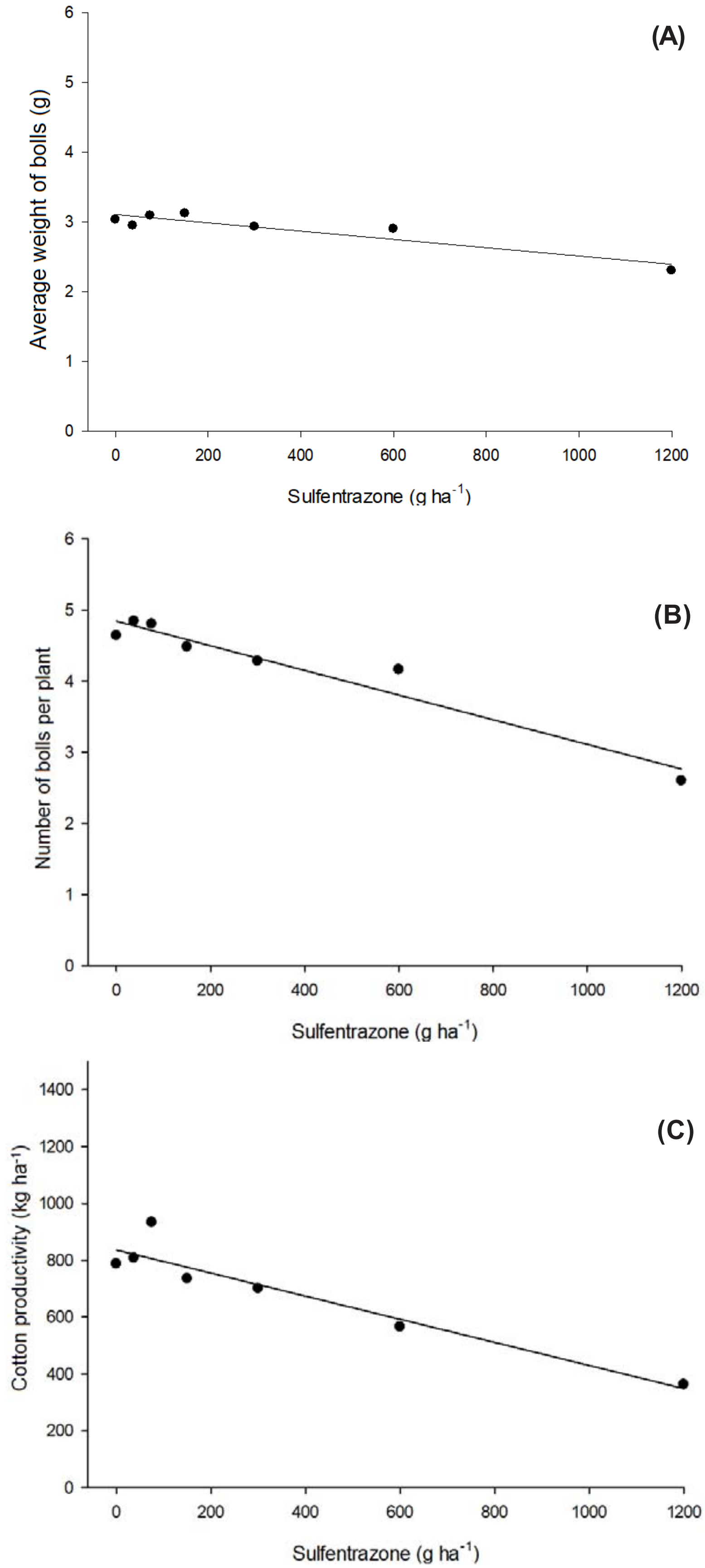

Figure 4 - Production and productivity components (A: average weight of bolls; B: number of bolls per plant; C: cotton productivity) assessed in cotton in succession to soybean submitted to the pre-emergence application of increasing sulfentrazone doses. Sorriso, MT, 2016.

Regarding the variables of fiber quality, no effect was observed in the residual activity of sulfentrazone, regardless of the dose applied in the soybean crop 112 days before cotton sowing. Although there is a lack of information in the literature about the effects of the residual activity of this herbicide on such variables. Main et al. (2004) reported a reduced cotton fiber length due to the application of this herbicide. However, this effect was not observed in our study, which can be attributed to the different cultivars and/or edaphoclimatic conditions.

In addition, the use of soybean cultivars of different cycles in the soybean-cotton succession tends to directly influence the period between herbicide application and cotton sowing, if it is carried out immediately after harvest. For the soybean cultivar used in this study, the interval between the application of herbicide doses and cotton sowing was 112 days. However, if an early cultivar were used, cotton sowing would be carried out about 100 days after sulfentrazone application, which may potentiate the residual activity of the herbicide on the crop. Furthermore, the effects of sulfentrazone application are more pronounced in compacted soils and may even affect herbicide-tolerant species, as verified by Zobiole et al. (2007) in the soybean crop.

Thus, sulfentrazone application up to a dose of 1,200 g ha^{-1} did not significantly interfere with the assessed variables in the soybean crop. However, residual of doses of 217.5 and 314.4 g ha^{-1} reduced the yield of the cotton cv. TMG 42 WS by 5 and 10%, respectively, and the residual of the recommended dose (600 g ha^{-1}) reduced cotton yield by 30%.

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