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Organic residue controls *Meloidogyne javanica* and improves gas exchange and development in the gilo[1]

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ABSTRACT - Root-knot nematodes cause a significant reduction in the productivity of the gilo due to physiological stress. Incorporating organic residue into the soil has a positive effect in reducing nematode infestation. The aim of this study was to evaluate the effect of the addition of organic residue on the reproduction of *Meloidogyne javanica* and its role in the physiology of the gilo. One-litre pots, each containing one gilo seedling, were inoculated with 5000 eggs of *M. javanica* and the following treatments evaluated: 1) no inoculation and no residue (NIR); 2) NIR; 3) 12.5 g L^{-1} poultry manure; 4) 25 g L^{-1} cattle manure; 5) 20 g L^{-1} filter cake; 6) 5 g L^{-1} of the shoots of *Tagetes patula*; 7) 6.25 g L-1 of the shoots of *Brassica oleracea* var. *capitata*; 8) 20 mL L^{-1} vinasse and 9) 1 mL Abamectin-based commercial product (18 g L^{-1} a.i.). A randomised block design was used, with six repetitions. Gas exchange variables were evaluated 15, 30 and 45 days after inoculation with the nematode (DAI) and the vegetative and nematological variables at 60 DAI. The treatments that included cattle manure and filter cake afforded the best physiological rate and development in the gilo. The best results in controlling the nematode were given by the poultry manure, cattle manure and filter cake, reducing the reproduction of *M. javanica* by 41.76, 51.44 and 52.40%, respectively. Based on the results, poultry manure, cattle manure and filter cake are efficient in controlling *M. javanica* and show potential to be used in the integrated management of *M. javanica* in the gilo.

Key words: Poultry manure. Cattle manure. Root-knot nematode. *Solanum aethiopicum* gr. *Gilo*. Filter cake.

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INTRODUCTION

In Brazil, cultivation of the gilo (*Solanum* aethiopicum gr. gilo) is widespread, especially on small rural properties, as it is easy to grow and is highly profitable. The fruit is appreciated for its bitter taste and is rich in protein, phosphorus, calcium and iron, and vitamins A, B and C (PINHEIRO *et al*., 2015). Production in Brazil is around 93 thousand tons yr^{-1}, concentrated in the states of Minas Gerais and Rio de Janeiro, with a mean productivity of 30 tons ha^{-1} (IBGE, 2017).

Among the main factors that can reduce productivity in the gilo, the root-knot nematode, genus *Meloidogyne*, deserves special attention. After penetrating the roots, the nematode causes physical, biochemical and physiological damage to the plant as a result of the infestation (ABAD *et al*., 2003). These changes interfere with nutrient absorption, gas exchange, photosynthesis, respiration and the metabolism in general (STRAJNAR *et al*., 2012) with a reduction in development and productivity; presence of the nematode can even lead to the activity being abandoned due to high infestation in the area (NOLING, 2012).

Losses in gilo productivity caused by the root-knot nematode vary from 15% to 20% and may reach 100%. In Brazil, the most harmful and widespread species in areas of gilo cultivation are *M. incognita* and *M. javanica* (PINHEIRO, 2017).

Incorporating organic residue into the soil is an excellent option, offering beneficial effects, especially in the medium and long term. These effects include a greater supply of nutrients, lower rate of volatilisation and nitrogen leaching, improved water retention capacity, an increase in the beneficial microbial population, and suppression of phytopathogen populations (DALORIMA; SAKIMIN; SHAH, 2021). In controlling nematodes, incorporating organic residue into the soil releases toxic compounds during decomposition and stimulates the population of antagonistic fungi and bacteria in the soil (HERNANDES *et al*., 2020; McSORLEY, 2011).

The sugar-energy sector has expanded a lot in recent decades in Brazil and is expected to continue to grow over the coming years. The most important residues from sugarcane processing are filter cake and vinasse due to their significant concentrations of organic matter and their use in agriculture (PRADO; CAIONE; CAMPOS, 2013). Green manure, such as *Crotalaria*, velvet beans, the marigold and *Brassicae*, and animal waste, such as cattle, pig and poultry manure play a notable role in agriculture, especially as they supply the crops with substantial nutrients and add organic matter to the soil (ISLAM *et al*., 2019).

In today's third-millennium agriculture, in addition to studying their role in plant physiology, the search for alternative and more sustainable measures to control nematodes is fundamental. The aim of this study, therefore, was to evaluate the addition of different organic residues on the control of *Meloidogyne javanica* and the vegetative development and physiological responses of the gilo.

MATERIAL AND METHODS

The Meloidogyne population used in the study came from the roots of the 'Santa Cruz Kada' tomato. The species was identified using esterase phenotype isoenzyme electrophoresis (ITO *et al*., 2019), which confirmed *M. javanica* (EST phenotype = J3). Ten females and their respective egg masses were then extracted, transferred to 1-L plastic pots containing a 2:1 mixture (v v^{-1}) of soil and sand previously autoclaved (2 h at 120ºC) and multiplied for 60 days in seedlings of the gilo.

The method proposed by Boneti and Ferraz (1981) was used for extracting the eggs and possible second-stage juveniles (J2). The suspension resulting from the extraction was quantified using a Peters counting chamber under a photonic microscope at 100X magnification, calibrated for 1000 eggs + J2 per mL.

The experiment was conducted in a greenhouse with a controlled internal temperature of 25 ± 2 ºC and a relative humidity of 60%. The daily irrigation depth was 2.5 mm, applied by automatic micro sprinkler and divided into three applications, each of two minutes, in order to maintain the soil at 60% to 80% of field capacity.

The results of the analysis of the substrate mixture, dystrophic Red latosol and sand in the ratio of 2:1 (v v^{-1}) were as follows: 0 $cmol_c.dm^{-3}$ Ca; 0.3 $cmol_c.dm^{-3}$ Mg; 0 $cmol_c.dm^{-3}$ Al; 1.5 $cmol_c.dm^{-3}$ H; 0 $mg.dm^{-3}$ K; 0.954 $mg.dm^{-3}$ P; 3.4 $mg.dm^{-3}$ Cu; 25.5 $mg.dm^{-3}$ Fe; 10.3 $mg.dm^{-3}$ Mn; 4.3 $mg.dm^{-3}$ Zn; 437.6 $g.kg^{-1}$ clay; 60 $g.kg^{-1}$ silt and 502.4 $g.kg^{-1}$ sand. The soil was corrected to a base saturation of 70%. Fertilisation was carried out using 100-200-160 kg ha^{-1} N-P-K divided into three applications. Transplanting was at 15 and 30 days.

The organic residue was incorporated into the soil and incubated for three days. The vinasse and the nematicide treatments, as they are post-emergent, were applied 10 days after transplanting the seedlings. Following the incubation period, one seedling of the 'Morro Grande Verde Escuro' cultivar of the gilo, 20 days old and with two pairs of leaves, was transplanted into a 1-L plastic pot containing the 2:1 (v v^{-1}) mixture of soil and sand, previously sterilised in an autoclave (2 h at 120 °C). Three days after transplanting, the soil was inoculated with 5000 eggs + possible J2 of *M. javanica* in four holes, 2 cm deep, around the collar of the plant using an automatic pipette (5 mL). In order to avoid leaching of the eggs, irrigation during the first week was carried out manually with great care using a 100 mL beaker.

The trial was set up in a randomised block design with six repetitions. The following treatments were added: 1) no nematodes and no residue (control 1); 2) no residue (control 2); 3) 12.5 g L^{-1} poultry manure; 4) 25 g L^{-1} cattle manure; 5) 20 g L^{-1} sugarcane filter cake; 6) 5 g L^{-1} of the shoots of *Tagetes patula*; 7) 6.25 g L^{-1} of the shoots of *Brassica oleracea* var. *capitata*; 8) 20 mL L^{-1} sugarcane vinasse; and 9) 1 mL Abamectin-based commercial product (18 g L^{-1} a.i.) (positive control). The treatments were chosen by horticulturists in the region according to the accessibility of the materials. The dose of each treatment was determined based on pre-tests and also on literature related to the use of residue for plant nutrition and the suppression of nematodes.

Gas exchange was evaluated using an infrared gas analyser (IRGA LI-6800, LI-COR Inc., Lincoln, NE, USA) 15, 30 and 45 days after inoculating the soil with *M. javanica*. The following variables were analysed: *E* = transpiration rate (mmol m^{-2} s^{-1}); *A* = photosynthetic rate (µmol m^{-2} s^{-1}); and gsw = Stomatal conductance (mol mm^{-2} s^{-1}). Finally, the *Ci/Ca* ratio (µmol mol^{-1}) was calculated, where *Ci* is the internal CO_2 concentration and *Ca* the external CO_2 concentration. Measurements were taken on the second pair of fully expanded leaves from the apex of the plant, on sunny, cloudless days, from 08:00 to 11:00, considering a constant photon flux density of 1500 µmol m^{-2} s^{-1}, relative humidity of 50% and CO_2 concentration of 400 µmol mol^{-1}. The temperature in the chamber was kept at 25 °C.

Sixty days after inoculating the soil in the pots with *M. javanica*, the following variables were evaluated: plant height, root fresh matter, shoot dry matter, number of galls and number of eggs + J2 per root system. Finally, the nematode reproduction factor was calculated (RF= Pf/Pi), where Pf is the final population and Pi is the initial population (OOSTENBRINK, 1966).

The data were submitted to analysis of variance and the mean values compared using the Scott-Knott test ($p \leq 0.05$); the Singh criterion (1981) was also used to quantify the relative contribution of each variable. The variables were then submitted to linear correlation by t-test at 5% significance to determine the trend of the association. Finally, the principal component biplot method was used to visualise the overall variability of the experiment and multivariate trends. The analyses were carried using the R v3.5.3 statistical software. (R CORE TEAM, 2019).

RESULTS AND DISCUSSION

There was no significant difference ($P > 0.05$) in the results of evaluating gas exchange in the gilo 15 days after infestation with M. javanica. However, there was a difference ($P \leq 0.05$) in the evaluations made 30 days after infestation, where the treatments with cattle manure and filter cake showed the highest rates of transpiration (89.25% and 99.79%), photosynthesis (55.64% and 98.15%) and stomatal conductance (136.67% and 156.67%), respectively, compared to control treatment 1 (Table 1).

Table 1 - Mean values of gas exchange variables in the gilo, analysed with an infrared gas analyser 15, 30 and 45 days after soil infestation with 5000 eggs + J2 of *Meloidogyne javanica*

Gas exchange data				
- 15 days -				
Treatment	E	A	Ci/Ca	gsw
Control 1	8.59	12.79	0.88	0.60
Control 2	7.89	11.89	0.86	0.55
Poultry manure	8.54	14.57	0.86	0.59
Cattle manure	8.77	15.18	0.86	0.62
Filter cake	9.32	11.33	0.89	0.66
T. patula	8.08	10.80	0.88	0.59
B. oleracea	8.71	13.78	0.86	0.58
Vinassa	7.18	10.95	0.86	0.49
Nematicide	4.21	5.97	0.85	0.29
CV (%)	33.04	32.07	4.55	42.15

Continuation Table 1

Treatment	E	A	Ci/Ca	gsw
- 30 days -				
Control 1	4.93 b	10.28 b	0.82	0.30 b
Control 2	4.87 b	7.56 b	0.85	0.31 b
Poultry manure	6.25 b	12.13 b	0.81	0.44 b
Cattle manure	9.33 a	16.53 a	0.86	0.71 a
Filter cake	9.85 a	20.37 a	0.83	0.77 a
T. patula	3.96 b	8.31 b	0.82	0.23 b
B. oleracea	5.26 b	8.08 b	0.84	0.33 b
Vinassa	4.80 b	9.61 b	0.81	0.29 b
Nematicide	6.89 b	12.25 b	0.84	0.48 b
CV (%)	43.07	28.33	6.39	53.45
- 45 days -				
Treatment	E	A	Ci/Ca	gsw
Control 1	4.05	10.24 a	0.77	0.25
Control 2	3.69	6.05 b	0.83	0.22
Poultry manure	7.16	14.39 a	0.81	0.49
Cattle manure	3.43	8.63 a	0.74	0.23
Filter cake	4.06	13.25 a	0.70	0.26
T. patula	2.42	6.52 b	0.77	0.14
B. oleracea	2.77	3.65 b	0.81	0.17
Vinassa	3.71	9.85 a	0.78	0.22
Nematicide	3.61	10.56 a	0.77	0.22
CV (%)	56.40	40.30	11.01	67.63

Mean values followed by the same letter in a column do not differ significantly at 0.05 probability by Scott-Knott test. Control 1: no nematodes and no residue; Control 2: no residue; CV = coefficient of variation; *E* = transpiration (mmol m^{-2} s^{-1}); *A* = photosynthesis (μmol m^{-2} s^{-1}); *Ci* = internal CO_2 concentration (μmol mol^{-1}); *Ca* = external CO_2 concentration (μmol mol^{-1}); gsw = stomatal conductance (mol m^{-2} s^{-1})

The evaluations carried out 60 days after inoculation with the nematode showed that the treatments with cattle manure and filter cake had a positive effect on plant height (8.88% and 18.38%), shoot dry matter (54.24% and 91.50%) and root fresh matter (147.95% and 141.53%), respectively, in relation to control treatment 1 (Table 2).

With the variables related to nematode reproduction, it was found that, for the number of eggs + J2 in 10 grams of roots, the treatments comprising poultry manure, cattle manure and filter cake were more efficient in controlling *M. javanica*, reducing reproduction by 41.76%, 51.44% and 52.40%, respectively, in relation to control 2 (Table 2).

Up to 15 days after inoculating the soil with *M. javanica*, there was no significant affect on the physiological variables of the gilo, which shows that at this stage of infestation, the nematode did not interfere in the photosynthesis or transpiration of the plant.

The higher rates of transpiration and photosynthesis seen in the treatments with cattle manure and filter cake are probably related to greater stomatal conductance. These treatments also afforded the greatest vegetative development, and the lowest reproductive rate in the nematode, showing a positive correlation (Figure 1) with control of the nematode by the organic residue, and making the plants more tolerant to parasitism by *M. javanica*.

Ten pairs of significant correlations were identified using Pearson correlation analysis. Of these, 81.25% were positive and 18.75% negative. The highest-magnitude correlations were observed for E+J2 x RF (1.00) and E x GSW (0.99) (Figure 1). The results of the correlation reflected the number of galls induced by the nematode and its reproduction, confirmed by the number of eggs, i.e. the more galls, the greater the number of eggs in the roots of the gilo infected by *M. javanica*. Whereas the higher the reproductive rate of *M. javanica*, the lower the values of the vegetative variables of the gilo, such as root dry matter (RDW), confirming the harmful effect of nematode parasitism on the plant.

According to the Singh criterion (1981), the characteristics that most helped differentiate the treatments under study were: plant height (PH), shoot dry matter (SDM), number of eggs + second-stage juveniles (J2) per 10 g of roots (E+J2/r) and the ratio between *Ci*, the internal CO_2 concentration (μmol mol^{-1}) and *Ca*, the external CO_2 concentration, (Ci/Ca) which accounted for 47.23% (Figure 2).

In the multivariate analysis, the first two principal components captured 75% of the total variation in the data. It can be seen that the treatment including filter cake increased the mean value for root fresh matter (RFM), while the cattle manure increased the mean value for plant height (PH). It can also be seen from Figure 3 that the addition of vinasse to the soil caused a reduction in the number of galls (NG) induced in the root system of the gilo by the *M. javanica* infestation.

The Pearson correlation analysis showed a negative correlation between the reproduction factor (RF) of *M. javanica* in the gilo and the variables related to plant development, i.e. the higher the reproductive rate of the nematodes, the lower the values of the vegetative variables. The M. javanica infestation of the gilo had a negative effect

Table 2 - Mean values of vegetative and nematological variables in the gilo at 60 days after soil inoculation with 5000 eggs + J2 of *Meloidogyne javanica*

Vegetative data			
Treatment	PH	SDM	RFM
Control 1	26.33 b	1.53 c	7.32 b
Control 2	22.00 c	1.04 c	6.64 b
Poultry manure	19.67 c	1.33 c	10.17 b
Cattle manure	28.67 a	2.36 b	18.15 a
Filter cake	31.17 a	2.93 a	17.68 a
T. patula	22.50 c	1.16 c	7.89 b
B. oleracea	23.83 c	0.93 c	7.10 b
Vinassa	23.50 c	1.28 c	7.67 b
Nematicide	26.33 b	1.33 c	8.21 b
CV (%)	12.16	21.00	28.88

Nematological data					
Treatment	NG	NO + J2	NO + J2/r	PRR (%)	RF
Control 1	-	-	-	-	-
Control 2	398	50294	76050 b	-	10.06
Poultry manure	329	44407	44288 a	41.76	8.88
Cattle manure	359	61807	36926 a	51.44	12.36
Filter cake	371	63507	36202 a	52.40	12.70
T. patula	451	50550	67436 b	11.33	10.11
B. oleracea	405	50836	72817 b	4.25	10.17
Vinassa	451	44043	55617 b	26.87	8.81
Nematicide	271	51774	64412 b	15.30	10.35
CV (%)	36.67	37.24	42.08	-	-

Mean values followed by the same letter in a column do not differ significantly at 0.05 probability by Scott-Knott test. Control 1: no nematodes and no residue; Control 2: no residue; CV = coefficient of variation; PH= plant height (cm); SDM = shoot dry matter (g); RFM = root fresh matter (g); NG = number of galls; NO + J2 = number of eggs + second-stage juveniles (J2); NO + J2/r= NO + J2 per 10 grams of roots; PRR = percentage reduction in nematode reproduction compared to control 2; RF = reproduction factor on vegetative development, in addition to compromising the vital functions linked to physiological responses. Upon invading the roots, the root-knot nematodes migrate between cells to a region close to the vascular cylinder, where they establish a feeding site; during migration they cause disruption of the parenchyma cells and vascular tissue (ABAD *et al*., 2003). Hypertrophy also occurs, the formation of giant cells at the feeding site, associated with cell hyperplasia, the disorderly multiplication of cells; in addition, the body of the female hinders the flow of water and nutrients (VILELA *et al*., 2019). These changes interfere with many physiological and biochemical processes related to nutrient absorption, gas exchange, photosynthesis, respiration and the metabolism in general (STRAJNAR *et al*., 2012).

There was a drastic reduction in the rates of transpiration, photosynthesis and stomatal conductance in gilo plants infested by *M. javanica*; similar results to those reported in tomato plants inoculated with *M. ethiopica*, in which there was a reduction in water potential with a consequent reduction of 60% to 70% in stomatal conductance and photosynthetic rate due to the

Figure 2 - Relative contribution of the vegetative, physiological and nematological variables (%) to divergence in the gilo x *M. javanica* interaction as a function of the treatments with the organic residue. *E* = transpiration (mmol m^{-2} s^{-1}); *A* = photosynthesis (μmol m^{-2} s^{-1}); *Ci* = internal CO_2 concentration (μmol mol^{-1}); *Ca* = external CO_2 concentration (μmol mol^{-1}); gsw = stomatal conductance (mol m^{-2} s^{-1}); PH= plant height (cm); SDM = shoot dry matter (g); RFM = root fresh matter (g); NG = number of galls; E + J2 = number of eggs + second-stage juveniles (J2); E + J2/r = E + J2 per 10 grams of roots; RF = reproduction factor

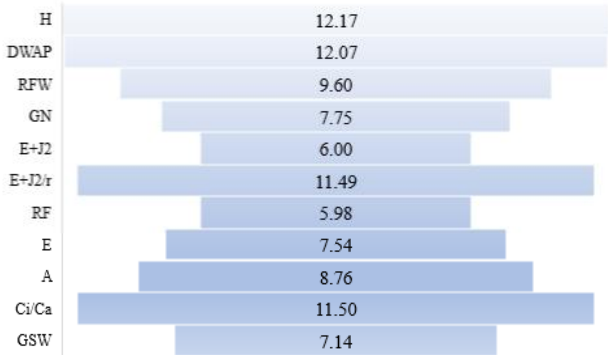


Figure 1 - Phenotypic correlations of the characteristics of the gilo x *M. javanica* interaction as a function of the treatments with organic residue. *E* = transpiration (mmol m^{-2} s^{-1}); *A* = photosynthesis (μmol m^{-2} s^{-1}); *Ci* = internal CO_2 concentration (μmol mol^{-1}); *Ca* = external CO_2 concentration (μmol mol^{-1}); gsw = stomatal conductance (mol m^{-2} s^{-1}); PH= plant height (cm); SDM = shoot dry matter (g); RFM = root fresh matter (g); NG = number of galls; E + J2 = number of eggs + second-stage juveniles (J2); E + J2/r = E + J2 per 10 grams of roots; RF = reproduction factor. Significance: * 5% probability; **1% probability by t-test

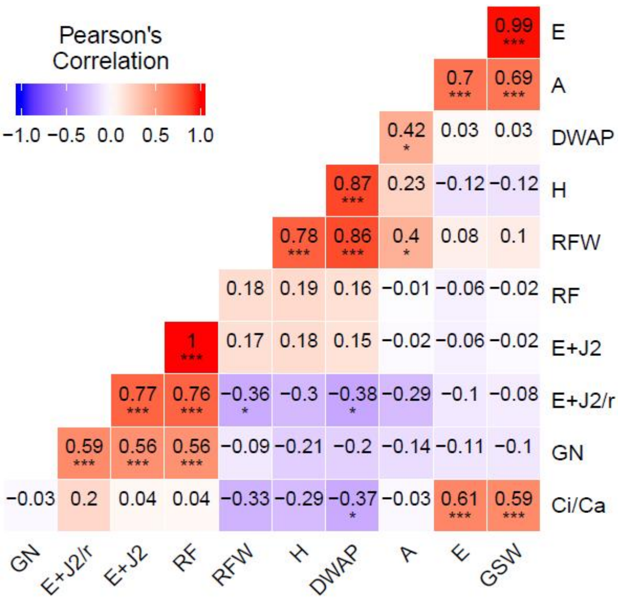
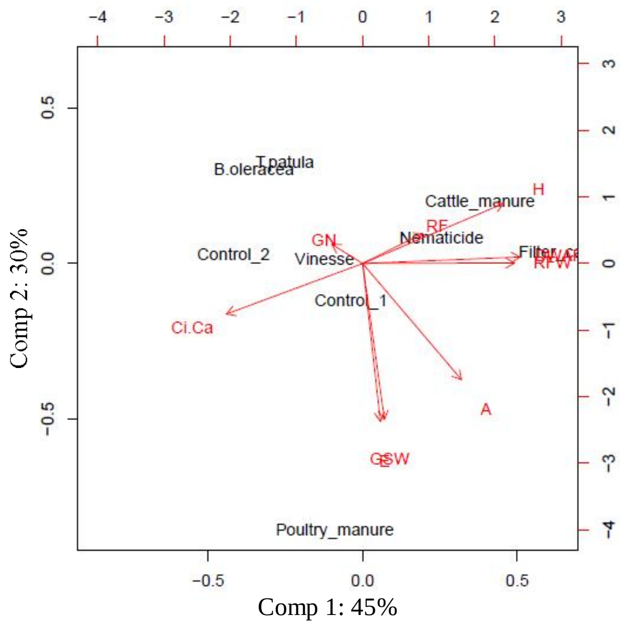


Figure 3 - Principal component analysis applied to the variables of the gilo x *M. javanica* interaction as a function of the treatments with organic residue. E = sweating (mmol m-2 s-1); A = photosynthesis (μmol m-2 s-1); Ci = internal concentration of CO_2 (μmol mol-1); Ca = external concentration of CO_2 (μmol mol-1); gsw = Stomatal conductance (mol m-2 s-1). H= plant height (cm); DWAP = shoot dry matter (g); RFM = root fresh matter (g); GN = number of galls; E+J2 = number of eggs + second-stage juveniles (J2); E + J2/r = E + J2 per 10 grams of root; RF = reproduction factor



nematode (STRAJNAR *et al*., 2012). It is known that CO_2 diffuses from the atmosphere to the carboxylation site of ribulose-1,5-bisphosphate carboxylase oxygenase (RuBisCo) via the stomata, and greater stomatal conductance reduces the stomatal limitations regulating photosynthesis (BELLASIO; QUIRK; BEERLING, 2018). Greater stomatal conductance promotes greater CO_2 uptake, increasing the internal CO_2 concentration and consequently, the *Ci/Ca* ratio. Photosynthesis responds to increases in *Ci* depending on the activity of RuBisCo and the regeneration of ribulose biphosphate (RuBP) (SHARKEY *et al*., 2007). In general, the greater the stomatal conductance, the greater the increase in photosynthesis, as it increases the amount of internal CO_2 available (GÁLVEZ *et al*., 2019).

In the treatment including nematode inoculation but without the application of organic residue, the high values of the Ci/Ca ratio, in contrast to the low photosynthetic rates, are probably related to non-stomatal limitations, such as the availability and kinetics of enzymes (BELLASIO; QUIRK; BEERLING, 2018). Reduced carboxylation leads to an accumulation of *Ci*, promoting stomatal closure and a reduction in transpiration. For this reason, one of the main symptoms observed in the gilo is wilting caused by stomatal closure.

The higher photosynthetic rates observed in the treatments with cattle manure and filter cake explain the increase in root and shoot biomass and plant length, as the conversion of light energy into biomass is driven by the extraction of electrons from the water molecule by photosynthesis (ZAVŘEL *et al*., 2018).

In the present study, the results showed no effect from incorporating 5 g L^{-1} of the shoots of *Tagetes patula* into the soil for three days to control *M. javanica* in the gilo. The compound caused a small reduction of 11.33% in the rate of nematode reproduction. Despite this, *T. patula* is considered an efficient antagonistic plant in reducing the reproduction of phytonematodes. The plant has a negative effect on the phytonematode population through the production of toxic compounds, such as α-tertienyl and its derivatives, albeit in greater quantities in the roots of the plant (HOOKS *et al*., 2010). This may explain the low level of suppression seen in the phytonematode population in the present study, as does the reduced time for incorporation into the soil, which was only three days before transplanting the gilo seedlings.

Incorporating 6.25 g L^{-1} of the shoots of *Brassica oleracea* var. *capitata* into the soil provided only 4.25% control over *M. javanica* in the gilo. However, in the tomato, Neves *et al*. (2007), incorporating 50 g L^{-1} of fresh *B. oleracea* material for biofumigation over 30 days, reported reductions of up to 61.3% in the population of *M. javanica*. During its decomposition, toxic compounds with nematicidal action are released, such as sulphur dioxide and glucosinolates, including thiocyanates, isothiocyanates, nitriles and epinitrils (FERRAZ *et al*., 2010; MCSORLEY, 2011; NEVES *et al*., 2007). The level of suppression of the *M. javanica* population in the present study, considered low, may be associated with the short time in the soil.

The use of 20 mL L^{-1} vinasse afforded 26.87% control of *M. javanica* in the gilo. According to Pedrosa *et al*. (2005), the suppressive effect of the residue on the populations of *M. javanica* and *M. incognita* in sugarcane was directly proportional to the volume of vinasse applied. The higher the dose, the lower the number of eggs and eclosion of second-stage juveniles. However, the effect of vinasse on shoot development was inversely proportional, causing phytotoxicity. The action of this residue on the phytonematode population is probably indirect, associated with the proliferation of natural enemies of the phytonematode, making it a viable means for multiplication (CARDOZO; ARAÚJO, 2011).

Incorporating 12.5 g L^{-1} poultry manure into the soil reduced the population of *M. javanica* in the gilo by 41.76%. In work carried out with the eggplant, the addition of 2.5 g L^{-1} poultry manure to the soil seven days before infestation with the nematode led to an 87.36% reduction in the reproduction of *M. incognita* (ABOLUSORO *et al*., 2015). This can be explained by the presence of ammonia, released during decomposition of the compound, having a plasmolytic effect on the nematode (MCSORLEY, 2011; SILVA *et al*., 2006). The lower percentage reduction in *M. javanica* in relation to this study can be attributed to the shorter period of incubation in the soil and the temperature in the greenhouse, since high temperatures and high soil humidity favour the mineralisation of organic matter (RAMÍREZ; MATOS, 2022).

In the present study, the incorporation of 25 g L^{-1} cattle manure suppressed 51.54% of *M. javanica* reproduction in the gilo. It is worth emphasising the role of this compound in increasing the variables related to photosynthesis and the vegetative development of the plant, increasing shoot dry matter by over 54% and root fresh matter by 147%. Other researchers found that incorporating 35 g L^{-1} cattle manure into the soil to manage *M. javanica* in the tomato caused an increase in shoot and root biomass and a reduction of more than 70% and 90% in the number of galls and nematode eggs, respectively (MACHADO *et al*., 2013). An increase in shoot biomass was also seen by Lopes *et al*. (2018) in the gilo, with a 48% increase when 40 g L^{-1} cattle manure was added to the soil and incubated for 20 days. Cattle manure results in an accumulation of organic nitrogen and increases the potential for mineralisation, in addition to increasing the availability of such nutrients as nitrogen, phosphorus and potassium (NPK), as well as several other macronutrients, such as Ca, B, Cu, Mn, Mg, S and Zn (DALORIMA; SAKIMIN; SHAH, 2021), thereby stimulating greater vegetative growth. Furthermore, during decomposition in the soil, compounds that are toxic to phytonematodes are released, such as humic acids, which can act directly on second-stage juveniles of the root-knot nematode (DIAS *et al*., 1999). These properties may explain the positive action of the residue seen in the present study.

The incorporation of 20 g L^{-1} filter cake into the soil reduced the population of *M. javanica* by 52.40%, in addition to an increase in physiological variables and the vegetative development of the plant. In sugarcane cultivation, incorporating 30 g L^{-1} filter cake into the soil when transplanting reduced the reproduction of *Meloidogyne* spp. by 53.16% (CHAVES *et al*., 2009). The application of filter cake in agricultural cultivation affords an increase in water retention capacity and nitrogen availability. This organic residue is also rich in calcium, phosphorus and iron, contributing to better nutritional status in the plants and a reduction in the phytonematode population.

Incorporating organic residue into the soil with the aim of controlling phytonematodes is a practice of recognised efficiency that has been used by farmers and researchers for some decades. The modes of action of organic matter in suppressing phytonematodes have been attributed to improvements in the soil structure, including a change in the pH, moisture and chemical and physical properties of the soil (DALORIMA; SAKIMIN; SHAH, 2021). As a result, there is an increase in the water retention capacity of the soil and an improvement in plant nutrition by the release of nutrients, especially nitrogen. Furthermore, the release of toxic compounds resulting from the decomposition of organic matter, such as phenolic compounds, ammonia and nitrite, helps reduce phytonematodes in the soil (MCSORLEY, 2011); this is well-known in the literature. the present study also showed that organic compounds reduce the biological stress caused by *M. javanica* parasitism in the gilo.

Organic matter stimulates multiplication of beneficial microorganisms, such as fungi and bacteria (POVEDA *et al*., 2019). Some of these microorganisms are parasites of phytonematodes, and compete for water, space and nutrients. Toxins can also be produced by microorganisms, with an adverse effect on the speed of activity, survival and population density of the phytonematodes. These beneficial antagonists can also promote plant growth and development (SUMMER, 2011). However, the type of organic residue, the amount incorporated into the soil, the degree of decomposition, the characteristics of the substrate and the pathosystem involved can all affect the level of phytopathogen suppression by the soil (HECK; GHINI; BETTIOL, 2019).

The use of organic residue is a good alternative in managing *M. javanica*. In third-millennium agriculture, the combined use of several control measures generally takes priority: the so-called integrated management of phytonematodes. This strategy enables the adoption of more-efficient control practices and seeks to provide better conditions for plant development, by which they become more tolerant and suffer less damage from phytonematode infestation.

In the present study, the use of cattle manure and filter cake stood out with good results on the physiology of the gilo, the accumulation of biomass and the suppression of nematode reproduction; poultry manure was also positive for this last variable. As such, they are seen as a good strategy for managing *M. javanica*, since they all afforded an increase in photosynthesis and stomatal conductance, as well as greater plant height and better shoot dry matter and root fresh matter development. The incorporation of 12.5 g L^{-1} poultry manure, 25 g L^{-1} cattle manure or 20 g L^{-1} filter cake into the soil is therefore recommended for the management of *M. javanica* in the gilo.

CONCLUSIONS

1. Infestation of the gilo by *M. javanica* has a negative effect on vegetative development, in addition to compromising the vital functions linked to physiological responses;
2. Cattle manure and filter cake reduce the stress caused by the nematode in the gilo; this can be seen by the greater responses for gas exchange and plant height, and shoot dry matter and root fresh matter accumulation in gilo plants infested by *M. javanica*;
3. In cultivating the gilo, poultry manure, cattle manure and filter cake suppress the population of *M. javanica* by 41.76%, 51.44% and 52.40%, respectively. The use of these organic residues for managing the nematode can therefore be recommended.

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