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Effect of herbicides on *Pratylenchus brachyurus* in conventional and transgenic soybean cultivars

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Abstract

The root lesion nematode (*Pratylenchus brachyurus*) is a major constraint in soybean (*Glycine max* (L.) Merr.) production in Brazil's Midwest, where it causes significant yield losses. Weed management is also challenging, often requiring repeated herbicide applications. This study was developed in order to evaluate the effects of herbicides on *P. brachyurus* populations in conventional and transgenic soybean cultivars. Two experiments were carried out under naturally infested field conditions and in a greenhouse using a randomized block design. Treatments included four weed control methods (manual weeding, lactofen, chlorimuron-ethyl, and haloxyfop) applied to two conventional cultivars (BRSGO Iara and M-Soy 8001), plus two additional treatments on the transgenic cultivar BRS Valiosa RR (manual weeding and glyphosate). In the field, nematode density and reproduction factor were assessed at 45 and 90 days after emergence, along with root mass, leaf area, and pod biomass. Chlorimuron-ethyl increased nematode populations in both conventional cultivars, while lactofen reduced them in M-Soy 8001. Haloxyfop lowered the reproduction factor, and both chlorimuron and lactofen negatively affected plant growth. In the greenhouse, evaluations at 30 and 60 days after inoculation included nematode density and root and shoot biomass. At 30 DAI, chlorimuron increased nematode density in M-Soy 8001, while lactofen reduced it; all herbicides reduced shoot biomass. At 60 DAI, only glyphosate reduced shoot biomass in the transgenic cultivar. Overall, specific herbicides affected both nematode dynamics and plant development, with responses varying by cultivar and environment.

Keywords: Chlorimuron. *Glycine max.* glyphosate. Haloxyfop. Lactofen. Root lesion nematode.

Introduction

Soybean (*Glycine max* (L.) Merr.) is one of Brazil's most important export products and a key global commodity (FILASSI, OLIVEIRA, 2022). Brazil is currently the world's largest producer of soybeans (FAO, 2023), having recorded a production of 147.3 million tons during the 2023/2024 harvest, cultivated over an area of 46 million hectares, with an average yield of 3,739 kg ha^{-1} (CONAB, 2024). Consequently, the country has consolidated its position as a major international supplier of protein, both in grain and meal forms, and continues to expand its industrial capacity for oil production (PEREIRA *et al.*, 2022).

Hundreds of nematode species, representing approximately 50 genera, may occur in soybean crops (MACGUIDWIN *et al.*, 2024). However, in Brazil, one of the most damaging is *Pratylenchus* Filipjev, the root-lesion nematode (LIMA *et al.*, 2017; OLIVEIRA *et al.*, 2023). The expansion of soybean cultivation into the Midwestern region of Brazil has led to *P. brachyurus* becoming the most frequently encountered species (FREITAS *et al.*, 2019). Root-lesion nematodes are now considered the second most economically important group of plant-parasitic nematodes (BARROS *et al.*, 2022), owing to their broad geographic distribution, their capacity to cause significant yield losses across various agricultural crops, and the challenges associated with their management (LIMA *et al.*, 2015; CABI, 2021).

Weeds also represent a limiting factor for achieving high yields in soybean cultivation, as they can cause significant losses depending on the species present, their density, distribution within the crop (LANDAU *et al.*, 2022), and the effectiveness of control measures (DARAMOLA, 2020). In addition, weeds may serve as alternative hosts for various phytopathogens, including nematodes (BELLÉ *et al.*, 2015; ROCHA *et al.*, 2021). The most commonly adopted method for weed control is chemical, involving the use of synthetic herbicides (REIS, VIVIAN, 2011; WEBER *et al.*, 2016). It is well established that herbicides, once applied, can exert different physiological effects on plants and may follow various environmental pathways post-application (RUUSKANEN *et al.*, 2023).

Due to their widespread use in agriculture, the effects of herbicides on microorganisms and non-target species have been extensively investigated (HAGNER *et al.*, 2019), including their influence on the life cycle of nematodes (ZHAO *et al.*, 2013; DENNIS *et al.*, 2018). For various groups of plant-parasitic nematodes, herbicides may reduce population densities through multiple mechanisms: by eliminating weeds that may serve as alternative hosts; by directly affecting nematode populations—such as inhibiting juvenile hatching, restricting migration to host plants, and suppressing development within roots; and by altering plant secondary metabolism and defense responses (LEVENE *et al.*, 1998a,b; BARBOSA *et al.*, 2014; MARTINEZ *et al.*, 2018; SHARMA *et al.*, 2019; FRAGA *et al.*, 2020; DUKE, 2021).

However, few studies have evaluated the consequences of herbicide application on *P. brachyurus*, with most conducted several decades ago and none identified in Brazil. Johnson et al. (1975) reported that 14 different herbicides did not significantly affect the population density of nematodes, including *Pratylenchus* spp. Subsequent studies have shown variable responses within the genus: *P. penetrans* populations in apple roots were unaffected by the herbicide management (Costante et al., 1985); and Jordaan and De Waele (1988) found no significant impact of atrazine, alachlor, EPTC, or 2,4-D on *P. zeae* populations in corn. Conversely, Kornobis (2000) reported that *P. neglectus* populations either increased or decreased depending on the herbicide and crop, specifically chloridazon or cycloate. More recently, Garcia *et al.* (2018) observed no significant effects of herbicides on *Pratylenchus* spp. in different canola fields in France.

The mechanisms by which herbicides affect plant-parasitic nematodes remain insufficiently investigated. However, studies using *Caenorhabditis elegans* suggest that glyphosate, for example, may induce oxidative stress and exhibit neurotoxic activity (KRONBERG *et al.*, 2018; NARAINE *et al.*, 2022), effects that may also occur in *Pratylenchus* species. Given the scarcity of studies on the influence of herbicides in the soybean–root-lesion nematode (*P. brachyurus*) pathosystem in Brazil, this study was developed in order to evaluate the effects of herbicide application on *P. brachyurus* population density in conventional and transgenic soybean cultivars. The findings are expected to provide insight into whether herbicides influence cultivar performance and nematode dynamics.

Material and methods

Two experiments were carried out: one under field conditions and the other in a greenhouse. The field experiment was conducted in a commercial area naturally infested with *P. brachyurus* in Vicentinópolis, Goiás, Brazil, from December 2010 to April 2011. This municipality is situated in the southern region of the state of Goiás (17º 44’ 06” S, 49º 48’ 18” W; altitude: 646 m) and is characterized by two distinct seasons—a dry season from May to October and a rainy season from November to April (CARDOSO *et al.*, 2014).

Field experiment

The experimental design followed a randomized block structure, arranged in a 2 × 4 + 2 factorial scheme with four replications. The treatment factors consisted of two soybean cultivars (BRSGO Iara and M-Soy 8001) and four weed control methods: manual uprooting; chemical control using the herbicides lactofen (Naja, 180 g a.i. ha^{-1}), chlorimuron-ethyl (Classic, 20 g a.i. ha^{-1}), and haloxyfop-R (Verdict, 63.35 g a.i. ha^{-1}) combined with Nimbus mineral oil (0.5 % v/v). Additionally, two extra treatments were included, comprising the transgenic cultivar BRS Valiosa RR, subjected to either manual weed control or chemical control with the herbicide glyphosate (Roundup, 720 g a.e. ha^{-1}).

The cultivars were selected based on a previous study by Ferreira *et al.* (2009), in which BRSGO Iara was classified as resistant to *P. brachyurus*, exhibiting a reproduction factor (RF) of less than 1.0, whereas M-Soy 8001 was considered susceptible, with an RF of 4.9. The transgenic cultivar BRS Valiosa RR was included due to its resistance to the herbicide glyphosate and, in the same study, demonstrated an intermediate level of susceptibility with an RF of 2.5.

The treatments were arranged in plots consisting of eight rows, each 6.0 meters in length and spaced 0.5 meters apart (total plot area 6.0 m × 3.5 m = 21 m^2). Prior to sowing, soil samples were collected from each plot and processed in the laboratory (16°35'52.1"S, 49°16'53.5"W) to determine the initial population of *P. brachyurus*, following the methodology described by Jenkins (1964). Each soil sample, from each plot, comprised four subsamples collected 20 cm deep. Further evaluations were performed as follows: the two outer rows of each plot (rows 1 and 8) served as borders; the intermediate rows (rows 2 and 7) were designated for the evaluation of biomass and leaf area index (LAI); rows 3 and 6 were used to assess nematode population density; and rows 4 and 5 were allocated for grain yield evaluation.

The cultivars were sown at a population density of 500,000 plants per hectare. Herbicides were post-emergence applied using a CO_2 backpack pressurized sprayer, operating at a pressure of 4 kgf cm^{-2}, with a flow rate of 200 L ha^{-1} and flat fan-type nozzles. Both manual weed control and herbicide applications were carried out when the plants reached the V4 to V5 stage, as described by Fehr and Caviness (1977).

Leaves used to determine the leaf area index (LAI) were collected two and six weeks after herbicide application, from four randomly selected plants. LAI measurements were performed using a Bio-Science CI-202 Laser Area Meter (Leaf Area Meter). Biomass determination was carried out at phenological stages R3 and R8. For this purpose, plants were cut close to the ground, counted, and dried in a forced-air oven at 65° C until weight stabilization. The dried material was then weighed on an analytical balance, and the weight was converted to grams per square meter (g m^{-2}). In addition to these evaluations, the fresh and dry masses of the pods formed were quantified.

To determine the population density of *P. brachyurus*, roots from four plants were collected from each plot at 45 and 90 days after emergence (DAE) and transported to the laboratory. After being washed, the roots underwent the nematode extraction process, following the methodology described by Coolen and D'Herde (1972). Nematode identification and quantification were carried out under an optical microscope (40 × magnification) using a Peters chamber, with the population density expressed as the number of nematodes per 10 grams of roots.

The reproduction factor (RF) is calculated as the ratio between the final population (Pf) and the initial population (Pi) (OOSTENBRINK, 1966). In the present study, the initial population obtained at 45 days after emergence (DAE) was used to calculate the RF, while the final population obtained at 90 DAE was considered. This approach was adopted because, at the time of experiment installation (when the initial population was determined), a low number of nematodes was observed in the soil samples. Despite the area having a history of high populations of *P. brachyurus*, there were no plants at the time of installation, and soil moisture was low, which likely led to an underestimation of the population.

Greenhouse experiment

The greenhouse experiment was carried out from September to November (16°35'52.1" S, 49°16'53.5" W). The experimental design followed a completely randomized layout, also arranged in a 2 × 4 + 2 factorial scheme, with six replications. The treatments were identical to those evaluated under field conditions. The cultivars were sown in ceramic pots with a capacity of 1.4 L. A sterilized mixture of sand and soil, in a 1:1 (v/v) ratio, was used as the substrate. The pots were placed on benches with raised edges, and the spaces between the pots were filled with moist sand to maintain a uniform temperature and humidity within the pots.

Five seeds were sown per pot, and thinning was conducted after seedling emergence, leaving two plants per pot. Inoculation with *P. brachyurus* was carried out 15 days after emergence. The inoculum, consisting of approximately 500 individuals, was obtained from soybean plants of cultivar BRS Valiosa RR, maintained in a greenhouse. A 2.5 mL suspension was applied to each pot using a pipette, placing it in a groove near the plant collar. Herbicide applications were made 20 days after emergence. Throughout the experiment, daily watering was performed, ensuring that the substrate remained moist but not saturated.

At 30 and 60 days after inoculation (DAI), the population density of nematodes in the roots was assessed. Roots were collected, washed, weighed, and subjected to nematode extraction using the method described by Coolen and D'Herde (1972). The results were expressed as the number of nematodes per 10 g of roots. The reproduction factor (RF) was calculated as the ratio between the final population at 60 DAI and the initial population. Additionally, the fresh weight of the roots and the biomass of the aerial part were measured at 30 and 60 days.

Statistical analysis

The experimental data were subjected to normality and homogeneity of variance tests. Statistical analyses were performed using data transformed through the Box and Cox (1964) power transformation. Analysis of variance (ANOVA) was performed using the F test (Snedecor) at a 5 % significance level. To compare treatment means, orthogonal contrasts were constructed and tested, with statistical significance determined by Student's t-test at a 5 % significance level. Orthogonal contrasts were used to test specific treatment comparisons independently. These analyses were performed using the Genes computational application (SAS INSTITUTE, 1999).

Results

In both the field and greenhouse experiments, no significant interaction was observed between the weed control methods and soybean cultivars on the populations of the nematode *P. brachyurus* at 45 days. The use of the transgenic cultivar along with the herbicide glyphosate did not have any significant impact on the population density or reproduction factor (RF) of the nematode (Tables 1 and 3).

Field experiment

The effect of the control methods was only observed 90 days after emergence. A higher population density of *P. brachyurus* was observed when the herbicide chlorimuron was used, compared to the other methods. In the M-Soy 8001 cultivar, the application of lactofen reduced the population of *P. brachyurus* compared to the chlorimuron treatment. The evaluation at 60 days after inoculation (DAI) resulted in much higher population densities, with no significant differences, and consequently, much higher reproduction factors (RF) than those observed in the field. In the field, the RF ranged from 0.79 to 1.97 across all treatments (Table 1).

Due to the low population densities observed at the time of the experiment installation in the field, it was decided to use the population obtained at 45 days after emergence (DAE) as the initial population for calculating the reproduction factor (RF). Therefore, the population density determined at 45 DAE refers to the nematodes that penetrated and managed to develop in the roots. The population determined at 90 DAE refers to the nematodes that multiplied in the roots of the plants and was used as the final population for calculating the RF. This variable resulted, on average, in 0.92 for the BRSGO Iara cultivar, 1.56 for the M-Soy 8001 cultivar, and 0.87 for the BRS Valiosa RR cultivar, with no significant differences between the cultivars (Table 1).

Table 1. Population density of *Pratylenchus brachyurus* (nematodes per 10 g of roots) at 45 and 90 days after emergence (DAE) and reproduction factor (RF) as a function of weed control methods and soybean cultivars under field conditions.

Cultivars	Control methods					Averages
	Manual	Lactofen	Chlorimuron	Haloxyfop	Glyphosate	
			Population density*			
			45 DAE			
BRS IARA	412.50	255.79	542.78	221.08	-	358.04
M-SOY 8001	168.37	241.45	303.11	414.79	-	281.93
BRS VALIOSA RR	315.80	-	-	-	383.51	349.66
Averages	298.89	248.62	422.95	317.94	383.51	
CV(%)			13.71			
			90 DAE			
BRS IARA	206.86 A**	250.47 A	504.69 B	198.13 A	-	290.04
M-SOY 8001	306.61 AB	175.90 A	535.83 B	238.96 AB	-	314.33
BRS VALIOSA RR	357.83 A	-	-	-	284.43 A	321.13
Averages	290.43	213.19	520.26	218.55	284.43	
CV(%)			9.25			
			RF			
BRS IARA	0.83 A	0.98 A	0.83 A	1.05 A	-	0.92
M-SOY 8001	1.95 B	1.60 AB	1.97 B	0.86 A	-	1.56
BRS VALIOSA RR	0.95 A	-	-	-	0.79 A	0.87
Averages	1.24	1.29	1.4	0.96	0.79	
CV(%)			34.71			

*Data were transformed by the Box and Cox (1964) power at $x^{0.1}$ for statistical analyses; **Means followed by the same capital letter in the rows do not differ from each other (t test, 5 %).

Source: authors (2025)

Regarding herbicide treatments, only in the M-Soy 8001 cultivar was it observed that, with the use of the herbicide haloxyfop, the reproduction factor (RF) was lower than that observed with the use of lactofen. In general, the RF in the M-Soy 8001 cultivar was almost twice that observed in the BRSGO Iara cultivar. However, with the use of haloxyfop, the RF was lower in the M-Soy 8001 cultivar than that observed in the BRSGO Iara cultivar (Table 1).

Concerning the variables that reflect plant growth, no significant differences were observed among the cultivars tested, in the field trial (Table 2). In the field experiment, it was observed that, in general, the use of lactofen and chlorimuron reduced the fresh root weight, LAI, and fresh and dry pod biomass of M-Soy 8001 and BRSGO Iara cultivars.

Greenhouse experiment

In the greenhouse, only the cultivars had an effect at 30 DAI. In general, the density was lower in the M-Soy 8001 cultivar, but the difference was significant only in the lactofen treatment (Table 3). In the BRS Iara cultivar, there was no difference between the control methods; while in the M-Soy 8001 cultivar, the density was higher in the chlorimuron treatment, similar to the untreated control. In the greenhouse, the RF ranged from 4.10 to 8.77, considering all treatments. In the BRS Iara cultivar, the RF was higher in the treatments with lactofen and haloxyfop; while in M-Soy 8001, there was no difference among treatments.

The effect of cultivars on the population density of *P. brachyurus* was only observed in the greenhouse experiment, during the evaluation at 30 DAI, when lactofen was used (Table 3). In this case, it was observed that in the M-Soy 8001 cultivar, the density was 61.4 % lower than in the BRS Iara cultivar. However, this effect was not maintained in the reading at 60 days after inoculation.

The fresh weight of roots was lower in the BRSGO Iara cultivar with the use of chlorimuron at 30 DAI. This effect was not maintained at 60 DAI (Table 4). In the evaluation of shoot biomass, all herbicides caused a reduction in the values observed compared to the control at 30 DAI. At 60 DAI, only glyphosate reduced shoot biomass in the transgenic cultivar BRS Valiosa RR.

Discussion

In both experiments (field and greenhouse), no significant interaction was observed between the factors of weed control methods and soybean cultivars on the populations of the nematode. The results obtained in the present study corroborate the reports of Noel and Wax (2009) and Barbosa *et al.* (2014), where no effect of the application of the herbicide glyphosate in transgenic RR cultivars was observed on populations of *Heterodera glycines*. These findings are consistent with those of Garcia et al. (2018), who reported that the application of herbicides did not affect *Pratylenchus* abundance in canola fields in France.

In the field, a higher population density of the nematode was observed when the herbicide chlorimuron was used. The application of lactofen reduced the population of *P. brachyurus* compared to the treatment with chlorimuron in the M-Soy 8001 cultivar (considered susceptible). A similar reduction was observed in *P. neglectus* populations in beetroot when two different herbicides (chloridazon and cycloate) were applied (KORNOBIS, 2000). According to Barbosa *et al.* (2014), the association of lactofen and chlorimuron in soybean in the field reduced the number of viable cysts of *H. glycines*, showing that the reaction of the susceptible cultivar matched that of the cultivar resistant to the nematode.

In the experiment conducted in the greenhouse, the results observed in the field

Table 2. Fresh weight of roots (g), leaf area index (LAI) (cm^2), and biomass ($g.m^2$) in different soybean cultivars under different weed control methods, in field conditions.

Cultivars	Control methods					Averages
	Manual	Lactofen	Chlorimuron	Haloxyfop	Glyphosate	
			Fresh weight of roots[1]			
			45 DAE			
BRS IARA	6.38 A*	3.37 AB	2.48 B	6.09 A	-	4.58
M-SOY 8001	5.99 A	3.46 B	3.61 B	3.89 B	-	4.24
BRS VALIOSA RR	6.33 A	-	-	-	5.97 A	6.15
Averages	6.23	3.42	3.05	4.99	5.97	
CV (%)			15.61			
			90 DAE			
BRS IARA	9.39	5.50	5.43	8.80	-	7.28
M-SOY 8001	8.38	6.64	4.59	5.57	-	6.30
BRS VALIOSA RR	5.01	-	-	-	6.80	5.91
Averages	7.59	6.07	5.01	7.19	6.80	
CV (%)			19.23			
			LAI[2]			
			3 weeks			
BRS IARA	1307.55 AB	874.59 B	711.52 B	1765.87 A	-	1164.88
M-SOY 8001	1362.73 AB	661.31 B	814.86 B	2274.57 A	-	1278.37
BRS VALIOSA RR	1379.87 A	-	-	-	1586.55 A	1483.21
Averages	1350.05	767.95	763.19	1020.22	1586.55	
CV(%)			7.38			
			6 weeks			
BRS IARA	1997.23 AB	1212.48 B	1125.49 B	2747.00 A	-	1770.55
M-SOY 8001	1937.09 A	1098.61 B	975.61 B	2076.99 A	-	1522.08
BRS VALIOSA RR	1922.27 A	-	-	-	2730.61 A	2326.44
Averages	1952.20	1155.55	1050.55	2412.00	2730.61	
CV (%)			4.19			
			Biomass - Fresh pod[3]			
BRS IARA	64.39 A	31.26 B	22.14 B	86.92 A	-	51.18
M-SOY 8001	69.06 A	23.19 B	34.48 B	52.53 A	-	44.82
BRS VALIOSA RR	97.81 A	-	-	-	100.84 A	99.33
Averages	77.09	27.23	28.31	69.73	100.84	
CV (%)			21.28			
			Biomass - Dry pod[4]			
BRS IARA	18.09 A	9.16 B	6.74 B	23.07 A	-	14.27
M-SOY 8001	20.70 B	7.32 C	3.81 C	28.98 A	-	15.20
BRS VALIOSA RR	15.66 B	-	-	-	28.09 A	21.88
Averages	18.15	8.24	5.28	26.03	28.09	
CV (%)			9.94			

[1, 2, 3 and 4]Averages presented in original scale, but with statistical tests resulting from the Box and Cox (1964) transformation in $x^{0,3}$, $x^{0,1}$, $x^{0,4}$ and $x^{0,2}$; *Means followed by the same capital letter in the rows do not differ from each other (t-test, 5 %).

Source: authors (2025)

Table 3. Population density of *Pratylenchus brachyurus* (nematodes/10 g of roots)* at 30 and 60 days after inoculation (DAI) and reproduction factor (RF) as a function of weed control methods and soybean cultivars, in a greenhouse.

Cultivars	Control methods					Averages
	Manual	Lactofen	Chlorimuron	Haloxyfop	Glyphosate	
			Population density*			
			30 DAI			
BRS IARA	1133.21 a**	1210.57 b	759.42 a	655.22 a	-	939.64
M-SOY 8001	753.20 a	467.06 a	585.53 a	673.36 a	-	619.79
BRS VALIOSA RR	1201.34 a	-	-	-	946.58	1073.82
Averages	1029.25	838.82	672.48	664.29		
CV (%)			18.81			
			60 DAI			
BRS IARA	2051.25	3609.76	3213.08	3764.96	-	3159.76
M-SOY 8001	3091.47	3821.39	2789.72	4385.04	-	3521.91
BRS VALIOSA RR	2863.23	-	-	-	3089.80	2976.52
Averages	2668.65	3715.58	3001.4	4075.00	3089.80	
CV (%)			15.29			
			RF			
BRS IARA	4.10 A	7.22 B	6.43 AB	7.53 B	-	6.32
M-SOY 8001	6.18 A	7.64 A	5.58 A	8.77 A	-	7.04
BRS VALIOSA RR	5.73 A	-	-	-	6.18 A	5.96
Averages	5.34	7.43	6.01	8.15	6.18	
CV (%)			23.53			

*Data were transformed by the Box and Cox (1964) at $x^{0.2}$ and $x^{0.3}$, for statistical analyses; **Means followed by the same lowercase letter in the columns and uppercase in the rows do not differ from each other (t test, 5 %).
Source: authors (2025)

was not confirmed, possibly due to the use of an autoclaved substrate, prepared with a 1:1 (v/v) mixture of subsoil and sand. This condition resulted in much higher population densities of *P. brachyurus*, and some studies have associated a higher number of this nematode in soybean in sandy soils (LEIVA *et al.*, 2020; DIAS-ARIEIRA *et al.*, 2021). Thus, very high densities may have impaired better discrimination between treatments. In fact, differences were only observed in the evaluation at 30 DAI, in which the populations were, on average, three to five times smaller than at 60 DAI. Additionally, it is known that herbicides exhibit different dynamics or persistence in the environment, which may vary according to the type of soil (RUUSKANEN *et al.*, 2023).

Since low population densities were observed at the time of installation of the field experiment, the population obtained at 45 DAE was used as the initial population to calculate the reproduction factor (RF). This is based on the fact that, as an endoparasitic nematode, in the absence of plants — a condition found in the field before planting— its population was very low. Additionally, *Pratylenchus* is a slow-developing nematode genus, whose cycle is completed, on average, between 45 and 65 days (JONES, FOSU-NYARKO, 2014).

Table 4. Fresh weight of roots (g) and biomass of the aerial part (g.m²) of different soybean cultivars under different weed control methods, in a greenhouse.

Cultivars	Control methods					Averages
	Manual	Lactofen	Chlorimuron	Haloxyfop	Glyphosate	
			Fresh Weight of Roots*			
			30 DAI			
BRS IARA	2.62 Aa**	2.43 Aba	1.60 Bb	3.05 Aa	-	2.43
M-SOY 8001	2.88 Aa	2.98 Aa	3.24 Aa	2.86 Aa	-	2.99
BRS VALIOSA RR	2.48 Aa	-	-	-	2.71 A	2.60
Averages	2.66	2.71	2.42	2.96	2.71	
CV (%)			35.45			
			60 DAI			
BRS IARA	0.36	0.32	0.44	0.53	-	0.41
M-SOY 8001	0.40	0.49	0.37	0.49	-	0.44
BRS VALIOSA RR	0.51	-	-	-	0.46	0.49
Averages	0.42	0.41	0.41	0.51	0.46	
CV (%)			33.21			
			Biomass - Aerial part			
			30 DAI			
BRS IARA	8.52 A	3.85 B	4.42 B	4.27 B	-	5.27
M-SOY 8001	8.05 A	4.39 B	4.55 B	5.04 B	-	5.51
BRS VALIOSA RR	7.39 A	-	-	-	4.33 B	5.86
Averages	7.99	4.12	4.49	4.67	4.33	
CV (%)			17.49			
			60 DAI			
BRS IARA	3.18 A	2.46 A	2.99 A	3.64 A	-	3.07
M-SOY 8001	3.26 A	2.77 A	2.04 A	3.29 A	-	2.84
BRS VALIOSA RR	4.74 A	-	-	-	2.03 B	3.39
Averages	3.73	2.62	2.52	3.47	2.03	
CV (%)			25.13			

*Averages presented in original scale, but with statistical tests resulting from the Box and Cox (1964) power transformation in $x^{-0,1}$ and $x^{0,4}$; **Means followed by the same capital letter in the rows do not differ from each other (t-test, 5 %).

Source: authors (2025)

Only in the M-Soy 8001 cultivar was it observed that the use of the herbicide haloxyfop resulted in a lower RF compared to lactofen. Furthermore, the RF in this cultivar (considered susceptible to the nematode) was lower than that observed in the BRSGO Iara cultivar (considered resistant). No studies were found that reported the effect of this herbicide on the nematode reproduction factor; however, Barbosa *et al.* (2014), evaluating this herbicide in the field, observed that its use in the BRSGO Ipameri cultivar resulted in the lowest number of viable cysts of *H. glycines*. This cultivar is considered resistant to the nematode; therefore, the herbicide did not influence this variable.

Considering that the soybean cultivars used in this study were chosen based on preliminary studies, which had resistance and susceptibility behavior for the cultivars BRSGO Iara and M-Soy 8001, significant differences were expected to be observed between the cultivars in the evaluations of population density of *P. brachyurus*, both in the field experiment and in the greenhouse. This was not observed, as the number of individuals was relatively uniform among the cultivars, not reproducing the results obtained previously by Ferreira *et al.* (2009). Although several studies have been achieved to evaluate the behavior of soybean cultivars in relation to *P. brachyurus*, the results have not been consistent for some genotypes (RIBEIRO *et al.*, 2007; DIAS *et al.*, 2007; FERREIRA *et al.*, 2009; DIAS *et al.*, 2023). In the studies developed by Ribeiro *et al.* (2007) and Ferreira *et al.* (2009), the cultivar BRSGO Iara presented RF between 1.0 and 1.5, while Dias *et al.* (2007) described an RF of 6.2 for the same cultivar. These same authors found RF ranging from 4.9 to 38.2 for the cultivar M-Soy 8001 and between 2.5 and 7.6 for the cultivar BRS Valiosa RR.

In general, in the field experiment, it was observed that the use of lactofen and chlorimuron reduced the fresh root weight, LAI, and fresh and dry pod biomass of the M-Soy 8001 and BRSGO Iara cultivars. Other studies have shown that lactofen did not affect expanded soybean leaves or yield (WICHERT, TALBERT, 1993), although in another research, chlorimuron affected the growth and biomass of this plant (GONÇALVES *et al.*, 2018).

Finally, under greenhouse conditions, in the evaluation of shoot biomass, only glyphosate reduced shoot biomass in the transgenic cultivar BRS Valiosa RR. This effect may be attributed to the dissipation half-life of the products, which could have interfered with plant development during the initial evaluation. According to Okada et al. (2019), glyphosate exhibits a dissipation half-life ranging from 9 to 39 days. Furthermore, since this herbicide may affect the initial development even of resistant cultivars (ALONSO *et al.*, 2011; CASONATTO *et al.*, 2014), this could explain the observed effect.

Conclusions

The herbicide glyphosate does not affect *Pratylenchus brachyurus* populations in the field or under greenhouse conditions in the transgenic cultivar BRS Valiosa RR, but it may reduce shoot biomass. Regarding the other herbicides tested, chlorimuron increases the nematode population in the cultivars BRS Iara and M-Soy 8001, while lactofen reduces the population in the cultivar BRS Iara in the field. Also, under field conditions, the herbicides lactofen and chlorimuron reduced root mass, leaf area index, and pod biomass.

References

ALONSO, D. G.; CONSTANTIN, J.; OLIVEIRA JÚNIOR, R. S.; ARANTES, J. G. Z.; CAVALIERI, S. D.; SANTOS, G.; RIOS, F. A.; FRANCHINI, L. H. M. Selectivity of glyphosate tank mixtures for RR soybean. **Planta Daninha**, v. 29, p. 929-993, 2011.

BARBOSA, K. A. G.; SEII, A. H.; ROCHA, M. R.; TEIXEIRA, R. A.; SANTOS, L. C.; ARAÚJO, F. G. Interação entre herbicidas e cultivares de soja sobre o nematoide de cisto *Heterodera glycines*. **Bioscience Journal**, v. 30, p. 154-163, 2014.

BARROS, F. M. D. R.; PEDRINHO, A.; MENDES, L. W.; FREITAS, C. C. G.; ANDREOTE, F. D. Interactions between soil bacterial diversity and plant-parasitic nematodes in soybean plants. **Applied and Environmental Microbiology**, v. 88, e0096322, 2022.

BELLÉ, C.; LIMA-MEDINA, I.; KASPARY, T. E.; KUHN, P. R. Host suitability of weeds to *Pratylenchus brachyurus* in Northwest of Rio Grande do Sul Brazil. **Nematropica**, v. 45, p. 144-149, 2015.

BOX, G. E. P.; COX, D. R. An analysis of transformations. **Journal of the Royal Statistical Society, Series B (Statistical Methodology)**, v. 26, p. 211-252, 1964.

CABI - Centre for Agriculture and Bioscience International. ***Pratylenchus brachyurus*** **(root-lesion nematode).** Available at: https://doiorg/101079/cabicompendium43894, 2021. Accessed in: 6 Jul. 2024.

CARDOSO, M. R. D.; MARCUZZO, F. F. N.; BARROS, J. R. Classificação climática de Köppen-Geiger para o Estado de Goiás e o Distrito Federal. **Acta Geográfica**, v. 8, p. 40-55, 2014.

CASONATTO, M. S.; ARANTES, S. A. C. M.; RIEGER, E. A.; ANDRADE, E. A. How glyphosate may affect transgenic soybean in different soil and phosphorus levels. **Planta Daninha**, v. 32, p. 843-850, 2014.

CONAB - Companhia Nacional de Abastecimento. 2024. **12º Levantamento - Safra 2023/24.** Available at: https://www.conab.gov.br/ultimas-noticias/5728-ultimo-levantamento-da-safra-2023-2024-estima-producao-de-graos-em-298-41-milhoes-de-toneladas#:~:text=De%20acordo%20com%20os%20dados,de%20hectares%20sobre%202022%2F2023. Accessed: 6 Apr. 2025.

COOLEN, W. A.; D'HERDE, C. J. **A method for the quantitative extraction of nematodes from plant tissue.** Ghent Belgian: State of Nematology and Entomology Research Station, 1972. 77 p.

COSTANTE, J. F.; MAI, W. F.; KLEIN, R. M. Effects of rootstock and soil type on *Pratylenchus penetrans* populations in apple feeder roots. **Journal of the American Society for Horticultural Science**, v. 110, p. 38-41, 1985.

DARAMOLA, O. Timing of weed management and yield penalty due to delayed weed management in soybean. **Planta Daninha**, v. 38, e020236046, 2020.

DENNIS, P.; KUKULIES, T.; FORSTNER, C.; ORTON, T. G.; PATTISON, T. The effects of glyphosate glufosinate paraquat and paraquat-diquat on soil microbial activity and bacterial archaeal and nematode diversity. **Scientific Reports**, v. 8, e2119, 2018.

DIAS, W. P.; RIBEIRO, N. R.; LOPES, I. O. N.; GARCIA, A.; CARNEIRO, G. E. S.; SILVA, J. F. V. Manejo de nematóides na cultura da soja. In: CONGRESSO BRASILEIRO DE NEMATOLOGIA, 27., 2007, Goiânia. **Anais**...Goiânia: SBN, 2007. p. 26.

DIAS, W. P.; WENDLAND, A.; SOUZA CARNEIRO, G. E.; OLIVEIRA FILHO, F. G.; LOPES, I. O. N. Reaction of common bean genotypes to plant parasitic nematodes. **Pesquisa Agropecuária Tropical**, v. 53, e7471, 2023.

DIAS-ARIEIRA, C. R.; CECCATO, F. J.; MARINELLI, E. Z.; BOREGIO, J. L.; OLIVEIRA, G.; SANTANA-GOMES, S. Correlations between nematode numbers chemical and physical soil properties and soybean yield under different cropping systems. **Rhizosphere**, v. 19, e100386, 2021.

DUKE, S. O. Glyphosate: Uses other than in glyphosate-resistant crops mode of action degradation in plants and effects on non-target plants and agricultural microbes. **Reviews of Environmental Contamination and Toxicology**, v. 255, p. 1-6, 2021.

FAO - Food and Agriculture Organization of the United Nations. 2023. **Countries by commodity:** top 10 country production of soya beans. Available at: https://wwwfaoorg/faostat/en/#rankings/countries_by_commodity. Accessed: 6 Apr. 2025.

FEHR, W. R.; CAVINESS, C. E. **Stages of soybean development**. Special Report 80 Ames: Iowa State University, 1977. 12p.

FERREIRA, A. D.; ROCHA, M. R.; ALVES, T. G.; FERREIRA, C. S.; BARBOSA, K. A. G.; TEIXEIRA, R. A.; SANTOS, L. C. Reação de cultivares de soja a *Pratylenchus brachyurus* em área naturalmente infestada. In: CONGRESSO BRASILEIRO DE NEMATOLOGIA, 33, 2009, Piracicaba. **Anais**... Piracicaba: SBN, 2009. p. 311.

FILASSI, M.; OLIVEIRA, A. L. R. Competitiveness drivers for soybean exportation and the fundamental role of the supply chain. **Revista de Economia e Sociologia Rural**, v. 60, e235296, 2022.

FRAGA, D. S.; AGOSTINETTO, D.; RUCHEL, Q.; LANGARO, A. C.; OLIVEIRA, C. Changes in the metabolism of soybean plants submitted to herbicide application in different weed management systems. **Planta Daninha**, v. 38, e02021552, 2020.

FREITAS, J. R. B.; TEIXEIRA, D. B.; MOITINHO, M. R.; SILVA JÚNIOR, J. F.; SIQUEIRA, D. S.; BARBOSA, B. F. F.; SOARES, P. L. M.; PEREIRA, G. T. Distribuição espacial de *Pratylenchus brachyurus* em área de soja no Leste do Maranhão. **Revista Brasileira de Ciências Agrárias**, v. 14, p. 1-6, 2019.

GARCIA, N.; FOLCHER, L.; BIJU-DUVAL, L.; MAUPETIT, A.; RICCI, B.; GRENIER, E. Impact of agricultural practices and environmental variables on plant-parasitic nematode communities in fields at a landscape scale. **Environmental Science, Agricultural and Food Sciences**, v. 20, p. 211-233, 2018.

GONÇALVES, C. G.; SILVA JUNIOR, A. C.; SCARANO, M.; PEREIRA, M. R. R.; MARTINS, D. Chlorimuron-ethyl in conventional and transgenic soybean cultivars under water deficit stress. **Revista Caatinga**, v. 31, p. 832-84, 2018.

HAGNER, M.; MIKOLA, J.; SALONIEMI, I.; SAIKKONEN, K.; HELANDER, M. Effects of a glyphosate-based herbicide on soil animal trophic groups and associated ecosystem functioning in a northern agricultural field. **Scientific Reports**, v. 9, n. 1, e8540, 2019.

JENKINS, W. R. A rapid centrifugal-flotation technique for separating nematodes from soil. **Plant Disease Report,** v. 48, p. 69, 1964.

JOHNSON, A. W.; DOWLER, C. C.; HAUSER, E. W. Crop rotation and herbicide effects on population densities of plant-parasitic nematodes. **Journal of Nematology**, v. 7, p. 158-168, 1975.

JONES, M.G.K.; FOSU-NYARKO, J. Molecular biology of root lesion nematodes (*Pratylenchus* spp.) and their interaction with host plants. **Annals of Applied Biology**, v. 164, p. 163–181, 2014.

JORDAAN, E. M.; WAELE, D. Effects of four herbicides on the infestation of maize by the nematode *Pratylenchus zeae*. **South African Journal of Plant and Soil**, v. 5, p. 165, 1988.

KORNOBIS, S. Effects of six year herbicides use on population dynamics of migratory plant parasitic nematodes in the field. **Journal of Plant Protection Research**, v. 40, p. 68-72, 2000.

KRONBERG, M. F.; CLAVIJO, A.; MOYA, A.; ROSSEN, A.; CALVO, D.; PAGANO, E.; MUNARRIZ, E. Glyphosate-based herbicides modulate oxidative stress response in the nematode *Caenorhabditis elegans*. **Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology**, v. 214, p. 1-8, 2018.

LANDAU, C. A.; HAGER, A. G.; WILLIAMS, M. M. Deteriorating weed control and variable weather portends greater soybean yield losses in the future. **Science of The Total Environment**, v. 830, e154764, 2022.

LEIVA, N. P. F.; SANTANA-GOMES, S. M.; ZABINI, A. V.; VELÁZQUEZ, L. M. G.; DIAS-ARIEIRA, C. R. Soil chemical properties and their relationship with phytonematode populations inside and outside patches of soybean fields. **Rhizosphere**, v. 15, e100231, 2020.

LEVENE, B. C.; OWEN, M. D. K.; TYLKA, G. L. Influence of herbicide application to soybeans on soybean cyst nematode egg hatching. **Journal of Nematology**, v. 30, p. 347-352, 1998a.

LEVENE, B. C.; OWEN, M. D. K.; TYLKA, G. L. Response of soybean cyst nematodes and soybeans (*Glycine max*) to herbicides. **Weed Science**, v. 46, p. 264-270, 1998b.

LIMA, F. S. D. O.; SANTOS, G. R. D.; NOGUEIRA, S. R.; SANTOS, P. R. R. D.; CORREA, V. R. Population dynamics of the root lesion nematode *Pratylenchus brachyurus* in soybean fields in Tocantins State and its effect to soybean yield. **Nematropica**, v. 45, p. 170–177, 2015.

LIMA, F. S. O.; CORREA, V. R.; NOGUEIRA, S. R.; SANTOS, P. R. R. **Nematodes affecting soybean and sustainable practices for their management**. In: KASAI, M. (Ed.). United Kingdom: Intechopen, 2017. p. 327-345.

MACGUIDWIN, A. E.; SMITH, D. L.; CONLEY, S. P.; SAIKAI, K. A. Prevalence of pest nematodes associated with soybean (*Glycine max*) in Wisconsin from 1998 to 2021. **Journal of Nematology**, v. 55, e20230053, 2024.

MARTINEZ, D. A.; LOENING, E. U.; GRAHAM, M. C. Impacts of glyphosate-based herbicides on disease resistance and health of crops: A review. **Environmental Sciences Europe**, v. 30, e2, 2018.

NARAINE, A.S.; AKER, R.; SWEENEY, I.; KALVEY, M.; SURTEL, A.; SHANBHAG, V.; DAWSON-SCULLY, K. Roundup and glyphosate's impact on GABA to elicit extended proconvulsant behavior in *Caenorhabditis elegans*. **Scientific Reports**, v. 12, e13655, 2022.

NOEL, G. R.; WAX, M. *Heterodera glycines* population development on soybean treated with glyphosate. **Nematropica**, v. 39, p. 247-253, 2009.

OKADA, E.; COSTA, J. L.; BEDMAR, F. Glyphosate dissipation in different soils under no-till and conventional tillage. **Pedosphere**, v. 29, p. 773-783, 2019.

OLIVEIRA, J. C.; CARVALHO, M. A. C.; RABELO, H. O.; FERREIRA. P. A.; PIVA, R. P.; OLIVEIRA, L. C. A. Genetic chemical and biological management strategies of control of *Pratylenchus brachyurus* in soybean. **Revista em Agronegocio e Meio Ambiente**, v. 16, p. 1-15, 2023.

OOSTENBRINK, M. Major characteristics of the relation between nematodes and plants. **Mededelingen Landbouwhoogeschool Wageningen**, v. 66, p. 1-46, 1966.

PEREIRA, R. P. T.; GALO, N. R.; FILIMONAU, V. Food loss and waste from farm to gate in Brazilian soybean production. **Journal of Agriculture and Food Research**, v. 10, e100431, 2022.

REIS, A. R.; VIVIAN, R. Weed competition in the soybean crop management in Brazil. In: NG, T.B. (Ed) **Soybea**n: applications and technology. Rijeka, Croatia: InTech, 2011. p. 185-210.

RIBEIRO, N. R.; DIAS, W. P.; HOMECHIN, M.; SILVA, J. F. V.; FRANCISCO, A.; LOPES, I. O. N. Reação de algumas espécies vegetais a *Pratylenchus brachyurus*. In: CONGRESSO BRASILEIRO DE NEMATOLOGIA, 27., 2007, Goiânia. **Anais**...Goiânia: SBN, 2007. p. 5.

ROCHA, L. F.; GAGE, K. L.; PIMENTEL, M. F.; BOND, J. P.; FAKHOURY, A. M. Weeds hosting the soybean cyst nematode (*Heterodera glycines* Ichinohe): management implications in agroecological systems. **Agronomy**, v. 11, n. 1, e146, 2021.

RUUSKANEN, S.; FUCHS, B.; NISSINEN, R.; PUIGBÒ, P.; RAINIO, M.; SAIKKONEN, K.; HELANDER, M. Ecosystem consequences of herbicides: the role of microbiome. **Trends in Ecology and Evolution**, v. 38, p. 35-43, 2023.

SAS - Statistical Analysis System. **User's Guide:** statistics. SAS Institute Cary NC: SAS Institute Inc, 1999.

SHARMA, A.; KUMAR, V.; THUKRAL, A. K.; BHARDWAJ, R. Responses of plants to pesticide toxicity: an overview. **Planta Daninha**, v. 37, e019184291, 2019.

WEBER, J. F.; KUNZ, C.; GERHARDS, R. Chemical and mechanical weed control in soybean (*Glycine max*). **Julius-Kühn-Arch**, v. 452, p. 171-176, 2016.

WICHERT, R. A.; TALBERT, R. E. Soybean [*Glycine max* (L.)] response to lactofen. **Weed Science**, v. 41, n. p. 23-27, 1993.

ZHAO, J.; NEHER, D. A.; FU, S.; LI, Z.; WANG, K. Non-target effects of herbicides on soil nematode assemblages. **Pest Management Science**, v. 69, p. 679-684, 2013.