RESEARCH/INVESTIGACIÓN

ROTATIONAL COVER CROPS IN SANDY SOILS: EFFECT ON ROOT-KNOT NEMATODE POPULATION DENSITIES AND SOYBEAN YIELD

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ABSTRACT

Andreotti, E.L.T.[1], S. A. Silva[2], O. F. Dorigo[3], and A. C. Z. Machado[2*]. 2024. Rotational cover crops in sand soils: Effect on root-knot nematode population densities and soybean yield. Nematropica 54:149-157.

Soybean cultivation has increased in the sandy soils of Brazil but improvements in yields have not been realized due to soil degradation and plant-parasitic nematodes. The objective of this study was to analyze the effects of crop rotation on the population dynamics of *Meloidogyne incognita* and soybean yield. Additionally, the host reaction of sorghum cv. AGRI 002E to *M. incognita* and *M. javanica* was evaluated under greenhouse conditions. The field study was conducted in São Pedro do Turvo, SP, in a sandy soil with high *M. incognita* population densities. Treatments were soybean-maize and soybean-sorghum in rotation with the biological fertilizers Microgeo and Supergan and one additional treatment of *Crotalaria spectabilis*-maize rotation. Soil and root samples were collected prior to planting and 60 days after establishment of treatments to quantify nematodes. The productivity of soybean was estimated, and costs were quantified. In the greenhouse, sorghum plants were inoculated with 1,000 eggs of *M. incognita* and *M. javanica* and, after 60 days, nematodes were extracted to obtain the reproduction factor (RF = final density/initial density). Results showed that higher productivity, as well as a significant reduction in nematode population densities was observed in the plots where *C. spectabilis* was cropped. With the replacement of soybean by *C. spectabilis*, the reduction in *M. incognita* population densities was greater, which allowed for an increase in yield. The biological fertilizers Supergan and Microgeo did not increase soybean yields and did not reduce *M. incognita* population densities when used once. Sorghum AGRI 002E was susceptible to *M. incognita* and *M. javanica* with RF values of 15.1 and 9.5, respectively, and cultivation of this crop must be avoided in areas infested with root-knot nematodes.

Key words: Crotalaria spectabilis, green manure, management, root-knot nematode

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RESUMO

Andreotti, E.L.T., S. A. Silva, O. F. Dorigo, A. C. Z. Machado. 2024. Culturas de cobertura vegetal na sucessão em solos arenosos: Efeito na população do nematoide das galhas e na produtividade da soja. Nematropica 54:149-157.

O cultivo da soja tem crescido nos solos arenosos do Brasil, mas melhorias na produtividade não foram alcançadas devido à degradação do solo e aos nematoides parasitas de plantas. O objetivo deste trabalho foi analisar os efeitos da sucessão de culturas na dinâmica populacional de *Meloidogyne incognita* e na produtividade da soja. Além disso, a reação do sorgo AGRI 002E como hospedeiro de *M. incognita* e *M.*

javanica foi avaliada em condições de casa de vegetação. O estudo de campo foi conduzido em São Pedro do Turvo, SP, em um solo arenoso com altas densidades populacionais de *M. incognita*. Os tratamentos foram soja-milho e soja-sorgo em rotação de culturas com os fertilizantes biológicos Microgeo e Supergan, e um tratamento adicional de rotação de *Crotalaria spectabilis*-milho. Amostras de solo e raízes foram coletadas antes do plantio das culturas e 60 dias após o estabelecimento dos tratamentos para quantificação dos nematoides. A produtividade da soja foi estimada e os custos foram quantificados. Na casa de vegetação, plantas de sorgo foram inoculadas com 1.000 ovos de *M. incognita* ou *M. javanica* e, após 60 dias, os nematoides foram extraídos para obter o fator de reprodução (RF). Os resultados mostraram que a maior produtividade, bem como uma redução significativa na população do nematoide, foi observada nas parcelas onde a crotalária foi cultivada. Com a substituição da soja por *C. spectabilis*, a redução nas densidades populacionais de *M. incognita* foi maior, o que permitiu aumento na produtividade. Os tratamentos com Supergan e Microgeo não aumentaram a produtividade da soja e não reduziram as densidades populacionais de *M. incognita* quando utilizados uma única vez. O sorgo AGRI 002E foi suscetível a *M. incognita* e *M. javanica*, com valores de RF de 15,1 e 9,5, respectivamente, e seu cultivo deve ser evitado em áreas infestadas por nematoides de galhas.

Palavras-chave: Crotalaria spectabilis, adubos verdes, manejo, nematoide das galhas

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INTRODUCTION

Soybean (*Glycine max*) holds significant agricultural importance in Brazil, particularly with the substantial expansion of soybean cultivation into sandy soils over the last few decades. These sandy soils constitute approximately 8% of the national territory, prevalent in the Matopiba region (Maranhão, Tocantins, Piauí, and Bahia states) representing 20% of soybean fields (Spera *et al*., 1999; Lumbreras *et al*., 2015). Sandy soils, common in this region, are prone to erosion due to the low cohesion among soil particles and poor aggregate stability (Fidalski, 1997). Cover crops known to enhance nutrient cycling, increase organic matter content, and improve soil microbiome and physicochemical characteristics have been implemented to mitigate soil erosion and enhance soybean yields (White and Broadley, 2009).

Beyond soil characteristics, soybean yields are constrained by pests and pathogens, including plant-parasitic nematodes. The root-knot nematodes, particularly *Meloidogyne incognita* and *M. javanica*, pose a significant threat to soybean production in Brazil (Rocha and Dias-Arieira, 2023). Cover crops, such as pearl millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*), commonly used in no-tillage systems in Brazil, have been used to enhance soil properties and suppress nematode population densities. Green manures like *Crotalaria* spp., especially *C. spectabilis*, have been used in crop rotation to reduce population densities of *M. incognita*, *M. javanica,* and *Pratylenchus brachyurus* (Tanaka *et al*., 1992; Wang *et al*., 2002), though their economic appeal is limited. Additionally, these plant species contribute to increasing soil organic matter content and fostering beneficial soil microorganisms like fungi and bacteria, which can parasitize nematode eggs and juveniles in the soil. Enhancing soil microorganisms can also be achieved through the addition of organic fertilizers.

This study aimed to evaluate the effects of crop rotation on *M. incognita* population densities and soybean productivity. The treatments included soybean-maize and soybean-sorghum rotations, with or without the application of biological fertilizers Microgeo and Supergan. Additionally, one treatment replaced soybean with *C. spectabilis*, followed by maize in rotation. Sorghum cv. AGRI 002E was also evaluated under greenhouse conditions to assess host status for *M. incognita* and *M. javanica*.

MATERIALS AND METHODS

Field experiment

The experiment was conducted during two crop seasons in a naturally infested field with *M. incognita*, previously identified through α-esterase isozyme phenotypes (I1) (Carneiro *et al*., 2000), in the municipality of São Pedro do Turvo, São Paulo State, Brazil (22º44'49"S, 49º44'23"W, 457 m). The climate in this area is characterized by a rainy, tropical climate with dry winters. Soil characteristics are as follows: 7.5% clay, 2.7% silt, 90% sand, 0.01 cmol/dm^3 Al, 2.17 cmol/dm^3 H+Al, 1.72 cmol/dm^3 Ca, 0.48 cmol/dm^3 Mg, 0.12 cmol/dm^3 K, 2.32 cmol/dm^3 sum of bases, 4.61 cmol/dm^3 cation capacity exchange, pH 5.40, 4.80 g/dm^3 C, 78.65 mg/dm^3, 49.95 % base saturation, and 0.42% aluminum saturation.

The presence of *M. incognita* in this field was identified through characteristic symptoms such as poorly developed plants and galled roots. The experiment consisted of seven treatments replicated four times, arranged in randomized blocks in plots measuring 24 m^2 (6 x 4 m). The layout followed a factorial scheme with one additional treatment. The treatments included: 1) soybean/maize + Supergan; 2) soybean/maize + Microgeo; 3) soybean/maize (control, no fertilizer); 4) soybean/sorghum + Supergan; 5) soybean/sorghum + Microgeo; 6) soybean/sorghum (control, no fertilizer); 7) *C. spectabilis/*maize, as an additional treatment.

Seeds were planted with no-tillage machinery, maintaining a 50 cm spacing between lines, as follows: i) soybean cv. Agroeste 3730 (14 seeds/m) treated with 0.1 L/ha of *Bradyrhizobium*; ii) maize cv. Agroceres 8480 VT PRO3 (2.5 seeds/m); iii) sorghum v. cAGRI 002E (6 to 8 seeds/m); iv) *C. spectabilis* cv. Comum (20 seeds/m). Two organic fertilizers, Microgeo and Supergan (NPK 04-14-08; Superbac, Mandaguari, Paraná State, Brazil), were included. Maize and sorghum seeds were sown 30 days after soybean desiccation with glyphosate (2 L/ha) or after mechanical mowing of *C. spectabilis*.

Soybean received fertilizer applications of 250 kg/ha NPK 08-28-16 in plots treated with Microgeo and in the control. In plots treated with Supergan, the NPK 08-28-16 was substituted for 350 kg/ha Supergan NPK 04-14-08, applied in furrow. Microgeo was applied post-emergent to soybean (V3 stage) using a CO_2-pressurized, 3 m bar-equipped sprayer with six fan-shaped nozzles (model 110 015, Jacto, Pompeia, São Paulo State, Brazil). Maize and sorghum were fertilized with 200 kg/ha of urea 45% as a coverage application. Sorghum residue was left on the soil after mechanical mowing.

Phytosanitary management included glyphosate (2.5 L/ha, 2x), clorimuron (0.07 L/ha, 1x), cletodim (0.8 L/ha, 1x) for weed control in soybean, and abamectin (0.3 L/ha, 2x) for spider mites, imidacloprid + bifentrina (0.4 L/ha, 1x) for bedbugs, sulfoxaflor + bifentrina (0.3 L/ha, 2x) for bedbugs, and picoxistrobina + cyproconazole (0.3 L/ha, 1x), picoxistrobina + benzovinflupir (0.6 L/ha, 1x), and epoxiconazole + fluxapiroxade + piraclostrobina (0.8 L/ha, 1x) for fungi. Weed control in maize was with glyphosate (2.5 L/ha, 1x) and atrazine (3 L/ha, 1X), and insect control with imidacloprid + bifentrina (0.4 L/ha, 1x) for bedbugs and imidacloprid + bifentrina (0.3 L/ha, 1x) for aphids.

Nematode sampling was conducted before soybean planting and during the soybean/maize rotation at the reproductive stage. To obtain nematode density in the roots, 5 plants per plot were sampled using a straight shovel to collect roots and soil 10 cm equidistant from each side of the plant to a depth of 20 cm. All roots present in this soil square were used for nematode extraction and varied according to plots and treatments. Soil from each sampling point was homogenized and 50 cm^3 soil was collected for nematode extraction. Nematodes were extracted from soil and roots using the Baermann funnel and Boneti and Ferraz methodologies, respectively, as described in Machado and Silva (2019). The number of *M. incognita* eggs and juveniles extracted from roots was divided by the root weight and data are presented as number of *M. incognita* per gram of root. *Meloidogyne incognita* juveniles present in soil were quantified and data are presented as number of *M. incognita* per 50 cm^3 of soil.

Soybean and maize yields were estimated by harvesting complete plots, threshing the grain, adjusting humidity to 13%, and determining yield in kilograms per hectare for each treatment. Costs were estimated through the value of the inputs obtained through consulting three cooperatives (Coopermota – Santa Cruz do Rio Pardo, São Paulo State; Cooplacana – Chavantes, São Paulo State; Camda – Ourinhos, São Paulo State) located in neighboring municipalities where the study was conducted. The values used in the analysis were determined by the mean of these three cooperatives. The operational values (as machine-hours) were provided by the farmer who owns the field where the study was conducted. The value of a sack of grain was obtained as the market price on the day sold (R$ 78.00 and R$ 48.00 to 60 kg sc of soybean and maize, respectively) (US$ = 5.44).

The data were analyzed using analysis of variance (ANOVA), taking into account crop and treatments as factors. The normality of the residuals was assessed using the Shapiro-Wilk test, and the homogeneity of variances was checked using Bartlett's test. When necessary, data were transformed using the Box-Cox method. After conducting ANOVA and confirming that the assumptions of the linear model were met, a factorial analysis was performed in relation to the additional treatment. Specifically, the mean of the treatment with *C. spectabilis* (which did not involve the application of any other treatment) was compared with the combined mean of all treatments in the full factorial design (soybean and maize with combinations of Microgeo and Supergan), including an analysis of interaction effects within the factorial model. Mean comparisons were conducted using the Scott-Knott method, with a significance level of 5%. All the analyses were performed with the R software (R Core Team, Vienna, Austria), using the packages MASS (Venables and Ripley, 2002) and ExpDes (Ferreira *et al.* 2018).

Greenhouse experiment

A greenhouse experiment was conducted in Londrina, Paraná State (23°21'20.0" S 51°09'58.2" W, 610 m) to assess the host reaction of sorghum cv. AGRI 002E to *M. incognita* and *M. javanica*. The experiments were arranged in a completely randomized design with two treatments (sorghum and standards) with eight replicates. The experiment was conducted twice. The inoculum consisted of pure populations of *M. incognita* and *M. javanica*, identified using α-esterase phenotypes (Carneiro *et al*., 2000) and morphological approaches (Hartman and Sasser, 1985). These populations were maintained on tomato (*Solanum lycopersicum*) cv. Santa Clara under greenhouse conditions.

Seeds of sorghum cv. AGRI 002E, and the susceptible standards for *M. javanica* and *M. incognita* - okra (*Abelmoschus esculentus*) cv. Santa Cruz and cotton (*Gossypium hirsutum*) cv. FM 975, respectively - were directly sown in 945 cm^3-capacity Styrofoam pots, containing a sterilized (160ºC/5 hr) substrate (80% sand, 15% clay, 5% silt)

A suspension obtained by extracting nematode from tomato roots by the Boneti and Ferraz methodology (Machado and Silva, 2019) containing 1,000 eggs (initial population density; Pi) was poured into two 2 to 4 cm deep holes in the soil beside the root system of 10-day-old seedlings. Plants were fertilized once, at sowing, with 3 g of Osmocote Plus (15% N, 9% P_2O_5, 12% K_2O, 1% Mg, 2.3% S, 0.05% Cu, 0.45 % Fe, 0.06% Mn, 0.02% Mo) per plant.

The final population density (Pf) was evaluated 60 days after inoculation (DAI). Pots were immersed in a bucket with 4 L of water to separate roots from soil. Roots were washed, cut into 1-cm pieces, and fresh weight was determined. The entire root system was then processed for nematode extraction by blender-sieving methodology (Machado and Silva, 2019). The Pf was estimated by counting eggs and juveniles using a Peter´s slide. The reproduction factor (RF) was calculated as RF = Pf/Pi (initial population density). The reaction of sorghum cv. AGRI 002E was classified according to Oostenbrink (1966), where RF values higher than 1.0 = susceptible, and RF values lower than 1.0 = resistant. Additionally, the number of nematodes per gram of root was calculated. Neither variable was analyzed using statistical approaches since the response was characterized by the Oostenbrink (1966) classification system.

RESULTS

Previous sampling indicated homogeneity in *M. incognita* distribution among the experimental plots, as no significant differences were observed between plots (Table 1). Additionally, there were no differences in nematode population densities 60 days after soybean plant emergence (Table 1). Soybean yields did not significantly differ between plots treated with organic fertilizers and control plots (Table 1). Following the soybean crop, maize and sorghum, grown in rotation, were sampled 60 days after plant emergence (Table 2). Again, no significant differences in *M. incognita* population densities in soil and roots were observed between treatments.

The application of organic fertilizers Microgeo and Supergan did not lead to reductions in *M. incognita* population densities in both soybean/maize and soybean/sorghum rotations compared to control plots (Tables 1 and 2). Moreover, soybean and maize yields were not positively affected by the use of organic fertilizers (Tables 1 and 3).

Table 1. *Meloidogyne incognita* population densities in soil (50 cm^3) and roots (per gram) of soybean collected prior to establishing the experiment and at 60 days after the emergence of plants and yield of soybean.

Rotation	Initial population density	Population density 60 days after planting	Yield (kg/ha)
Soybean/Maize + Supergan	139 a[y]	331 a	1,740 a
Soybean/Maize + Microgeo	79 a	113 a	1,320 a
Soybean/Maize	113 a	99 a	1,320 a
Soybean/Sorghum + Supergan	96 a	279 a	1,380 a
Soybean/Sorghum + Microgeo	106 a	120 a	1,560 a
Soybean/Sorghum	144 a	225 a	1,020 a
Crotalaria spectabilis/Maize[z]	201 a	-	-

[y] Mean values from four replicates. Means followed by the same letter in the columns did not differ at the 5% significance level, according to Scott-Knott Test.

[z] This was considered the additional treatment in the factorial analysis conducted.

Table 2. *Meloidogyne incognita* population present in soil (50 cm^3) and roots (per gram) collected in maize and sorghum plants at 60 days from the emergence of plants.

Rotation	Soil	Root
Soybean/Maize + Supergan	947 a[z]	36 a
Soybean/Maize + Microgeo	342 a	20 a
Soybean/Maize	1072 a	21 a
Soybean/Sorghum + Supergan	799 a	24 a
Soybean/Sorghum + Microgeo	974 a	25 a
Soybean/Sorghum	1210 a	9 a

[z] Mean values from four replicates. Means followed by the same letter in the columns did not differ at the 5% significance level, according to Scott-Knott Test.

Table 3. Effect of the combination of crops in the grain production (yield) of maize (kilograms per hectare).

Treatment	Yield
Soybean/Maize + Supergan	2,160 a[y]
Soybean/Maize + Microgeo	2,160 a
Soybean/Maize	2,280 a
Crotalaria spectabilis[z]	3,180 b

[y] Mean values from four replicates. Means followed by the same letter in the columns did not differ at the 5% significance level, according to Scott-Knott Test.

[z] Additional treatment.

Nematodes were also sampled at 60 days after maize plant emergence, cropped in rotation with *C. spectabilis* (Table 4). In the maize rotation with *C. spectabilis, M. incognita* population densities were significantly lower compared to plots cropped with soybean (Table 4). Additionally, maize yields in plots with soybean/maize + Supergan, soybean/maize + Microgeo, and soybean/maize were significantly lower than those obtained in plots cropped with *C. spectabilis/*maize (Table 3).

Detailed production costs and incomes for each treatment in soybean and maize are provided in Table 5. It was observed that the combination of crops and the application of organic fertilizers, as observed in control plots, did not yield economic returns in the analyzed crop seasons, with no significant differences between treatments. It was noted that production costs and accumulated yields in the 2019-2020 crop season were lower for plots where *C. spectabilis* was cropped. Despite lower yields, as only maize production was considered, the income loss was lower than in other treatments (Table 6).

In the greenhouse experiments (Table 7), using the Oostenbrink´s classification system, sorghum cv. AGRI 002E was classified as susceptible to *M. incognita* and *M. javanica* with RF values higher than 1.0. In the standard plants, okra and cotton, RF values were greater than 1 for both nematodes confirming the viability of the inocula and the adequacy of experimental conditions.

DISCUSSION

The distribution of plant-parasitic nematodes in a field often exhibits an uneven pattern, commonly characterized by aggregation (Ferraz and Brown, 2016). In the current field study, the homogeneous distribution of *M. incognita* allowed for the proper randomization of treatments, with all treatments being applied to plots with high *M. incognita* infestation levels.

The crop rotations evaluated in this study mirror the practices employed by Brazilian farmers across different regions. However, due to the wide prevalence of *M. incognita*, an increase in nematode population densities is expected in these rotations, as the crops are susceptible to *M. incognita*. Our study confirmed this expectation. Furthermore, certain organic fertilizers recommended for reducing nematode population densities in infested fields, which were tested in our study, were found to be ineffective when applied only once. The incorporation of organic fertilizers has the potential to enhance soil microbiome biodiversity, potentially leading to pest and disease suppression. This is achieved through mechanisms such as competition for food sources, plant defense responses via mycorrhizal colonization, and improvements in crop nutritional status (Marschner, 2012). However, in our study, we did not observe these effects. This could be attributed to the severe degradation of the soil and the level of *M. incognita* infestation. Additionally, the application of these fertilizers only once may not have been adequate to realize increases in yield under these conditions.

In a field experiment using Microgeo on soybean plants infested with *Heterodera glycines*, it was observed that applying this product preventively at a dosage of 150 L/ha after soybean emergence resulted in reductions in *H. glycines* densities in soybean roots (Microgeo, 2019). Conversely, in a similar experiment conducted in a field naturally infested with *P. brachyurus, Meloidogyne* sp., and *Helicotylenchus dihystera,* no reductions in population densities were observed, consistent with our findings. However, soybean yields were increased by 11% compared to control plants (Microgeo, 2019). The production of the organic fertilizer, Microgeo, is done locally using bovine residuals produced on the farm. Therefore, the diversity of microorganisms present in each batch can vary considerably, leading to inconsistent results and yield improvements (Microgeo, 2019).

A significant reduction in *M. incognita* population densities by *C. spectabilis* was observed, leading to the subsequent maize crop being exposed to lower densities of *M. incognita*. This led to higher maize yields in these plots, confirming the benefits of *C. spectabilis* in enhancing the yield of certain crops, such as soybean, primarily due to its ability to improve soil physical, chemical, and biological characteristics, as well as to reduce nematode densities (Tanaka *et al*., 1992; Wang *et al*., 2002; Inomoto *et al*., 2008).

Different species of *Crotalaria* have been extensively studied for nematode management, with *C. spectabilis* standing out for its positive outcomes in managing *M. incognita, M. javanica*, and *P. brachyurus* (Wang *et al*., 2002). Traditionally, these plants are used in summer crop rotations. However, there is considerable resistance among growers to incorporate *Crotalaria* spp. into their production system due to economic

Table 4. Effect of the combination of crops and biologic fertilizers (factorial treatment) and *Crotalaria spectabilis* (additional treatment) on *Meloidogyne incognita* population densities present in soil (50 cm^3) and roots (per gram) at 60 days from the emergence of maize and sorghum plants.

Treatment[x]	Soil	Root
Factorial	890 a[y]	22 a
Additional[z]	79 b	14 b

[x] Factorial treatment is a combined analysis of the different crop rotations using soybean followed by sorghum and/or maize.

[y] Mean values from four replicates. Means followed by the same letter in the columns did not differ at the 5% significance level, according to Scott-Knott Test.

[z] Additional treatment = *Crotalaria spectabilis* followed by maize.

Table 5. Costs and yields of soybean and maize in 2019-2020.

	Check		Microgeo		Supergan		*Crotalaria spectabilis*	
Treatment	Soybean	Maize	Soybean	Maize	Soybean	Maize	Soybean	Maize
Cost US$/ha	557.33	422.18	600.52	465.37	591.43	452.51	100.19	422.18
Cost sack/ha	38.87	47.85	41.88	52.74	41.25	51.28	6.99	47.85
Yield sack/ha	19.5	38.3	24.35	36.1	26.15	38.4	0	53.7
Yield US$/ha	279.59	337.94	349.13	318.53	374.94	338.82	-	473.82
Income sack/ha	- 19.37	- 9.55	- 17.53	- 16.64	- 15.10	- 12.88	-6.99	5.85
Income US$/ha	-277.73	- 84.24	-251.39	-146.85	-216.48	-113.68	-100.18	51.64

Costs were estimated through the value of the products and machine-hour used to plant, maintain, and harvest the crops. The value of a sack of grain was obtained at selling (R$ 78.00 and R$ 48.00 to 60 kg sack of soybean and maize, respectively). US$ = 5.44.

Table 6. Accumulated costs and yields of soybean and maize in 2019-2020.

Treatment	Check	Microgeo	Superbac	*Crotalaria spectabilis*
Cost US$/ha	979.50	1,065.90	1,043.93	522.36
Yield US$/ha	617.53	667.66	713.77	473.82
Income US$/ha	- 361.97	- 404.30	- 330.17	- 48.54

Costs were estimated through the value of the products acquired and machine-hour used to plant, grow, and harvest soybean and maize. US$ = 5.44.

Table 7. Reproduction factor (RF = final population density/initial population density) of *Meloidogyne incognita* and *M. javanica* and number of nematodes per gram of roots of sorghum AGRI 002E.

	RF		Nematodes/g root	
Nematode	Standard	Sorghum	Standard	Sorghum
Meloidogyne incognita	30.0	15.1	5,527	105
Meloidogyne javanica	182.7	9.5	7,042	204

Values are means of 8 replicates. Values are only descriptive of the host reaction of the genotype to the nematodes.

constraints. In our study, we found that replacing soybean with *C. spectabilis* brings benefits to nematode management and maize yields. Consequently, despite the absence of soybean yield, the reduced investment in plots cultivated with *C. spectabilis*, coupled with the higher maize yield in rotation, resulted in lower economic losses when *C. spectablilis* was grown compared to soybean. Thus, when the *M. incognita* infestations are severe, it may be more economically viable for growers to substitute soybean with *C. spectabilis* for one season.

Cover crops are also often used in rotation with soybean to reduce nematode population densities, provide mulch in no-tillage systems, and diversify crop rotation. In certain regions of Brazil where no-tillage is practiced, pearl millet is a common cover crop. However, in cooler temperatures, pearl millet growth can be slow. In such cases, sorghum is preferred due to its early maturity, hardiness, and drought resistance, allowing for the production of quality mulch in approximately 30 days (Duarte *et al.*, 2007).

The susceptibility of pearl millet and sorghum genotypes to nematodes varies, and this should be considered when choosing which cultivar to plant. In our study, sorghum cv. AGRI 002E was found to be susceptible to both *M. incognita* and *M. javanica* in greenhouse experiments. Therefore, planting this sorghum genotype in areas infested with these species should be avoided. Inomoto *et al.* (2008) also noted that grain sorghum genotypes were poor hosts for *M. javanica* compared to forage genotypes, which aligns with our findings.

The benefits of cover crops and soil microbial restructuring are well-documented in the literature, especially following periods of intensive soil use and chemical fertilizer application, which have depleted many soils in Brazil (Duan *et al.*, 2022; Gao *et al.*, 2022). It is crucial to adopt systems that ensure debris remains in the soil for an adequate period to support the establishment of the next crop.

Our economic analysis revealed that maize yields were negatively impacted by high population densities of *M. incognita*, especially when planted after soybean, resulting in significant economic losses. Therefore, adopting sustainable cropping systems with rotation and conservation practices is essential for managing and improving yields in nematode-infested areas.

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