Chemical control of *Melanagromyza sojae* (Zehntner, 1901) (Diptera: Agromyzidae) on soybean

Controle químico de *Melanagromyza sojae* (Zehntner, 1901) (Diptera: Agromyzidae) em soja

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ABSTRACT
Soybean is the main grain crop grown in Brazil, with great importance for world food security. The soybean stem fly (SSF) Melanagromyza sojae (Diptera: Agromyzidae) is an invasive pest recently identified and categorized in Brazil, which has the potential to cause significant damage to the soybean crop, especially in the second soybean crop (sown from December 31th). The damage caused by the SSF is due to its feeding process, as it forms galleries inside the stems of soybean plants, harming the development of the crop. As it is a recent pest in Brazil, there is only one insecticide registered for control via seed treatment. The objective of this study was to evaluate the reduction of damage caused by SSF in soybean, by 15 insecticides registered for soybean crop, regularly recommended for the management of other soybean pests. Two experiments were conducted during the 2021 (first season) and 2022 (second season) growing seasons, under different conditions of rainfall and SSF population pressure. The experimental design used was completely randomized with split plots in time with 16 treatments and 20 replications at 8 time levels in 2021 and 5 time levels in the 2022 season. The results showed that in the two seasons evaluated, the best treatments to reduce SSF damage were chlorpyrifos and cyantraniliprole weekly sprayed. The lowest levels of protection against SSF damage were registered for the methomyl treatment. The highest yields were obtained in the treatments with chlorpyrifos and cyantraniliprole, demonstrating correlation with the damage reduction data. The results of this study point to a high potential for damage by the soybean stem fly, which can be mitigated by the

use of chemical insecticides, as long as they are applied in the early stages of the soybean crop.

Keywords: Soybean Stem Fly. Invasive Species. Integrated Pest Management. *Glycine max*.

RESUMO

A soja é o principal grão cultivado no Brasil, com grande importância para a segurança alimentar mundial. A mosca-da-haste da soja (MDH), Melanagromyza sojae (Diptera: Agromyzidae), é uma praga invasora recentemente identificada e categorizada no Brasil, com potencial para causar danos significativos à cultura da soja, especialmente na segunda safra de soja (semeada a partir de 31 de dezembro). Os danos causados pela MDH são devido ao seu processo de alimentação, pois ela forma galerias dentro dos caules das plantas de soja, prejudicando o desenvolvimento da cultura. Como é uma praga recente no Brasil, há apenas um inseticida registrado para controle via tratamento de sementes. O objetivo deste estudo foi avaliar a redução dos danos causados pela MDH na soja, por 15 inseticidas registrados para a cultura da soja, regularmente recomendados para o manejo de outras pragas da soja. Dois experimentos foram conduzidos durante as safras de 2021 (primeira safra) e 2022 (segunda safra), sob diferentes condições de chuva e pressão populacional de MDH. O delineamento experimental utilizado foi inteiramente casualizado com parcelas subdivididas no tempo com 16 tratamentos e 20 repetições em 8 níveis de tempo em 2021 e 5 níveis de tempo na safra de 2022. Os resultados mostraram que nas duas safras avaliadas, os melhores tratamentos para reduzir os danos da MDH foram clorpirifos e ciantraniliprole pulverizados semanalmente. Os menores níveis de proteção contra danos de MDH foram registrados para o tratamento com metomil. Os maiores rendimentos foram obtidos nos tratamentos com clorpirifos e ciantraniliprole, demonstrando correlação com os dados de redução de danos de MDH. Os resultados deste estudo apontam para um alto potencial de dano causado pela mosca-da-haste da soja, que pode ser mitigado pelo uso de inseticidas químicos, desde que aplicados nos estágios iniciais da cultura da soja.

Palavras-chave: Mosca do Tronco da Soja. Espécies Invasivas. Gestão Integrada de Pragas. *Glycine Max*.

RESUMEN

La soja es el principal cultivo de granos cultivado en Brasil, con gran importancia para la seguridad alimentaria mundial. La mosca del tallo de la soja (SSF) Melanagromyza sojae (Diptera: Agromyzidae) es una plaga invasiva recientemente identificada y categorizada en Brasil, que tiene el potencial de causar daños significativos al cultivo de soja, especialmente en el segundo cultivo de soja (sembrado desde el 31 de diciembre). El daño causado por la SSF se debe a su proceso de alimentación, ya que forma galerías dentro de los tallos de las plantas de soja, perjudicando el desarrollo del cultivo. Como es una plaga reciente en Brasil, solo hay un insecticida registrado para su control mediante tratamiento de semillas. El objetivo de este estudio fue evaluar la reducción del daño causado por la SSF en la soja, por 15 insecticidas registrados para cultivo de soja, recomendados regularmente para el manejo de otras plagas de soja. Se realizaron dos experimentos durante las temporadas de crecimiento de 2021 (primera temporada) y 2022 (segunda temporada), bajo diferentes condiciones de lluvia y presión de la población de FSF. El diseño experimental utilizado fue completamente aleatorizado con parcelas divididas en el tiempo con 16 tratamientos y 20 repeticiones a 8 niveles de tiempo en 2021 y 5 niveles de tiempo en la temporada 2022. Los resultados mostraron que en las dos temporadas evaluadas, los mejores tratamientos para reducir el daño de la FSE fueron el clorpirifos y el ciantraniliprol rociado semanalmente. Se registraron los niveles más bajos de protección contra el daño de la FSE para el tratamiento con metomilo. Los mayores rendimientos se obtuvieron en los tratamientos con clorpirifos y ciantraniliprol, demostrando correlación con los datos de reducción de daño. Los resultados de este estudio apuntan a un alto potencial de daño por la mosca del tallo de la soja, que puede mitigarse mediante el uso de insecticidas químicos, siempre y cuando se apliquen en las primeras etapas del cultivo de soja.

Palabras clave: Mosca de Tallo de Soja. Especies Invasoras. Manejo Integrado de Plagas. *Glicina máx*.

1 INTRODUCTION

Soybean (Glycine max (L.) Merril) is a commodity of great importance on the world, due to its protein content it is essential for the world food security, a fact evidenced more during the recent COVID-19 pandemic (Yao *et al*., 2020). In order to meet the growing global demand of the grain, it is estimated that global crop soybean productivity should double by 2050 (Ray *et al*., 2013).

Brazil is the world's big soybean grower, and this crop production plays a key role in the country's economy, accounting for 24% of the national GDP in the recent decades (Castro, 2019). Soybean is the main crop cultivated in the country with an estimated area and production being 43 million hectares and 153 million tons of grain, respectively (USDA, 2023).

According to FAO, pests and disease control failures reduce between 20 to 40 percent of all agricultural production, respectively, while the direct and indirect damage, and the management of invasive insects in crops costs US$ 70 billion/year to the world economy (FAO, 2019). Brazil, as a key player in the international agricultural scenario, presents a subtropical environment that has extensive crops and intensive crops systems, favoring the development and maintenance of existing insect pests and the establishment of invasive pests that reduce the potential yield (Tay *et al*., 2017;).

The soybean stem fly, Melanagromyza sojae Zehntner (Diptera: Agromyzidae), is an invasive pest to Brazil, native to East Asia and detected in Brazil in 2015 (Arnemann *et al*., 2016), and spread throughout South America (Pozebon *et al*., 2020). The damage of this specie is occasioned by the larvae that penetrate the stem through the veins of the leaves and form galleries inside, damaging the vascular tissues, that compromises the transport of water, nutrients and flow of assimilates, causing reductions in the development and consequently productivity of the plant (Chiang et a., 1983; Talekar, 1989).

The SSF pest expresses a great potential for yield reduction, with 30% of losses recorded in Indonesia (DU, 1982) and up to 40% in India (Jadhav, 2011). In Brazilian growing conditions, studies showed that at each percentage point of the injured stem there is a reduction in grain production of 0.9 g plant-1 (Marques, 2023).

In Brazil this pest occurs mainly in the southern region of Brazil in the second crop of soybeans, sowed after corn, on approximately 250 thousand hectares in the states of Rio Grande do Sul and Santa Catarina (Pozebon et. al, 2020), constantly growing due to intensification of production. Although there are several control methods, currently the chemical control through insecticides remains the main control tactic of M. sojae (Curioletti, 2018). However, although there are 728 formulated insecticide products and 68 distinct active ingredients in Brazil, none is registered for the control of M. soybean as a foliar spray, having only one formulated product recently introduced in the market for use in seed treatment (Clothianidin) with recommendation for this pest control (AGROFIT, 2023).

The goal of this study was to evaluate the effect of chemical insecticides in the control of M. sojae searching for the more effective and reliable treatment to reduce the damage caused by this pest.

2 MATERIALS AND METHODS

2.1 EXPERIMENTAL CONDITIONS AND PLANT MATERIAL

Two experiments were conducted during two summer crops (2021 and 2022), at the Federal University of Santa Maria (29º42'48"S, 53º43'59"W, 119 meters' altitude), in Santa Maria, RS, Brazil. The soybean cultivar TMG 7063 IPRO was sown with population density of 300,000 plants ha-1 and spacing between lines of 0.5 meters. The sowing dates were January 25, 2021 (first year) and February 15, 2022 (second year), and in the second year there was a delay in the sowing date due to water stress conditions, owing to the lack of rainfall. Soybean seeds were treated with 30 g ia of carbendazim + 70 g ia thiram per 100 kg of seeds. The weeds were managed before sowing with 1.040 g ia ha-1 glyphosate + 1.005 g ia ha-1 glyphosate, and in the soybean stage V3 with of 1.040 g ia ha-1 glyphosate. Foliar fungicides strobilurins and triazole were used to control diseases in the growth stages V3, V8, R1 and R4. The soybean variety used contained a Bt insecticide protein, Cry1Ac, to control defoliating caterpillars. Sap-sucking pests (stink bugs and whitefly) were monitored on the field surrounds and managed with application of 60 g ha-1 acetamipride + 30 g ia/ha -1 pyriproxifen and 970 g ia ha-1 of acephate, before they reached the experimental plots.

2.2 EXPERIMENTAL DESIGN AND TREATMENTS

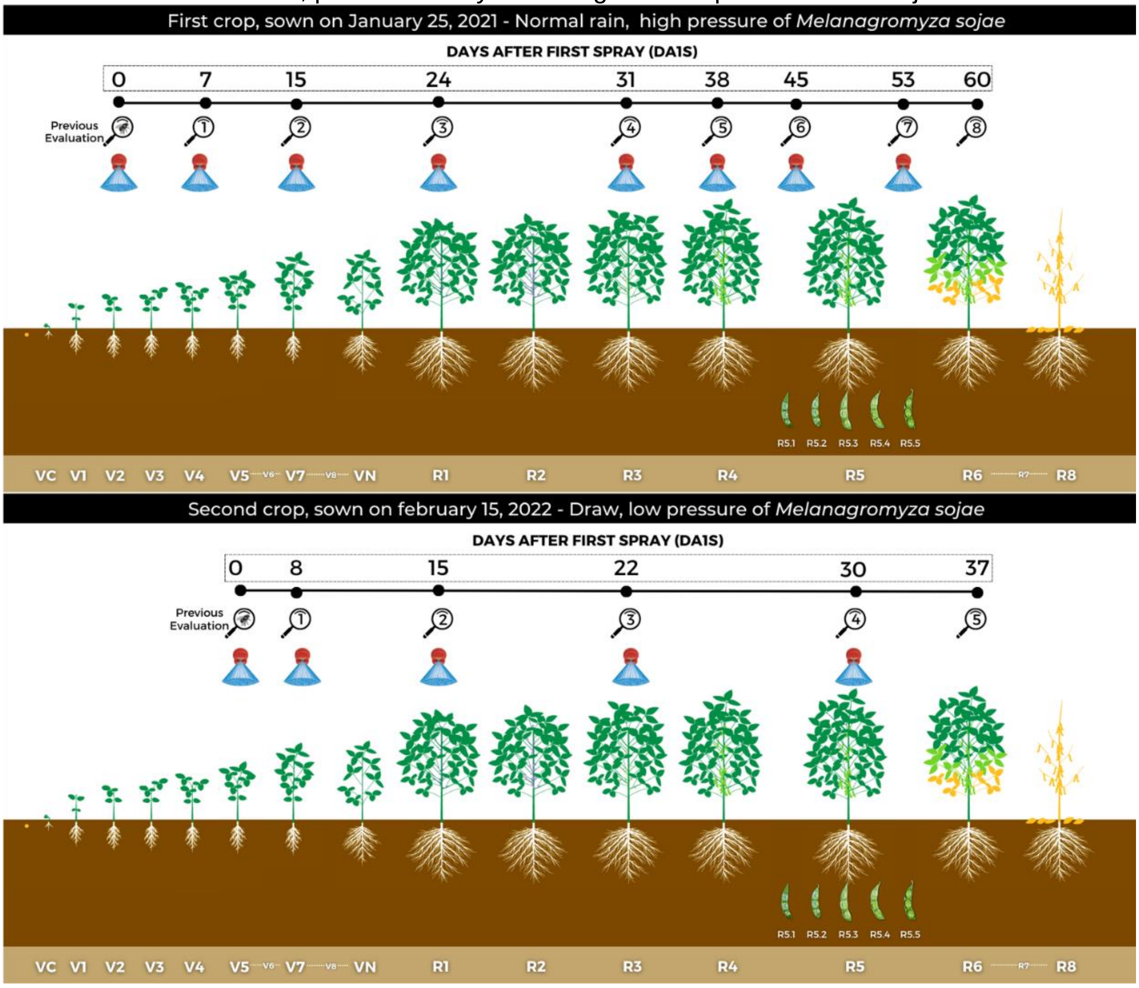
The experimental design was completely randomized with subdivided plot in time, the main plot were defined by 16 treatments (product factor) (Table 1) and the subplots defined by eight time levels in the 2021 crop season (7, 15, 24, 31, 38, 45, 53 and 60 days after the first application) and five time levels in the 2022 crop season (8, 15, 22, 30 and 37 days after the first application) (Figure 1). The treatments were chosen based on chemical groups and active ingredients regularly recommended by the field technicians in the control of other pests in the soybean crop. The first spray was performed after the identification of the pest in the area and field borders through monitoring and previous evaluations. The following sprays ranged from 7 to 9 days after the first spray of the active ingredient of each treatment according to the climatic conditions until the grain filling growth stage (R5.5).

Table 1. Number of treatments, active ingredient, concentration and dose of the insecticides that composes the treatments.

Treatment	Active ingredient	[1]Concentration	[2]Dose ha^{-1}
1	Methomyl	215 g/L	1000 mL
2	Chlorpyrifos	480g/L	1000 mL
3	Lambda-cyhalothrin	50 g/L	150 mL
4	Bifenthrin	100 g/L	150 mL
5	Chlorantraniliprole	200 g/L	50 mL
6	Fipronil	800 g/kg	40 g
7	Abamectin	72 g/L	400 mL
8	Acephate	750 g/kg	1000 g
9	Thiamethoxam	500 g/kg	70 g
10	Imidacloprid	480 g/L	250 mL
11	Cyantraniliprole	100 g//L	1000 mL
12	Clorfenapir	240 g/L	1000 mL
13	Lambda-cyhalotrin + Chlorantraniliprole	50+100 g/L	150 mL
14	Imidacloprid + Bifenthrin	250 + 50 g/L	400 mL
15	Thiamethoxan + Lambda-cyhalotrin	141+106 g/L	250 mL
16	Control	-	-

Note. [1]Concentration of the active ingredient in the commercial product. [2] Dose of the commercial product use.
Source: Authors

Figure 1. Moments of application of insecticides in the first crop (2021) under normal rain conditions and sowing period, with low pressure of M. sojae and second crop (2022) in dry conditions, period of delay in sowing and low pressure of M sojae.



Source: Author

Twenty replications were used to evaluate stem injury and plant height during each assessment, with each individual plant representing one repetition. Each plot was 6 by 20 meters and had approximately 3,600 soybean plants. Sprays were carried out using a CO2-pressurized backpack sprayer, with a spray volume of 150 L.ha-1 and six spray nozzles (model XR 110 020) spaced 0.5 m apart from each other. The representation of the moment of each spray and evaluations on the soybean growth stages are illustrated in Figure 1.

2.3 EVALUATIONS

Evaluations were performed weekly after the first spray and before the next spray by random sampling 20 soybean plants in each plot, starting at V2 in the 2021 crop season and V5 in the 2022 crop season. The evaluations were extended up to one week after the R5.5 growth stage of the soybean crop. Plant height was measured from the soil line to the last node of the main stem, and the presence of SSF tunnels was assessed and tunnels measured by opening the main stem longitudinally, from bottom to top. The percentage of injured stem (% IS) was determined as a ratio between plant height and tunnel length in the main stem.

The yield of each treatment was estimated from the harvest of 4 replications with 4 m² randomly arranged in the central rows of the plots. The harvest was performed manually, after which the mechanical trail was performed in a stationary railway, with subsequent weighing, correction of moisture to 13% and conversion of the values to Kg ha-1.

2.4 STATISTICAL ANALYSIS

Plant height, stem length injured, percentage of stem damage and yield data were submitted to analysis of variance (ANOVA) and treatment means were compared using the Scott-Knott test at 5% probability ($P \leq 0.05$). Analyzes were performed using Microsoft Excel and SISVAR (FERREIRA, 2014).

3 RESULTS AND DISCUSSION

3.1 FIRST CROPPING SEASON (2021): AVERAGE RAINFALL AND HIGHER SSF PRESSURE

The presentation and discussion of the results will be done by grouping the treatments according to their performance in the SSF control: best control treatments, intermediate control and no SSF control effect. On this season, with normal rainfall and higher SSF pressure, the best SSF control were observed in the treatments T2 (Chlorpyrifos) and T11 (Cyantraniliprole), with an average %IS of 22.40 and 27.11, respectively, significantly differing from each other and from the other treatments (Table 2).

Table 2. Percentage of stem length injured (% IS) by Melanagromyza sojae evaluated (7, 15, 24, 31, 38, 45, 53, 60 DA1S and general mean) in the 2021 crop. Santa Maria, RS, Brazil.

Treatment	Days after first spray (%)[1]								Mean (%)
	7	15	24	31	38	45	53	60	
1	39.83 c	38.17 d	42.80 c	54.45 c	47.50 b	49.04 b	60.53 b	46.16 a	47.31 e
2	0.00 a	4.46 a	26.16 a	26.27 a	22.37 a	31.21 a	35.06 a	33.64 a	22.40 a
3	13.06 a	27.49 b	34.95 b	43.60 c	42.87 b	45.19 b	41.29 a	58.93 b	38.42 c
4	26.14 b	34.44 c	42.04 c	50.83 c	42.86 b	42.76 b	45.52 b	50.67 b	41.91 d
5	15.21 a	34.53 c	46.73 c	46.86 c	47.81 b	50.38 b	50.38 b	55.69 b	43.45 d
6	11.04 a	37.87 c	50.43 c	53.53 c	41.34 b	42.15 b	50.91 b	52.05 b	42.41 d
7	3.83 a	17.91 b	36.71 b	41.94 b	35.45 a	45.46 b	51.12 b	57.59 b	36.25 c
8	21.40 b	36.55 c	43.39 c	39.27 b	40.56 b	42.22 b	47.28 b	54.32 b	40.63 c
9	6.18 a	26.82 b	37.54 b	45.10 c	46.24 b	48.16 b	45.87 b	47.32 a	37.90 c
10	13.35 a	22.11 b	45.97 c	50.01 c	42.92 b	37.01 a	38.47 a	43.54 b	36.67 c
11	1.67 a	18.73 b	25.65 a	30.50 a	29.83 a	33.24 a	35.68 a	41.62 a	27.11 b
12	19.42 b	51.16 d	45.77 c	42.19 b	48.59 b	45.22 b	50.90 b	54.03 b	44.65 d
13	12.34 a	41.36 c	43.96 c	47.63 c	45.91 b	42.00 b	46.68 b	49.33 b	41.15 c
14	7.41 a	19.66 b	50.40 c	41.31 b	40.22 b	44.37 b	39.80 a	54.24 b	37.18 c
15	9.52 a	29.83 b	46.16 c	39.32 b	45.17 b	41.83 b	44.34 b	42.24 a	37.30 c
16	32.43 c	47.16 d	45.63 c	54.82 c	56.14 b	47.15 b	52.34 b	66.39 b	50.26 e
CV (%)[2]	47.91								

Note. [1] = Percentage of stem length injured followed by the same letter and number in the column do not differ among themselves by the Scott-Knott test (P≤0.05). [2]CV (%) = Coefficient of variation.
Source: Authors.

Treatments T3 (Lambda-cyhalothrin), T4 (Bifenthrin), T5 (Chlorantraniliprole), T6 (Fipronil), T7 (Abamectin), T8 (Acephate), T9 (Thiamethoxam), T10 (Imidacloprid), T12 (Chlorfenapyr), T13 (Lambda-cyhalotrin + Chlorantraniliprole), T14 (Imidacloprid + Bifenthrin), T15 (Thiamethoxan + Lambda-cyhalotrin) showed an intermediate control effect of SSF, with average % IS ranging from 36.67 to 44.65, differing significantly from the other treatments. Yet, the treatments T3, T7, T8, T9, T10, T13, T14, T15, ranging from 36.67 to 41.15 of % IS and treatments T4, T5, T6, T12, ranging from 41.91 to 44.65 of % IS, showed significant difference between them. It is important to highlight among the treatments that demonstrated an intermediate control effect, the neonicotinoid insecticides T9 (Thiamethoxam) and T10 (imidacloprid), which had the best performance among the intermediate treatments, which can be explained by the high translocation capacity of this group of insecticides (Gazzoni, 2008).

The highest injury of SSF were registered in treatments T1 (Methomyl) and T16 (control), with 47.31 and 50.26 of % IS, respectively, differing significantly from the other treatments. Except for treatment T1, the other treatments differed significantly from treatment T16 (control) without insecticide spray, showing the control effect of SSF on the soybean plants.

Observing the weekly evaluations separately (Table 2) we can see that since the beginning of the evaluations (7 DA1S) they showed significant differences among themselves and in relation to T16 (control), highlighting the importance of sprays (protection) in the initial crop phenological stages of the soybean culture, since although the insect can infest soybean plants throughout the entire crop cycle, attacks in the early stages of development result in the man losses in grain yield (Talekar, 1989). Throughout the evaluations, a gradual increase in the % IS in the treatments can be observed, and it is important to emphasize that the greatest damage was recorded between 7 and 15 days after the first spray, corroborating the information that the first to four weeks after crop emergence are the most critical period for attack by M. Soyae. (Cabi, 2022; Talekar; Chen, 1985).

The average plant height (Table 3) of treatments T1 (Methomyl) and T16 (control) showed the lowest values, and significantly differed from the other treatments, demonstrating a relationship between % of IS and the reduction of plant height (Bhattacharjee, 1980). However, treatments T5 (Chlorantraniliprole), T7 (Abamectin), T8 (Acephate), T9 (Thiametoxam), T15 (Thiamethoxan + Lambda-cyhalotrin), showed average plant length between 40.3 cm and 41.21 cm, differing significantly from the other treatments. The average size of the soybean plant ranged from 35 to 41 cm in average length of the main stem.

Table 3. Mean of plant height (cm) evaluated (7, 15, 24, 31, 38, 45, 53, 60 DA1S and general mean) in the 2021 crop. Santa Maria, RS, Brazil.

Treatment	Days after first spray (DA1S)[1]								Mean (cm)
	7	15	24	31	38	45	53	60	
1	17.90 a	26.25 a	28.80 c	38.83 b	39.05 d	44.20 c	40.60 d	44.40 b	35.00 d
2	22.00 a	25.80 a	31.40 b	40.43 a	48.48 b	49.03 b	45.30 c	46.85 b	38.66 b
3	23.90 a	27.40 a	31.45 b	42.45 a	46.48 b	50.78 b	45.08 c	49.40 a	39.62 b
4	23.43 a	27.65 a	32.25 b	39.88 a	49.15 a	50.23 b	47.60 c	48.60 b	39.85 b
5	24.10 a	27.55 a	31.20 b	43.03 a	46.98 b	50.38 b	50.25 b	50.70 a	40.52 a
6	23.00 a	26.08 a	29.48 c	38.48 b	49.85 a	53.18 a	49.95 b	49.65 a	39.96 b
7	24.78 a	26.28 a	30.73 b	41.28 a	53.18 a	50.13 b	48.35 b	53.00 a	40.96 a
8	23.30 a	27.75 a	32.20 b	40.93 a	49.63 a	54.68 a	53.43 a	47.80 b	41.21 a
9	22.25 a	27.65 a	36.18 a	39.58 a	51.73 a	43.70 c	49.68 b	51.65 a	40.30 a
10	22.73 a	26.85 a	30.58 b	40.35 a	49.68 a	49.98 b	46.88 c	47.25 b	39.28 b
11	21.95 a	23.85 b	29.25 c	42.55 a	49.53 a	47.08 c	49.65 b	47.55 b	38.93 b
12	22.10 a	22.05 b	27.85 c	40.53 a	48.23 b	46.65 c	45.98 c	46.30 b	37.46 c
13	22.10 a	23.63 b	27.43 c	37.83 b	45.53 b	50.08 b	51.08 b	43.55 b	37.65 c
14	21.75 a	22.63 b	27.43 c	35.95 b	46.63 b	49.65 b	50.30 b	50.15 a	38.06 c
15	22.93 a	24.85 b	28.83 c	43.20 a	43.28 c	54.20 a	54.60 a	54.00 a	40.73 a
16	22.53 a	22.80 b	28.43 c	35.45 b	35.60 d	44.65 c	46.10 c	47.35 b	35.36 d
CV (%)[2]	16.38								

Note. [1] = Plant high followed by the same letter and number in the column do not differ among themselves by the Scott-Knott test (P≤0.05). 2CV (%) = Coefficient of variation.
Source: Authors

The highest values of average stem length damage (Table 4) were observed in treatments T1 (Methomyl), T4 (Bifenthrin), T5 (Chlorantraniliprole), T6 (Fipronil), T8 (Acephate) and T16 (control), which varied from 17.48 to 18.71 cm of stem damaged. On average, the treatments that had the lowest values for damaged stem length were T2 (Chlorpyrifos) and T11 (Cyantraniliprole), with 9.40 cm and 11.72 cm, respectively, differing from each other and from the other evaluated treatments.

Table 4. Mean of stem length injured (cm) evaluated (7, 15, 24, 31, 38, 45, 53, 60 DA1S and general mean) in the 2021 crop. Santa Maria, RS, Brazil.

Treatment	Days after first spray (DA1S)[1]								Mean (cm)
	7	15	24	31	38	45	53	60	
1	6.98 b	9.78 b	14.58 c	20.73 b	17.98 c	21.35 b	24.40 b	24.10 b	17.48 d
2	0.00 a	1.15 a	7.68 a	10.48 a	10.18 a	15.15 a	15.10 a	15.45 a	9.40 a
3	3.25 a	7.30 b	10.80 b	18.55 b	19.25 c	22.40 b	18.80 a	28.65 c	16.13 c
4	5.93 b	9.68 b	14.55 c	20.10 b	20.95 c	20.70 b	21.50 b	28.95 c	17.79 d
5	3.75 a	9.40 b	14.28 c	20.13 b	22.25 c	23.75 b	25.15 b	30.95 d	18.71 d
6	2.50 a	9.73 b	14.28 c	20.48 b	20.50 c	21.85 b	25.45 b	28.25 c	17.88 d
7	1.00 a	4.63 a	10.68 b	17.35 b	18.68 c	22.85 b	24.50 b	32.70 d	16.55 c
8	5.15 b	10.23 b	13.38 c	15.90 a	19.88 c	22.85 b	25.20 b	34.80 d	18.42 d
9	1.50 a	7.20 b	15.18 c	17.70 b	23.95 c	20.60 b	21.80 b	24.15 b	16.51 c
10	3.00 a	5.78 a	14.35 c	19.55 b	21.10 c	18.45 a	18.25 a	26.95 c	15.93 c
11	0.40 a	4.35 a	6.68 a	13.30 a	14.65 b	15.40 a	18.00 a	21.00 b	11.72 b
12	4.35 b	11.00 b	12.60 c	17.05 b	23.05 c	20.60 b	23.15 b	24.70 b	17.06 c
13	2.75 a	9.45 b	12.85 c	17.83 b	20.70 c	20.85 b	23.93 b	24.75 b	16.64 c
14	1.60 a	4.23 a	13.38 c	14.38 a	18.80 c	21.65 b	19.80 a	27.05 c	15.11 c
15	2.10 a	7.15 b	13.93 c	16.63 b	19.30 c	22.10 b	23.95 b	22.30 b	15.93 c
16	7.30 b	10.75 b	12.75 c	19.28 b	19.30 c	20.20 b	23.10 b	31.30 d	18.00 d
CV (%)[2]	44.21								

Note. [1] = Stem length injured followed by the same letter and number in the column do not differ among themselves by the Scott-Knott test ($P \leq 0.05$). [2]CV (%) = Coefficient of variation.

Source: Authors.

3.2 SECOND CROPPING SEASON (2022): DRAW AND LOWER SSF PRESSURE

In the second growing season of 2022, different environment conditions during the soybean crop were observed, with a delay in the sowing due to drought, and also a lower SSF pressure in the adjacent areas and, consequently, a delay in the infestation of SSF. The best SSF controls in the 2022 season were observed (Table 5) in treatments T2 (Chlorpyrifos) and T11 (Cyantraniliprole), with average of % IS of 0.92 and 1.56, respectively, significantly differing from the other treatments.

Table 5. Percentage of stem length injured (% IS) by *Melanagromyza sojae* evaluated (8, 15, 22, 30, 37 DA1S and general mean) in the 2022 crop. Santa Maria, RS, Brazil.

Treatment	Days after first spray (DA1S)[1]					Mean (%)
	8	15	22	30	37	
1	1.13 a	18.32 c	22.39 b	44.47 c	48.14 e	26.89 c
2	0.00 a	1.11 a	0.59 a	1.94 a	0.94 a	0.92 a
3	6.91 a	12.32 b	19.40 b	27.74 b	21.57 b	17.59 b
4	0.81 a	12.95 b	28.68 c	37.85 c	32.83 c	22.62 c
5	4.89 a	17.07 c	34.14 c	39.82 c	23.43 b	23.87 c
6	6.36 a	8.67 b	21.60 b	34.04 b	30.16 c	20.17 b
7	3.07 a	11.47 b	19.30 b	33.51 b	36.39 c	20.75 b
8	3.74 a	18.94 c	18.17 b	34.06 b	32.79 c	21.54 b
9	7.23 a	11.82 b	18.36 b	29.51 b	26.43 b	18.67 b
10	4.25 a	12.24 b	25.16 b	24.23 b	24.44 b	18.07 b
11	0.00 a	0.54 a	0.00 a	2.93 a	4.34 a	1.56 a
12	4.82 a	15.14 b	38.44 c	28.68 b	34.53 c	24.32 c
13	4.03 a	19.75 c	18.86 b	27.00 b	38.76 d	21.68 b
14	7.62 a	11.54 b	32.04 c	30.94 b	23.90 b	21.21 b
15	5.62 a	19.01 c	35.85 c	34.31 b	34.05 c	25.77 c
16	8.27 a	35.67 d	47.33 d	50.71 c	51.72 e	38.74 d
CV (%)[2]	**74.67**					

Note. [1] = Percentage of stem length injured followed by the same letter and number in the column do not differ among themselves by the Scott-Knott test (P≤0.05). 2CV (%) = Coefficient of variation.

Source: Authors

Treatment T16 (control) showed 38.74 of % IS, significantly differing from the other treatments. T1 (Methomyl), T4 (Bifenthrin), T5 (Chlorantraniliprole), T12 (Clorfenapyr), T15 (Thiamethoxan + Lambda-cyhalotrin) were the treatments that showed no effect on the SSF control, with an average percentage of attacked stems ranging from 22.62% to 26.89%. Observing together the variables plant height (Table 6) and length of damaged stem (Table 7), it is clear that as in the first season, the most attacked plants by SSF had a significant reduction in height in relation to the other treatments.

Table 6. Mean of plant height (cm) evaluated (8, 15, 22, 30, 37 DA1S and general mean) in the 2022 crop. Santa Maria, RS, Brazil.

Treatment	Days after first spray (DA1S)[1]					Mean (cm)
	8	15	22	30	37	
1	21.55 b	28.03 c	34.30 c	41.65 c	42.05 c	33.52 e
2	21.30 b	31.30 a	34.80 c	43.80 b	46.65 b	35.57 c
3	23.60 a	30.50 b	33.85 c	41.45 c	42.70 c	34.42 d
4	23.90 a	30.85 b	33.50 c	41.45 c	45.15 b	34.97 c
5	23.80 a	31.10 a	35.60 b	42.45 b	45.75 b	35.74 c
6	21.65 b	30.40 b	34.00 c	40.85 c	45.65 b	34.51 d
7	24.60 a	32.50 a	35.70 b	42.25 c	48.20 a	36.65 b
8	24.20 a	32.10 a	38.65 a	42.80 b	49.85 a	37.52 a
9	21.50 b	29.20 b	32.50 c	42.55 b	43.85 c	33.92 d
10	22.30 a	29.55 b	33.00 c	41.25 c	42.55 c	33.73 e
11	22.70 a	28.70 c	35.65 b	45.20 a	46.55 b	35.76 c
12	23.10 a	32.25 a	36.30 b	41.80 c	44.90 b	35.67 c
13	23.10 a	28.30 c	33.65 c	43.25 b	44.00 c	34.46 d
14	22.60 a	27.80 c	33.75 c	41.70 c	44.10 c	33.99 d
15	19.40 c	25.35 d	30.90 d	40.70 c	48.10 a	32.89 e
16	20.20 c	24.35 d	28.15 e	39.85 c	38.10 d	30.13 f
CV (%)[2]	16.38					

Note. [1] = Plant high followed by the same letter and number in the column do not differ among themselves by the Scott-Knott test (P≤0.05). 2CV (%) = Coefficient of variation.
Source: Authors.

Table 7. Mean of stem length injured (cm) evaluated (8, 15, 22, 30, 37 DA1S and general mean) in the 2022 crop. Santa Maria, RS, Brazil.

Treatment	Days after first spray (DA1S)					Mean (cm)
	8	15	22	30	37	
1	0.23 a	5.10 b	7.45 b	18.65 d	20.40 d	10.37 d
2	0.00 a	0.35 a	0.20 a	0.80 a	0.45 a	0.36 a
3	1.55 a	3.75 a	6.50 b	11.40 b	8.90 b	6.42 b
4	0.18 a	4.08 a	9.30 c	15.55 c	14.75 c	8.77 d
5	1.18 a	5.45 b	12.05 c	16.90 c	10.65 b	9.25 d
6	1.30 a	2.65 a	7.40 b	13.90 b	13.65 c	7.78 c
7	0.75 a	3.70 a	6.90 b	13.95 b	17.25 c	8.51 c
8	0.85 a	6.03 b	7.25 b	14.35 b	16.05 c	8.91 d
9	1.50 a	3.35 a	5.95 b	12.40 b	11.15 b	6.87 b
10	0.85 a	3.65 a	8.00 b	9.95 b	10.20 b	6.53 b
11	0.00 a	0.15 a	0.00 a	1.25 a	2.00 a	0.68 a
12	1.15 a	4.85 b	14.00 c	11.90 b	15.50 c	9.48 d
13	0.95 a	5.95 b	6.30 b	11.70 b	17.00 c	8.38 c
14	1.80 a	3.15 a	10.73 c	12.70 b	10.55 b	7.79 c
15	0.95 a	4.45 b	11.10 c	13.85 b	16.30 c	9.33 d
16	1.50 a	8.80 b	13.10 c	20.20 d	19.25 d	12.57 e
CV (%)	72.05					

Note. [1] = Stem length injured followed by the same letter and number in the column do not differ among themselves by the Scott-Knott test (P≤0.05). 2CV (%) = Coefficient of variation.
Source: Authors.

3.3 TWO-SEASONS ANALYSIS AND YIELD

In the two-season analysis the best control of SSF was achieved by T2 (Chlorpyrifos) and T11 (Cyantraniliprole) with the lowest % of IS and the highest soybean yield. With the delay in sowing of the 2022 season due to the intense period of drought and the need for resowing, there was a shortening of the crop cycle, along with a reduction in the yield potential of the crop and a smaller accumulation of dry matter, providing the plants with a lower capacity to overcome the injuries resulting from the attack of SSF (Talekar, 1989).

According to the results obtained from the yields (Table 8), the treatments that presented the lowest productive performance were treatments T1 (Methomyl) with 2214.56 Kg ha-1, T13 (Lambda-cyhalotrin + Chlorantraniliprole) with 2548.37 Kg ha-1 and the T16 (control) that showed the worst performance with productivity of 1729.14 Kg ha-1, these treatments differed significantly from the other treatments by the Scott Knott test ($P \leq 0.05$).

Table 8. Average soybean productivity in treatments for the 2021 and 2022 crop season. Santa Maria, RS, Brazil.

Treatment	Active ingredient	Productivity (Kg ha-¹)		
		2021	2022	Mean
1	Methomyl	2214.56 b	1071.73 d	1643.14
2	Chlorpyrifos	3995.58 a	2253.08 a	3124.33
3	Lambda-cyhalothrin	3404.90 a	1685.32 b	2545.11
4	Bifenthrin	3541.84 a	1379.48 c	2460.66
5	Chlorantraniliprole	2995.53 a	1261.32 c	2128.43
6	Fipronil	3444.36 a	1356.02 c	2400.19
7	Abamectin	3388.42 a	1670.75 b	2529.59
8	Acephate	3210.47 a	1417.28 c	2313.88
9	Thiamethoxam	3228.52 a	1676.05 b	2452.28
10	Imidacloprid	3292.69 a	1487.87 c	2390.28
11	Cyantraniliprole	4083.95 a	2187.40 a	3135.67
12	Clorfenapir	3246.65 a	1123.99 d	2185.32
13	Lambda-cyhalotrin + Chlorantraniliprole	2548.37 b	1427.59 c	1987.98
14	Imidacloprid + Bifenthrin	3105.75 a	1336.16 c	2220.96
15	Thiamethoxan + Lambda-cyhalotrin	3454.69 a	1169.76 d	2312.22
16	Control	1729.14 b	959.31 d	1344.22
CV (%)[1]		18.13	13.10	

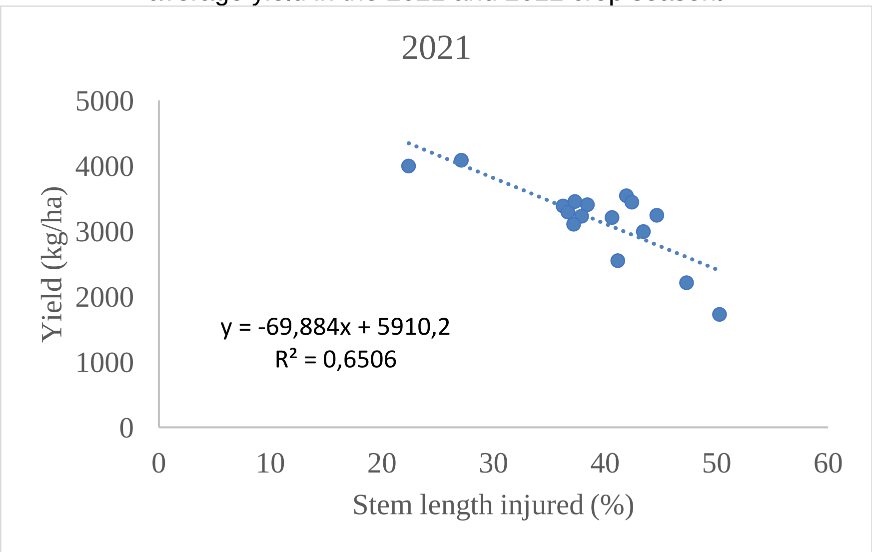
1CV (%) = Coefficient of variation.
Source: Authors.

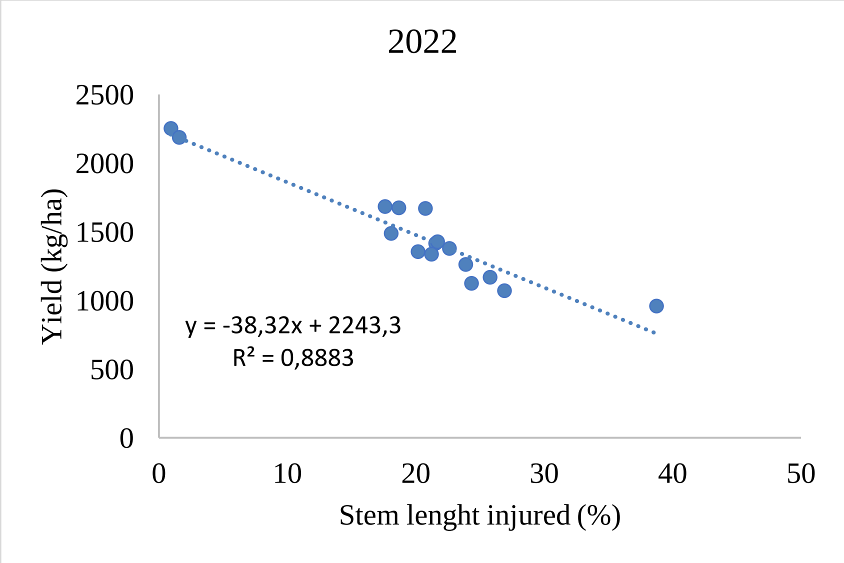
The other treatments did not differ significantly, however it is worth mentioning that the treatments with the highest productivity were T2 (Chlorpyrifos) and T11 (Cyantraniliprole) which presented average productivity of 3995.58 Kg ha^{-1} and 4083.95 Kg ha^{-1}, respectively.

In the second season, treatments T2 (Chlorpyrifos) and T11 (Cyantraniliprole) showed the highest yield, with 2253 Kg ha^{-1} and 2187 Kg ha^{-1}, respectively, significantly differing from the other treatments. The treatments with lowest average yield were treatments T1 (Methomyl), T12 (Chlorfenapyr), T15 (Thiamethoxan + Lambda-cyhalotrin) and T16 (Control), which presented average productivity between 959 to 1169 Kg ha^{-1}, significantly differing from the other treatments.

It is important to note that when we establish a correlation between the average productivity with the average percentage of damaged stems in each season (Figure 2), we can verify that the linear model fits the set of observations, with an R-square (R^2) of 0.6506 in the 2021 harvest and R^2 of 0.8883 in the 2022 harvest, corroborating the fact that the higher the percentage of damaged stems, the greater the loss of productive performance of the soybean crop (Marques *et al*., 2023).

Figure 2. Relationship between percentage of stem length injured by Melanagromyza sojae and average yield in the 2021 and 2022 crop season.





Source: Authors

4 CONCLUSION

The best control of the soybean stem fly in soybean was achieved through foliar sprays of Chlorpyrifos (480 g/hectare) and Cyantraniliprole (100 g/hectare). These treatments not only reduced the damage caused by this pest but also resulted in higher yields. Given the potential for yield reduction in Brazil, with a reduction in grain yield of 0.9 g per plant for each percentage point of the injured stem, these results provide valuable guidance to growers on the best control options to manage this pest in soybean fields and avoid losses. We suggest the next studies with SSF control should include biological control methods and its interaction with chemical control. It's an exciting area of research with promising implications for sustainable agriculture.

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