PLANTA DANINHA

SOCIEDADE BRASILEIRA DA CIÊNCIA DAS PLANTAS DANINHAS

<http://www.sbcpd.org>

ISSN 0100-8358 (print)
1806-9681 (online)

Article

Rates of Nicosulfuron Applied in Glyphosate-Tolerant and Sulfonylurea-Tolerant Soybean

Doses de Nicosulfuron Aplicadas em Soja Tolerante a Glyphosate e Sulfonilureias

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ABSTRACT - STS cultivars tolerate up to four times higher rates of chlorimuron than those recommended for non-tolerant cultivars, without significant damage. However, few studies position the selectivity of nicosulfuron in STS cultivars. The aim of this study was to assess the selectivity of rates of the herbicide nicosulfuron applied in the post-emergence (V4) of RR/STS soybean. The experiments were conducted in the 2015/16 and 2016/17 seasons in Piracicaba, SP. In the 2016/17 season, the experiment was also conducted in Palotina, PR. Treatments consisted of six rates of the herbicide nicosulfuron (0, 50, 100, 150, 200, and 250 g a.i. ha^{-1}). The experimental design was a randomized block design with four replications. The symptoms of injury were assessed at 7, 14, 21, and 28 days after application, as well as the assessment of variables related to the agronomic performance (plant height, number of pods per plant, yield, and one thousand-grain weight). The data were submitted to regression analysis ($p<0.05$). The estimated rates reduced yield by 5% in relation to the rate 0 and were between 57.79 and 68.37 g a.i. ha^{-1}. In general, the RR/STS soybean is tolerant to the application of nicosulfuron up to 57.79 g a.i. ha^{-1} when considering the estimated rates. Therefore, the RR/STS soybean is tolerant to the application of nicosulfuron up to 50 g a.i. ha^{-1}, according to the applied rates.

Keywords: herbicide-tolerant crops, ALS inhibitors, agronomic performance, selectivity, *Glycine max* (L.) Merrill.

RESUMO - Cultivares STS toleram doses até quatro vezes maiores de chlorimuron que as recomendadas para cultivares não tolerantes, sem apresentar danos significativos. Contudo, poucos trabalhos posicionam a seletividade de nicosulfuron em cultivares STS. O objetivo do presente trabalho foi avaliar a seletividade de doses do herbicida nicosulfuron aplicado em pós-emergência (V4) de soja RR/STS. Os experimentos foram conduzidos nas safras de 2015/16 e 2016/17, em Piracicaba - SP. Em 2016/17, também foi conduzido em Palotina - PR. Os tratamentos foram compostos por seis doses do herbicida nicosulfuron (0, 50, 100, 150, 200 e 250 g i.a. ha^{-1}). O delineamento experimental empregado nos quatro ensaios foi em blocos casualizados com quatro repetições. Foram avaliados os sintomas de injúria aos 7, 14, 21 e 28 dias após a aplicação, bem como realizada avaliação de variáveis relacionadas ao desempenho agronômico (altura de plantas, número de vagens por planta, produtividade e massa de mil grãos). Os dados obtidos foram submetidos à análise de regressão ($p<0{,}05$). Analisando as doses estimadas, que reduziram em 5% a produtividade em relação à dose 0, verifica-se que estas doses ficaram entre 57,79 e 68,37 g i.a. ha^{-1}; assim, pode-se inferir que de maneira geral a soja RR/STS é tolerante para aplicação de nicosulfuron até 57,79 g i.a. ha^{-1}, pelas doses estimadas. Pode-se concluir que a

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Received: November 24, 2017
Approved: November 27, 2017

Planta Daninha 2019; v37:e019188317

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Doi: 10.1590/S0100-83582019370100010

soja RR/STS é tolerante para aplicação de nicosulfuron até 50 g i.a. ha^{-1}, de acordo com as doses aplicadas.

Palavras-chave: culturas tolerantes a herbicidas, inibidores da ALS, desempenho agronômico, seletividade, *Glycine max* (L.) Merrill.

INTRODUCTION

The areas occupied by soybean crop in Brazil in the 2016/2017 season reached 32.89 million hectares (Conab, 2017), of which 96.5% were genetically modified herbicide-tolerant or insect-resistant or both (Céleres, 2017).

Researches aimed at increasing the quality and productivity of soybean are intense. This has required a constant reformulation and adaptation of technologies and management, such as a more adequate positioning of the herbicide glyphosate, in addition to the emergence of new technologies.

Sulfonylurea tolerant soybean (STS®) is not a transgenic crop developed by the seed mutagenesis technique (Rogozin et al., 2001). Mutant seeds of the soybean cultivar Williams 82 were selected according to the tolerance to sulfonylurea chlorsulfuron. Thus, the soybean cultivar W20 was developed and presented a high degree of tolerance in the post- and pre-emergence for some sulfonylureas (Sebastian et al., 1989; Walter et al., 2014). This characteristic was determined by the semi-dominant alleles Als1 (Sebastian et al., 1989; Ghio et al., 2013; Walter et al., 2014; Rizwan and Akhtar, 2015; Mantovani et al., 2017) and Als2 (Walter et al., 2014; Mantovani et al., 2017).

The allele Als1 gives soybean tolerance to chlorimuron, nicosulfuron, rimsulfuron, sulfometuron, thifensulfuron, tribenuron, and flucarbazone, while the allele Als2 gives soybean tolerance to these herbicides and imazapyr (Walter et al., 2014). STS cultivars are highly tolerant to the herbicide chlorimuron (Green, 2007; Albrecht et al., 2018), which can be applied up to four times the recommended rate for non-STS cultivars (Roso and Vidal, 2011).

Sulfonylureas mainly control dicotyledonous weeds and are widely used in wheat, rice, soybean, barley, cotton, potato, and corn (Brown, 1990; Zhou et al., 2007). The herbicide nicosulfuron belongs to the chemical group of sulfonylureas and is registered for use in Brazil in maize for post-emergence application, with a maximum recommended rate of 60 g a.i. ha^{-1} (Rodrigues and Almeida, 2018). However, few studies position the selectivity of nicosulfuron in STS cultivars. RR/STS soybean was tolerant to the herbicide nicosulfuron, which did not cause significant damage up to the rate of 200 g a.i. ha^{-1} (Albrecht et al., 2017). According to Silva et al. (2016), the application of nicosulfuron (60 g a.i. ha^{-1}) caused no injury and did not affect RR/STS soybean yield.

Considering the limited information on the rates of nicosulfuron that can be applied in STS soybean without yield reduction, the aim of this study was to assess the selectivity of rates of the herbicide nicosulfuron in the post-emergence (V4) of RR/STS soybean.

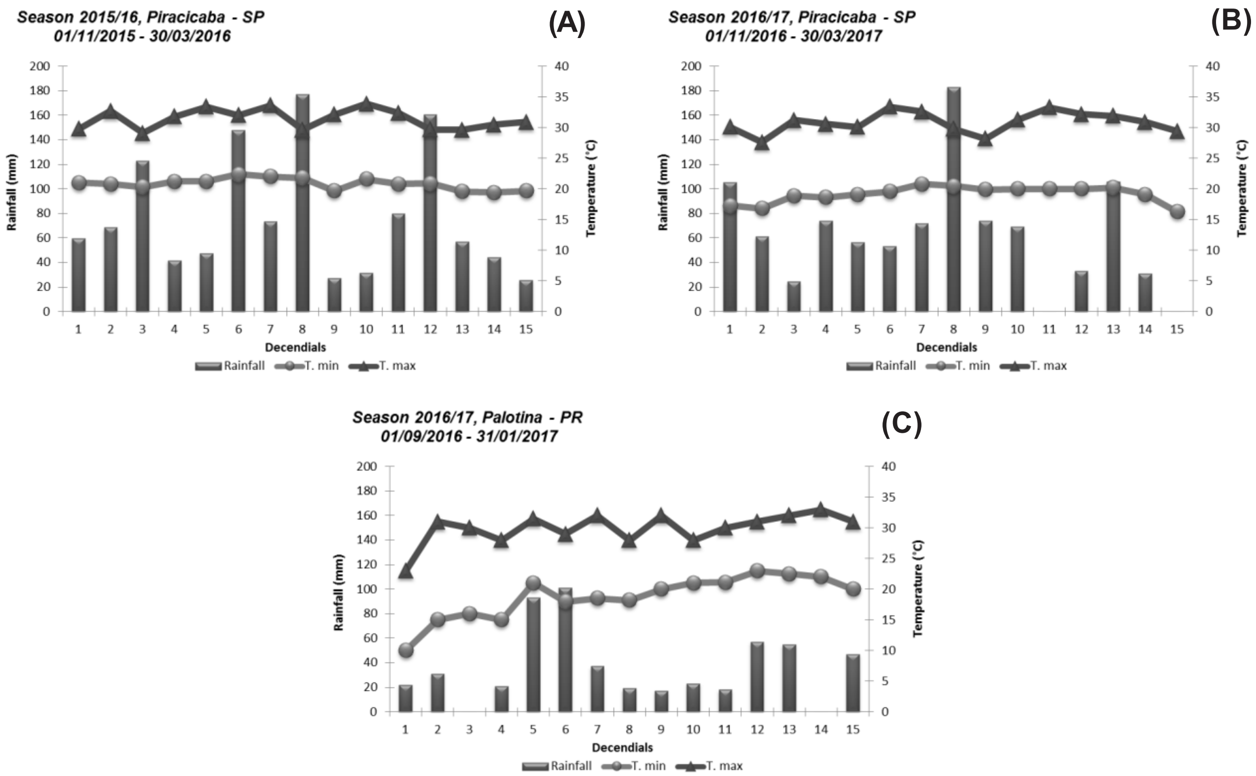
MATERIAL AND METHODS

The experiments were conducted in the 2015/16 and 2016/17 seasons in an area located in Piracicaba, SP. In the second season, the experiment was conducted in Palotina, PR. In the 2015/16 season, the cultivars CD 2630 RR/STS and BMX Turbo RR/STS were used in the experiments I and II, respectively. In the 2016/17 season, the cultivars DM 61I59 RR2/STS (experiment III) and BMX Garra RR2/STS (experiment IV) were used in Piracicaba and the cultivar BMX Garra RR2/STS (experiment V) was used in Palotina.

The cultivar CD 2630 presents an indeterminate growth habit and relative maturity group (RMG) 6.3. The cultivar BMX Turbo has an indeterminate growth habit and RMG 5.8. The cultivar DM 61I59 has an indeterminate growth habit and RMG 6.1, while the cultivar BMX Garra has an indeterminate growth habit and RMG 6.3.

The climate of the Piracicaba region is characterized as Cwa by the climatic classification of Köppen, i.e. subtropical humid with drought in the winter. The climate of the Palotina region is Cfa, i.e. mesothermal subtropical humid with a predominance of warm summers, low frequency of severe frosts, and the tendency of concentration of rains in the summer period. Figure 1 shows the precipitation and temperature distribution over the conduction period of each experiment.

A fertilization was carried out to correct the soil, considering crop extraction. All plots were maintained free of weed interference by means of manual weeding. Table 1 shows the soil physical and chemical analysis of the experimental areas.



Source: LEB – ESALQ/USP.

(A) 2015/16 season, Piracicaba, SP. (B) 2016/17 season, Piracicaba, SP. (C) 2016/17 season, Palotina, PR.

Figure 1 - Representation of rainfall, minimum average temperature, and maximum average temperature for the period referring to the soybean crop cycle.

Table 1 - Results of soil chemical and physical analysis of the experimental area at a depth of 0 to 20 cm

Piracicaba – SP									
pH ($CaCl_2$)	Al	H+Al	P (resin)	K	Ca	Mg	SB	CEC	V
5.3	< 1.0	25.0	10.0	2.8	26.0	13.0	41.8	66.8	63.0
Clay			Silt			Sand			
41.0			5.0			54.0			
Palotina – PR									
pH ($CaCl_2$)	Al	H+Al	P (Mehlich)	K	Ca	Mg	SB	CEC	V
5.6	< 1.0	46.1	19.4	2.2	55.1	14.7	72.0	118.1	61.0
Clay			Silt			Sand			
66.3			18.7			15.0			

Units: Al, H+Al, K, Ca, Mg, SB, and CEC ($mmol_c$ dm^{-3}); P (mg dm^{-3}); V, clay, silt, and sand (%).

Treatments were composed of six rates of the herbicide nicosulfuron (Sanson® 40 SC) (0, 50, 100, 150, 200, and 250 g a.i. ha^{-1}). The experimental design used in the five experiments was a randomized block design with four replications. The experimental units consisted of 5 m long plots with six soybean rows spaced 0.45 m from each other. The useful area was considered the four central rows, excluding the first and last meter of the plot.

The application of treatments was carried out by a CO_2-pressurized backpack sprayer with a boom equipped with four spraying nozzles (XR 110.02) at a constant pressure of 2 bar, flow rate of 0.65 L min^{-1}, working at a height of 50 cm from the target, and at a speed of 1 m s^{-1}, reaching an applied band of 50 cm wide per spray nozzle and providing a spray solution volume of 200 L ha^{-1}.

The symptoms of injury were assessed by means of visual assessments, in which percentage scores ranging from 0 to 100% were attributed to each experimental unit, where 0 represents no injury and 100% represents plant death (Velini et al., 1995). This assessment was performed at 7, 14, 21, and 28 days after application (DAA). For this data, we used the transformation option $(X+1)^{0.5}$.

Variables related to agronomic performance (plant height, number of pods per plant, yield, and one thousand-grain weight) were assessed. The assessment of height was performed when the plants reached the R7 stage. For this, 10 plants were randomly chosen in the useful area of each plot and measured with a wood millimeter ruler, with results expressed in centimeters. The number of pods per plant was assessed at full maturation (R8 stage) by manually counting the number of pods in 10 plants randomly chosen in the useful area of each plot.

For yield assessment, plants were collected from the three central rows, discarding the first and last meter of the plot, totaling a harvested area of 4.05 m^2. The plants were at the R8 stage, i.e. 95% of the pods had the typical mature pod color (Fehr et al., 1971). The pods were then threshed in a grain thresher for experimentation, cleaned with sieves, and packed in paper bags for further analysis and assessment. The grains produced in each plot had their mass measured and moisture corrected to 13%. From these data, the yield was calculated. For the one thousand-grain weight, the mass of two subsamples was measured per plot and moisture was corrected to 13%.

The data were analyzed according to the methods of Pimentel-Gomes and Garcia (2002). Once the basic assumptions for the variance analysis were met, the averages were subjected to regression analysis ($p<0.05$). Regarding the variables related to the agronomic performance, when the adjustment (linear regression) was possible, we determined the rate that reduced by 5% the average values in relation to the values obtained for the rate of 0 g a.i. ha^{-1} by the equation of each variable.

RESULTS AND DISCUSSION

In all five experiments, the data of symptoms of injury were adjusted for an increasing linear regression (Figures 2 to 6). An increase in the symptoms of injury was observed in soybean plants as nicosulfuron rates increased. The highest value (77.5%) was verified in experiment I at 21 DAA for the rate of 250 g a.i. ha^{-1} (Figure 2C).

In experiments I, II, III, and IV, the data of plant height was adjusted for a decreasing linear regression (Figure 7). Plant height of soybean plants decreased as nicosulfuron rates increased.

In experiment V (Table 2), the analysis of data allowed inferring that there was no effect of nicosulfuron application for the variable height, not allowing adjusting a linear regression model according to the observed criteria (biological explanation, significant regression, non-significant coefficient of determination, and analysis of residuals). The same was observed for the variables number of pods per plant (Table 2) and one thousand-grain weight (Table 3) in experiments II, III, IV, and V.

Only for the experiment I, we could adjust the data of the number of pods per plant and one thousand-grain weight for a decreasing linear regression (Figure 8). A decrease in these two variables was observed as nicosulfuron rates increased. However, the yield data was adjusted for a decreasing linear regression in the five experiments (Figure 9). A decrease in yield was observed as nicosulfuron rates increased.

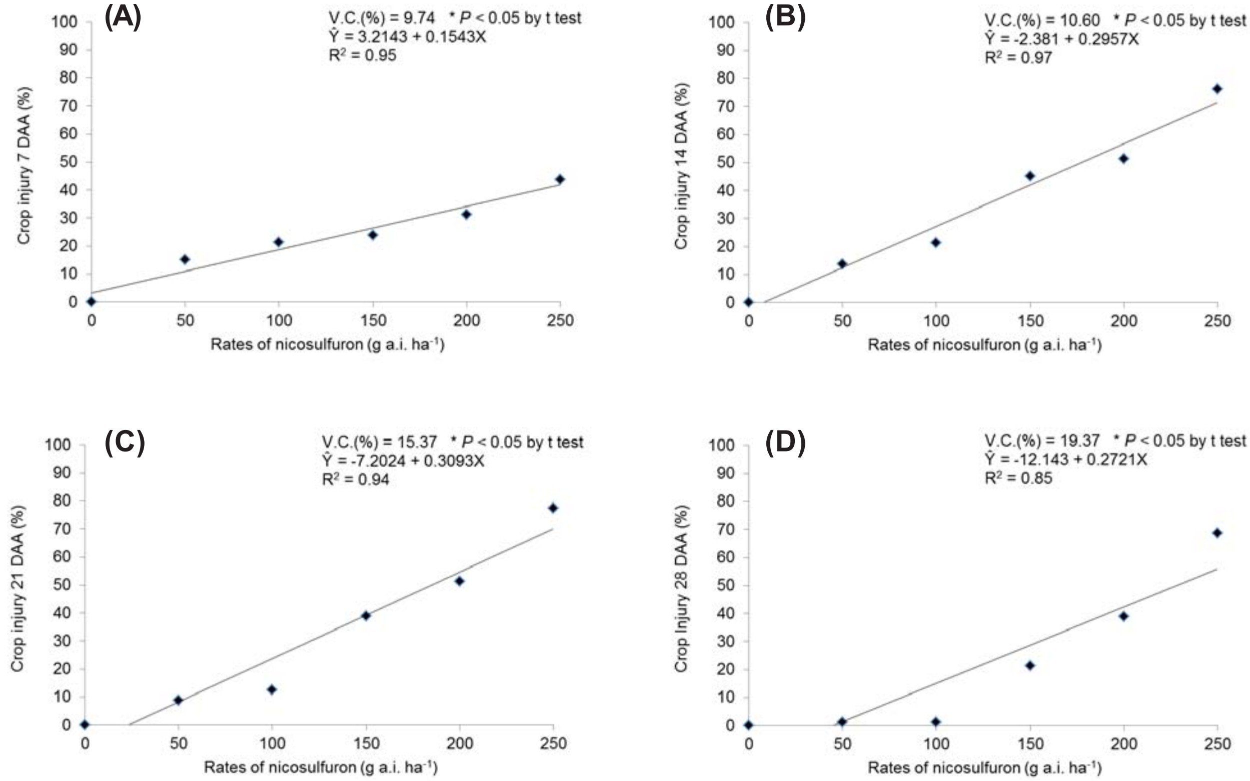


Figure 2 - (A) Injury symptoms (%) at 7 DAA, (B) 14 DAA, (C) 21 DAA, and (D) 28 DAA of RR/STS soybean plants under the application of nicosulfuron rates in post-emergence (V4). Experiment I.

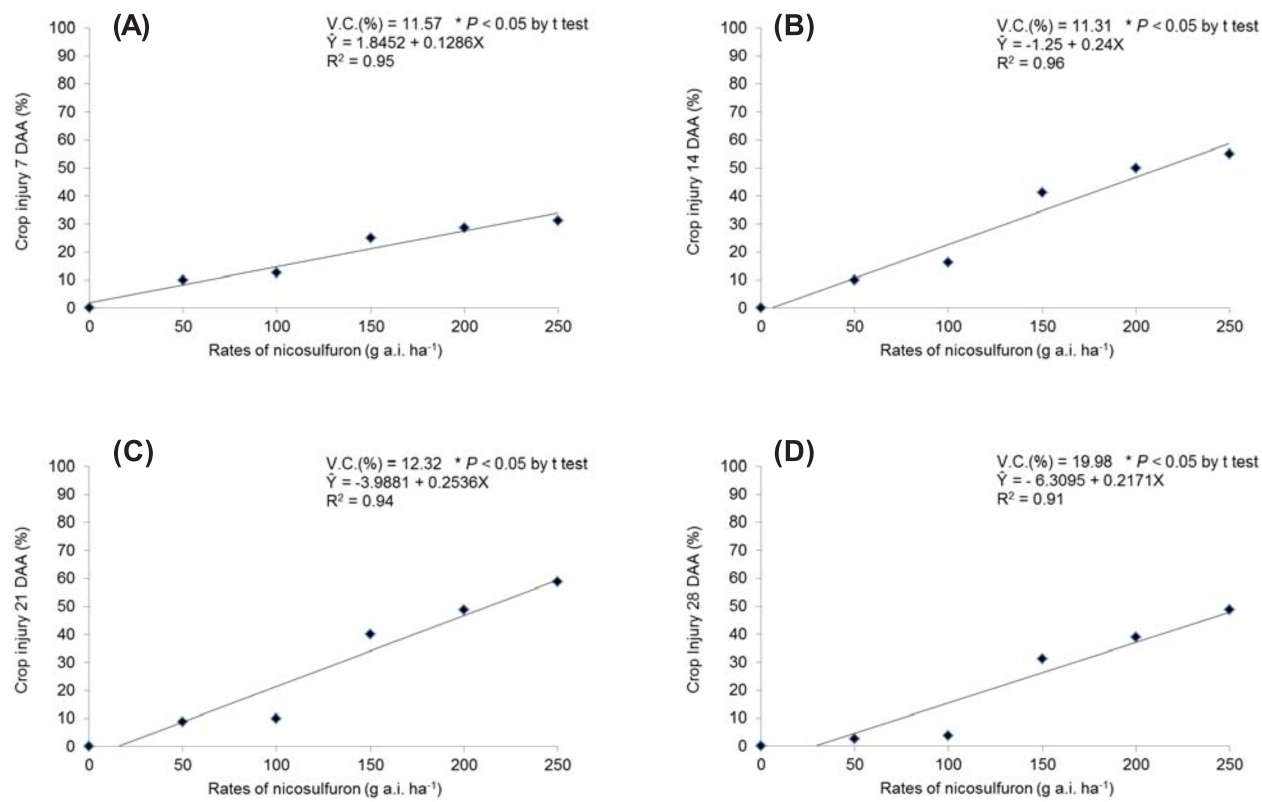


Figure 3 - (A) Injury symptoms (%) at 7 DAA, (B) 14 DAA, (C) 21 DAA, and (D) 28 DAA of RR/STS soybean plants under the application of nicosulfuron rates in post-emergence (V4). Experiment II, 2015/16 season.

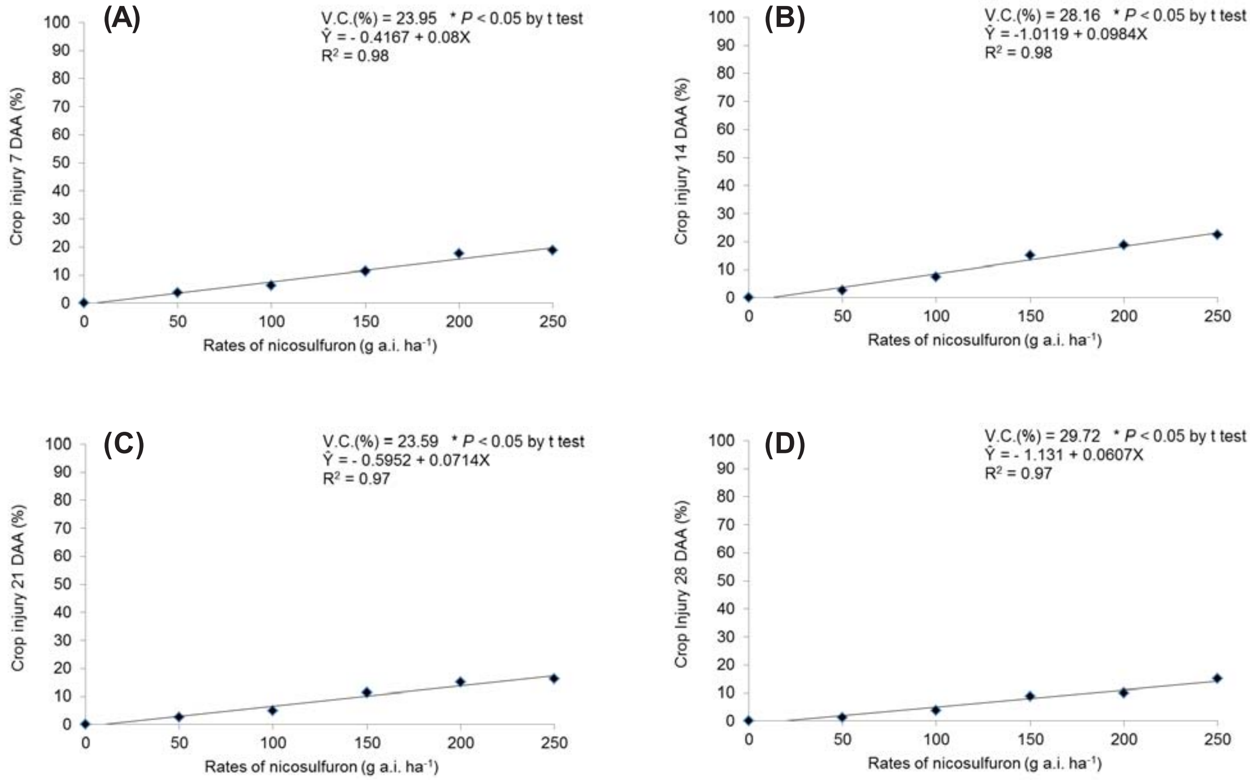


Figure 4 - (A) Injury symptoms (%) at 7 DAA, (B) 14 DAA, (C) 21 DAA, and (D) 28 DAA of RR/STS soybean plants under the application of nicosulfuron rates in post-emergence (V4). Experiment III.

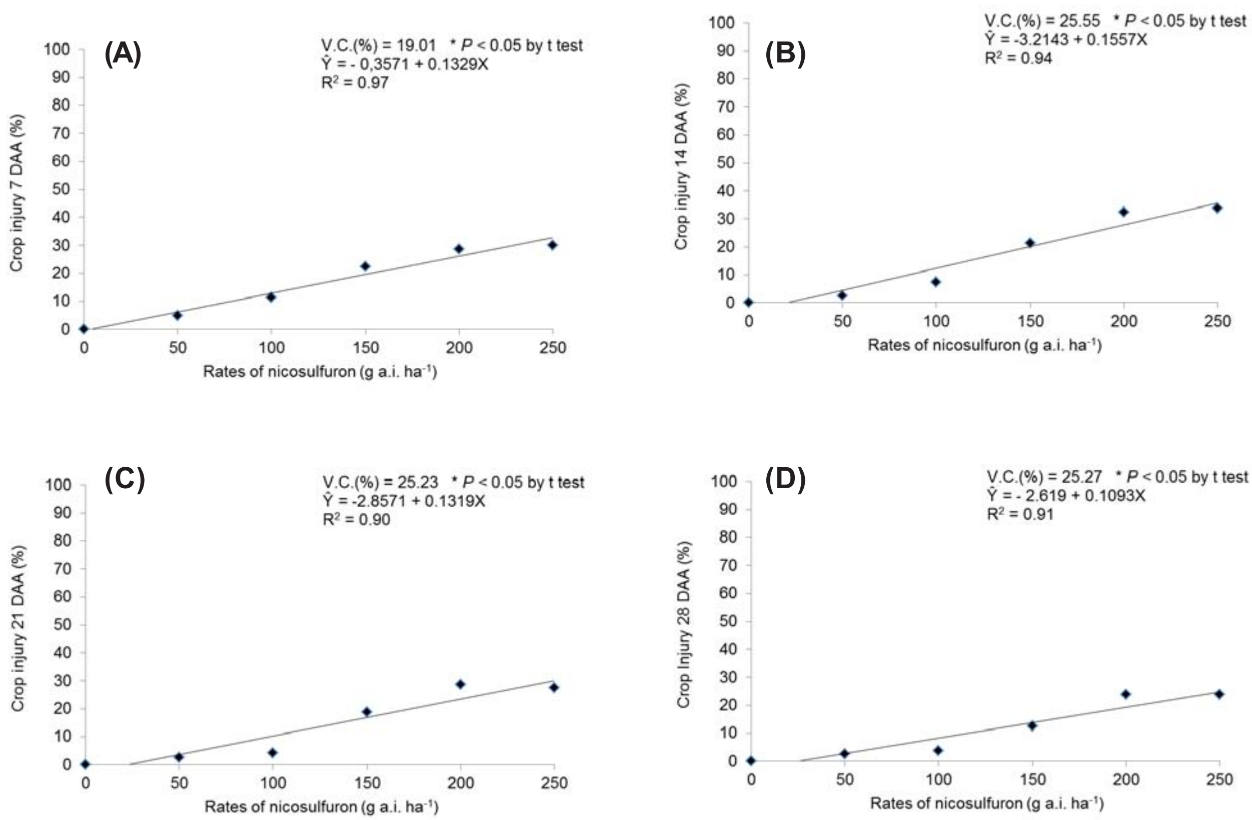


Figure 5 - (A) Injury symptoms (%) at 7 DAA, (B) 14 DAA, (C) 21 DAA, and (D) 28 DAA of RR/STS soybean plants under the application of nicosulfuron rates in post-emergence (V4). Experiment IV.

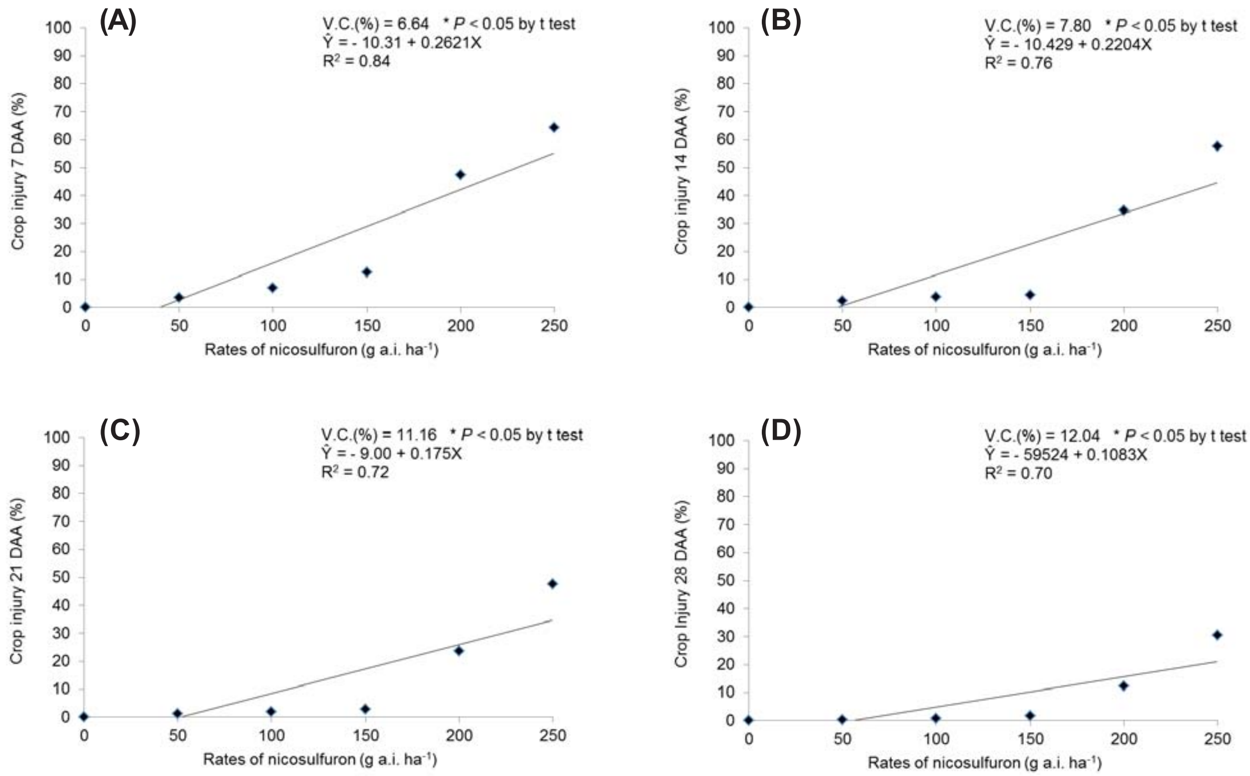
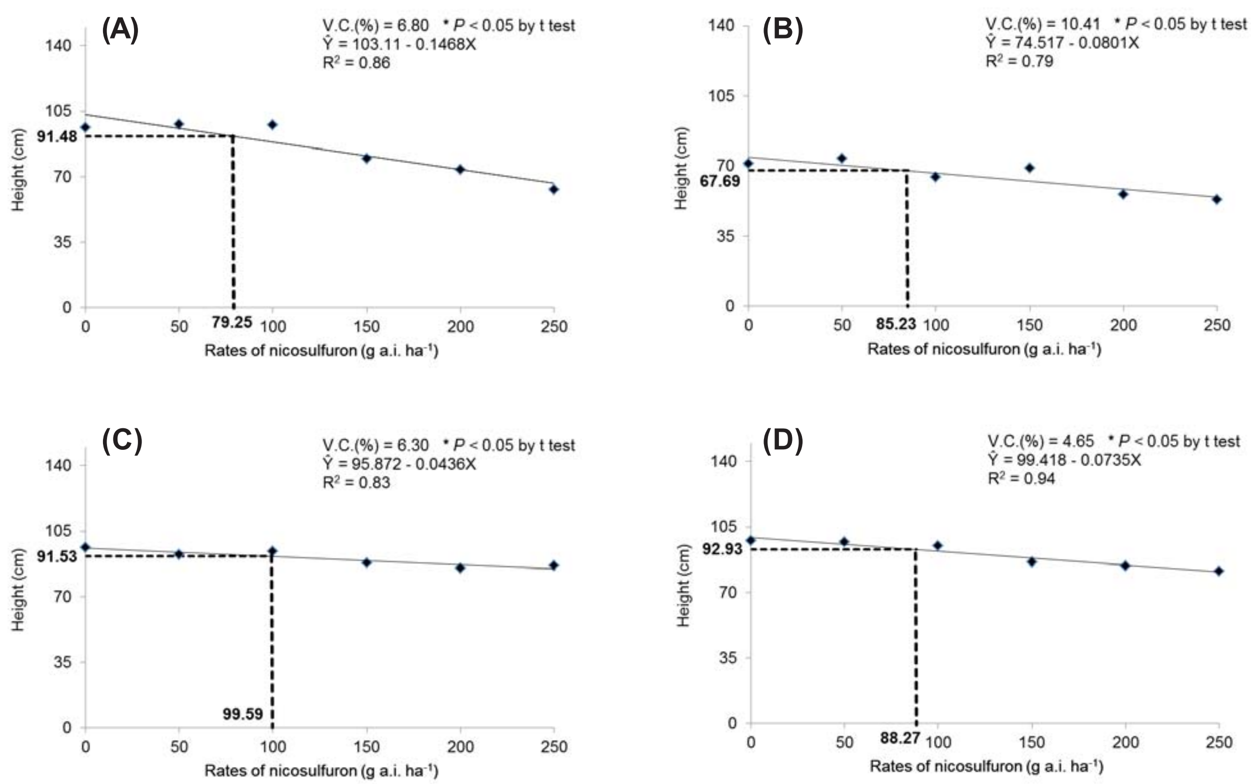


Figure 6 - A) Injury symptoms (%) at 7 DAA, B) 14 DAA, C) 21 DAA, and D) 28 DAA of RR/STS soybean plants under the application of nicosulfuron rates in post-emergence (V4). Experiment V.



Dashed lines represent the estimated rates that provide 5% reductions in relation to the 0 rate.
(A) Exp. I; (B) Exp. II; (C) Exp. III; and (D) Exp. IV.

Figure 7 - Height of RR/STS soybean plants under the application of nicosulfuron rates in post-emergence (V4).

Table 2 - Number of pods per plant and height (cm) of RR/STS soybean plants under the application of nicosulfuron in post-emergence (V4)

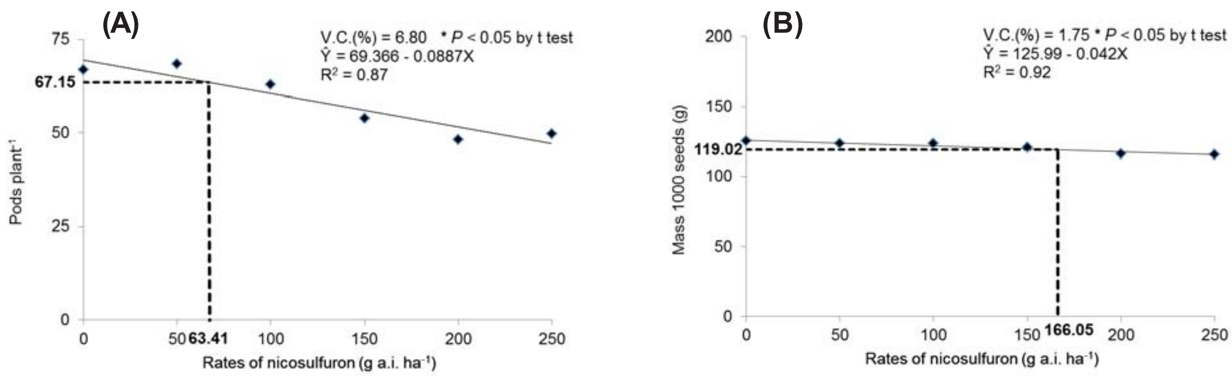
Rate	Pod				Height
	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. V
0	67.25	40.44	57.19	57.19	92.32
50	68.63	40.22	56.41	56.41	81.44
100	66.04	40.60	50.78	50.78	90.82
150	73.25	41.44	51.19	51.19	90.38
200	55.88	36.51	52.78	52.78	78.32
250	61.38	39.72	54.82	54.82	91.53
F	2.43 ns	1.03 ns	0.65 ns	0.83 ns	0.97 ns
Mean	65.40	39.82	53.86	53.86	87.47
CV (%)	11.86	8.51	12.44	12.44	13.90

ns - non-significant (p<0.05).

Table 3 - One thousand-grain weight (g) of RR/STS soybean plants under the application of nicosulfuron in post-emergence (V4)

Rate	One thousand-grain weight			
	Exp. II	Exp. III	Exp. IV	Exp.V
0	145.78	152.86	159.98	169.60
50	149.88	156.88	171.09	163.76
100	145.19	156.89	166.16	170.79
150	146.44	149.34	154.30	167.73
200	142.29	153.32	155.63	158.92
250	142.31	146.81	158.76	164.06
F	3.98 ns	0.76 ns	4.90 ns	0.78 ns
Mean	145.31	152.68	160.98	165.81
CV (%)	1.96	6.06	3.62	6.03

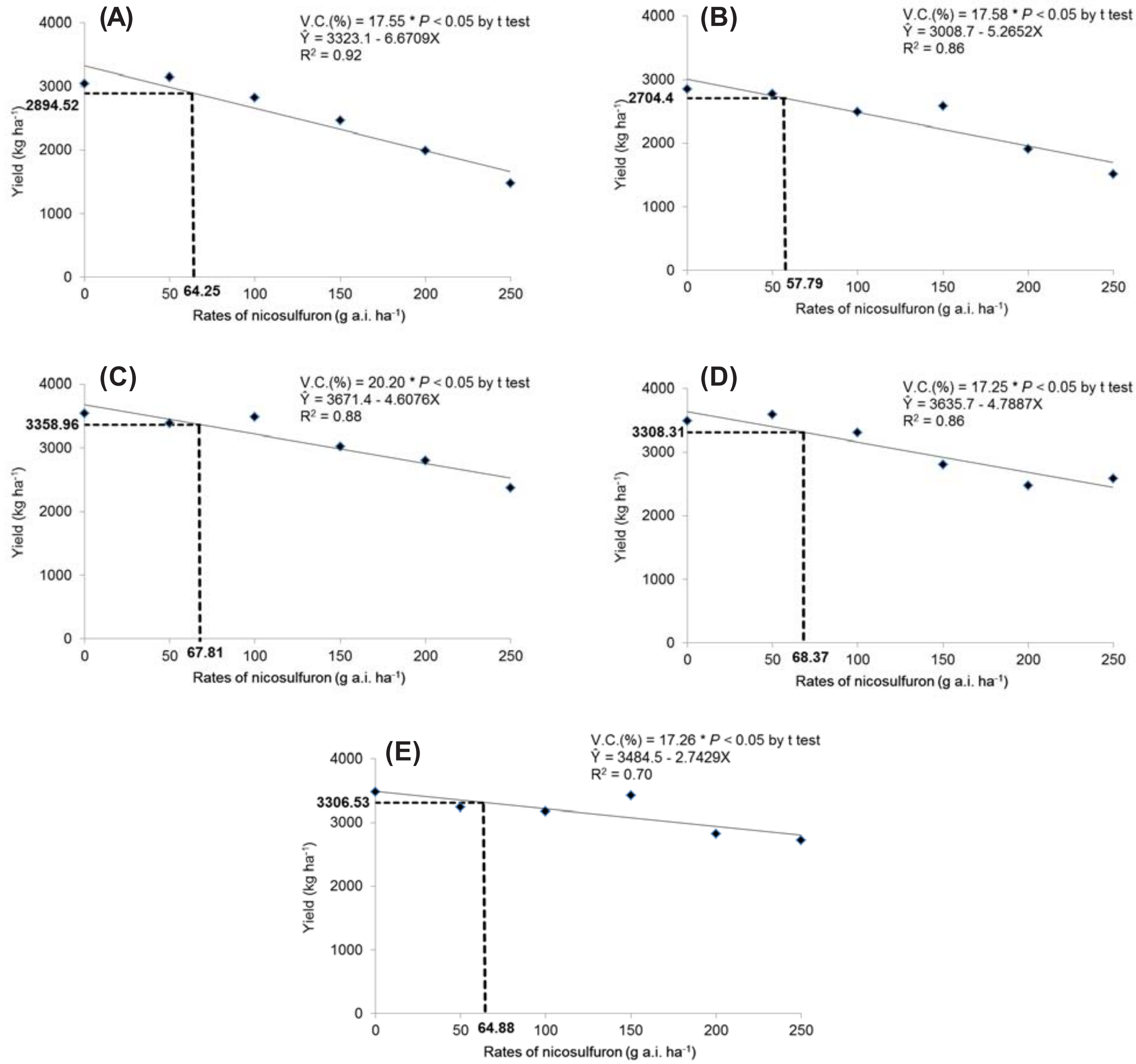
ns - non-significant (p<0.05).



Dashed lines represent the estimated rates that provide 5% reductions in relation to the 0 rate.

Figure 8 - (A) Number of pods per plant and (B) one thousand-grain weight of RR/STS soybean plants under the application of nicosulfuron rates in post-emergence (V4). Experiment I.

A study by Merotto Júnior et al. (2000) concluded that the cultivar CD 201, one of the first with sulfonylurea tolerance in Brazil, was 3.25 times more tolerant to nicosulfuron than the cultivar Ocepar 14 (non-STS). Manley et al. (2001) reported injuries in the cultivars W20 STS, Asgrow 9122 STS, Asgrow 3200 STS, and Asgrow 4045 STS for nicosulfuron application (35 g a.i. ha^{-1}) in the initial post-emergence. The percentages of injury varied from 24 to 45, but in general, no reductions in yield were observed during the four years of cultivation.



Dashed lines represent the estimated rates that provide 5% reductions in relation to the 0 rate.
(A) Exp. I; (B) Exp. II; (C) Exp. III; (D) Exp. IV; E) Exp. V.

Figure 9 - Yield of RR/STS soybean plants under the application of nicosulfuron rates in post-emergence (V4).

Silva et al. (2016) found symptoms of injury of at most 5.5% for nicosulfuron application (60 g a.i. ha^{-1}) in post-emergence (V4) alone or in combination with glyphosate (960 g a.e. ha^{-1}), as well as did not observe reductions in height, SPAD index, number of pods, and yield of the cultivar CD 2630 RR/STS. Albrecht et al. (2017) verified that nicosulfuron application in post-emergence (V4) up to the rate of 200 g a.i. ha^{-1} did not negatively influence the number of pods, height, chlorophyll content, one thousand-grain weight, and yield of the cultivar CD 250 RR/STS. Similarly, Silva et al. (2018) verified the selectivity of nicosulfuron (60 g a.i. ha^{-1}) in STS soybeans.

The estimated rates were reduced by 5% in relation to the rate 0, with values between 57.79 and 166.05 g a.i. ha^{-1} depending on the variable and experiment. Only for the yield data, these doses were between 57.79 and 68.37 g a.i. ha^{-1}. Thus, we can infer that, in general, the RR/STS soybean is tolerant for nicosulfuron application to at least 57.79 g a.i. ha^{-1} at the estimated doses. Therefore, the RR/STS soybean is tolerant for nicosulfuron application up to 50 g a.i. ha^{-1} according to the applied rates.

There is little information on nicosulfuron selectivity in STS cultivars. As mentioned, this herbicide presents a register of use in Brazil only for corn, with a maximum recommended rate of 60 g a.i. ha^{-1} (Rodrigues and Almeida, 2018). Therefore, studies like this are of great importance in the definition of nicosulfuron rates in STS soybean, an herbicide that has the potential to be used in the management of weeds in soybean with this technology.

In Argentina, Olea (2013) reported an increase in weed control by the use of nicosulfuron in STS soybean. Cultivars with the STS technology can be of a great value in the management and prevention of selection of herbicide-resistant biotypes due to the possibility of using other herbicides, as already pointed out by Green (2007, 2012). However, further research on the STS technology is needed since the tolerance to nicosulfuron may vary with the cultivar, as well as in the study with other molecules of the sulfonylurea group.

The soybean cultivars CD 2630 RR/STS, BMX Turbo RR/STS, DM 61I59 RR2/STS, and BMX Garra RR2/STS were tolerant for nicosulfuron application (up to 50 g a.i. ha^{-1}) in post-emergence (V4).

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