CORRELATIONS BETWEEN SOIL ATTRIBUTES AND THE OCCURRENCE OF NEMATODES AND GRAIN YIELD IN AN OFF-SEASON MAIZE CROP IN MATO GROSSO DO SUL

CORRELAÇÕES ENTRE OS ATRIBUTOS DO SOLO E A OCORRÊNCIA DE NEMATODES E PRODUTIVIDADE DE GRÃOS EM MILHO SAFRINHA EM MATO GROSSO DO SUL

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ABSTRACT: Systems of soil cultivation and use directly influence crop yield by interfering with the soil chemical, physical, and biological attributes. This study aimed to evaluate the correlation between maize grain yield, soil chemical and biological attributes, and the occurrence of nematodes in maize crops grown in the off-season, in the state of Mato Grosso do Sul. Soil samples from 21 off-season maize crops were collected in 2015. The samples were used to identify and quantify nematodes, determine biomass carbon and microbial activity, and for chemical analysis. The attributes were clustered based on the variables evaluated using the mean Euclidean distance and Ward's clustering method. The interrelationship between the variables was analyzed by correlations, and its unfolding in the cause and effect investigations was evaluated by the path analysis. Organic matter and microbial biomass carbon positively influence grain yield. Magnesium negatively influences the population of *Pratylenchulus* spp. in maize crops. The potential acidity and organic matter are related to the presence of *Rotylenchulus* spp.

KEYWORDS: Soil microbiology. Soil organic matter. Path analysis.

INTRODUCTION

Soil attributes are directly influenced by soil preparation. Thus, management systems and soil quality have a direct relationship with the soil physical, chemical, and biological attributes. Some technological methods are responsible for changes in soil attributes. Ribeiro et al. (2015) verified that cover crops, the use of smaller spacing between rows, intercropping, and larger plant populations increase grain yield in maize crops in the state of Mato Grosso do Sul. Most of these processes are influenced by the organic matter accumulation in the soil, leading to higher resistance to erosion, higher infiltration rate, and greater water retention in the soil. Also, it increases the cation retention capacity and the nutrient stock, adsorption and complexation of compounds, chemical elements cycling, atmospheric carbon sequestration, activity and diversity of the microbial population, and resistance to disturbances (VEZZANI, 2001). According to Vasconcellos et al. (1998), the concentration and activity of soil microorganisms, represented by the CO2 content in the soil and the mineralization of organic N, are influenced only by the quantity and quality of the organic residues added to the soil and the type of soil preparation.

Loss et al. (2012) state that soybean grown in succession to the fall-winter crops, such as off-season maize, *B. ruziziensis,* and maize - *B. ruziziensis* intercrop, increase the free fraction of soil organic matter, contributing to its redistribution on the subsurface. This result confirms one of the main objectives of the maize-brachiaria intercrop, which is the production of straw (in quantity and quality) for the no-tillage system (NTS) (ALMEIDA; FAVARIN, 2009), aiming at conditioning the soil for the subsequent crop. Almeida et al. (2008) state that soil managements not only alter the soil chemical, physical, and biological quality but also increase crop yield. These authors compared the effect of the no-tillage system and conventional soil preparation on some soil attributes. Their results revealed an increase in the organic matter content, pH, and maize grain yield in the no-tillage system.

Variations in the soil management system also influence the nematodes population density. Franchini et al. (2011) observed that the population density of *P. brachyurus* positively correlates with

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the potential soil acidity (H+Al). Therefore, crop development depends on soil management, considering that the latter influences all soil-related crops. In this context, this study aimed to evaluate the correlations between grain yield, soil chemical and biological attributes, and the occurrence of nematodes in maize crops in the state of Mato Grosso do Sul.

MATERIAL AND METHODS

Soil samples were collected in 21 maize crops grown in the 2015 off-season, and their agronomic aspects were described. The soil samples belonged to sole crop systems and maize-brachiaria intercropped systems installed in the municipalities of Nioaque, Maracajú, Sidrolândia, Rio Brilhante, Douradina, Dourados, Chapadão do Sul, São Gabriel do Oeste, Jutí, Naviraí, and Ponta Porã, in the state of Mato Grosso do Sul (Table 1).

Soil samples were collected from three points randomly determined in the area of each crop, at 0 to 20 cm depth, using a hoe. Afterward, samples were divided into three subsamples for soil chemical analysis, determination of microbial biomass carbon and microbial activity, and identification and quantification of nematodes.

To determine the grain yield, two five-meter rows were randomly selected in the sole and intercropped systems, and five ears were collected per sample. Grain yield was obtained in kg and then converted to kg ha^{-1}. Grain moisture was corrected to 13%.

Table 1. Maize crops sampled in Mato Grosso do Sul: Municipality, soil type, textural class, crop system, and climate.

Crop	Municipality	Soil type	Textural Class	Crop System	Climate[1]
F01	Nioaque	LVe	Average	Sole	AW
F02	Maracaju	LVef	Very clayey	Intercropped	AW
F03	Maracaju	LVef	Very clayey	Intercropped	AW
F04	Maracaju	LVef	Clayey	Intercropped	AW
F05	Sidrolândia	LVef	Very clayey	Sole	AW
F06	Rio Brilhante	LVe	Very clayey	Sole	AW
F07	Rio Brilhante	LVef	Very clayey	Intercropped	AW
F08	Douradina	LVef	Very clayey	Intercropped	Aw
F09	Douradina	LVef	Very clayey	Sole	AW
F10	Dourados	LVef	Very clayey	Intercropped	Am
F11	Sidrolândia	LVef	Clayey	Intercropped	AW
F12	Chapadão do Sul	LVdf	Very clayey	Sole	AW
F13	Chapadão do Sul	LVef	Very clayey	Sole	AW
F14	Chapadão do Sul	LVj	Clayey	Sole	AW
F15	São Gabriel do Oeste	LVef	Clayey	Sole	AW
F16	São Gabriel do Oeste	LVef	Clayey	Sole	AW
F17	Juti	LVef	Very clayey	Intercropped	Am
F18	Naviraí	LVdf	Average	Intercropped	Am
F19	Naviraí	LVd	Average	Sole	Am
F20	Naviraí	LVdf	Clayey	Sole	Am
F21	Ponta Porã	LVef	Clayey	Intercropped	Cwa

[1]: according to Köppen's classification. LVd- Dystrophic Red Latosol; LVfd – Dystroferric Red Latosol; LVef – Eutrophic Red Latosol; LVj – Perferric Red Latosol. AW-tropical climate with dry winter; Am- monsoon climate; Cwa- humid temperate climate with dry winter and hot summer

Identification and quantification of nematodes

For the quantification and identification, nematodes were separated from the soil particles and organic matter and extracted by the Jenkins method (JENKINS, 1964), which consists of sieving and flotation in a centrifuge. Nematodes were killed by gradual heating for five minutes in water, at 55° C, and then fixed in 4% formalin 2. Nematodes were quantified using Peters slide under an optical microscope and identified using an illustrated taxonomic key.

Biomass carbon and microbial activity

Biomass carbon was determined by the fumigation-extraction method, proposed by Vance et al. (1987).

The microbial activity was determined in 50g-soil samples, weighed and placed in individual flasks. Additionally, 10 mL of NaOH 1.0N was poured in each flask to absorb the CO_2 released by the microbial respiration. After the incubation period, NaOH was titrated with 0.5N HCl, added with 2mL of saturated $BaCl_2$ solution to precipitate Na_2CO_3. The released CO_2 was calculated by the difference between the volumes of HCl used to titrate the NaOH sample in the flask with soil and that of the blank test, transforming these values to CO_2 mass per soil mass. The metabolic quotient (qCO_2), defined by the respiration x biomass-C ratio, was determined according to Anderson and Domsch (1990).

Soil chemical analysis

Samples were analyzed in the soils laboratory of Embrapa Agropecuária Oeste, based on the methodology described by Silva (2009).

Statistical Analysis

The sampled crops were clustered based on the evaluated variables, using the means Euclidean distance and Ward´s clustering method (Ward, 1963). The interrelationship between the variables was analyzed by the correlations, and its unfolding in the cause and effect investigations was evaluated by the path analysis. The analyses were performed in the Genes (CRUZ, 2013) and Rbio (BHERING, 2017) software.

RESULTS AND DISCUSSION

Figure 2 shows the clustering of crops sampled in the state of Mato Grosso do Sul regarding the variables evaluated, based on the mean Euclidian distance and Ward´s clustering analysis. Two distinct groups were formed. The first one consisted of crops F1, F5, F6, F7, F9, F10, F14, F19, and F20, characterized by grain yield lower than 7500 kg/ha, as shown in Table 1. The second group consisted of crops F2, F3, F4, F8, F11, F12, F13, F15, F16, F17, F18, and F21, characterized by grain yield higher than 8000 kg ha^{-1}.

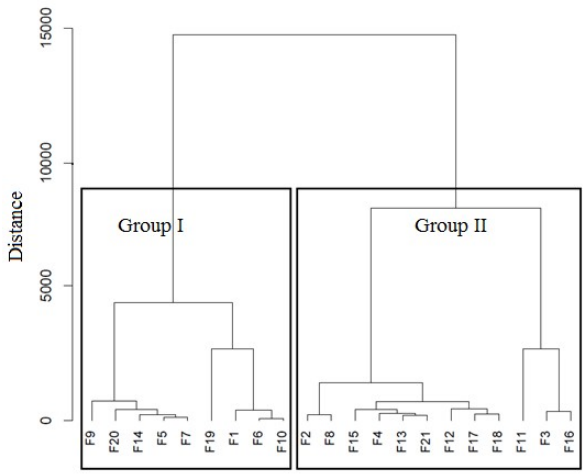

Figure 2. Clustering of crops sampled using the mean Euclidian distance and Ward´s clustering analysis.

Higher grain yields may be related to some particularities observed in group II (Table 3). Results showed that 66.7% of the crops represented areas of maize-brachiaria intercrop. Plant intercropping can improve soil physical and chemical attributes and soil conservation without affecting the yield of the intercropped crop. It also increases the yield of the subsequent crop (CORREIA et al., 2013).

The significant number of *Rotylenchulus* sp. nematodes reported in group II did not influence maize yield. However, if the subsequent crop is the nematode-susceptible soybean, grain yield will be affected. Leandro and Asmus (2015) observed that the rotation between soybean and maize could reduce the population density of *Rotylenchulus reniformis*. This fact was not observed in the Brachiaria off-season crop, which may explain the population verified in group II. According to Asmus and Richetti (2015), the annual or biannual rotation between soybean and maize or *Brachiaria ruziziensis* may reduce the population density of the reniform nematode. Moreover, the authors reported that longer periods of maize or *B. ruziziensis* crops are more efficient in reducing the population of this nematode. However, growing susceptible soybean after the rotations reestablishes high nematode population densities in the soil.

The higher occurrence of *Pratylenchus* sp. in group I (Table 2) suggests that this nematode may decrease grain yield. *Pratylenchus brachyurus* causes primary symptoms (root lesions) in soybean, cotton, maize, marandu grass, and mombaça grass crops (MAINARDI; ASMUS, 2015), consequently affecting the development of these crops.

Table 3 shows a higher amount of zinc in Group II. Domingues et al. (2004) state that adding zinc to maize crop increases grain yield, suggesting that zinc may be responsible for the higher yield in the crops of group II. The phosphorus content in the soil was more expressive in group II (Table 3). Prado et al. (2001) reported that the application of phosphorus doses increases maize grain yield, reinforcing the present results. The increase of the organic matter content in the soil increased the efficiency in the use and cycling of phosphorus by the plants. This fact may be directly related to the grain yield observed in this study since higher contents of organic matter were found in the crops of Group II (Table 3). Sousa et al. (1997) evaluated the efficiency of P application in areas with annual cultivation and pasture. The authors observed higher efficiency of P application in sites with higher levels of organic matter resulting from nine years of pasture cultivation. This fact may also suggest that the brachiaria-maize intercropping system is one of the factors that contributed to the higher yield of the areas of group II since 66.7% of the crops are cultivated in this system.

Besides the higher organic matter content, crops of group II had 13% higher microbial biomass carbon. Soil quality can be verified by the interaction of the chemical, physical and biological attributes, in which the organic matter has the critical role of promoting agricultural sustainability (CUNHA et al., 2015a).

The soil organic carbon and the microbial biomass carbon are indicators of soil changes and quality since they are related to the ecological functions of the environment and can evidence changes in the soil use (JACKSON et al., 2003). Feigl et al. (1998) state that, despite the influence of the climate and the addition of residue, the microbial biomass carbon is considered as a possible soil quality indicator for it is related to the active and biodegradable fraction of the OM, resulting in the possibility of changes in slower-cycling fractions. Figure 3 shows the correlations between nematodes occurrence, soil chemical and biological attributes, and grain yield, revealing a positive linear association between soil the chemical attributes (pH, Ca, K, Mn, Cu, SB, and CEC). Except for iron, copper, manganese, and zinc, whose availability decrease with the increase in pH, all the other elements (nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, molybdenum, and chlorine) are highly available due to the rational use of liming in acid soils (LOPES, 1998).

The association between Zn, P, and maize grain yield stand out for representing an unconventional result. In the case of Zn, some anions, such as P, may lead to the higher retention of the former, making it less soluble. Muner et al. (2011) state that P may alter the soil balance by at least four processes: changes in pH, due to the dissolution of the fertilizer in the soil solution; changes in pH, due to reactions, both of the phosphate and the accompanying cation with the soil components; changes in the surface charge, due to the phosphate adsorption by the colloids and the direct precipitation of Zn with phosphate, forming $Zn_3 (PO_4)_2$.

According to Oliveira (2004), the correlations between the nutrient concentrations found in the soil and those detected in the leaves are not always close. This is because the soil analysis uses extractive solutions (diluted acids, salts, hot water, resin). Thus, the laboratory conditions do not reflect those observed in the field. However, the author believes that soil and leaf analyses are complementary.

Table 2. Mean of the evaluated variables in different crops in the state of do Mato Grosso do Sul (group I and II).

Group	Crop	***Rothy***	***Praty***	**pH1**	**pH2**	**Al**	**Ca**	**Mg**	**H+Al**	**K**	**P**	**SB**	**CEC**	**CEC_ef**	**V**	**MO**	**Cu**	**Fe**	**Mn**	**Zn**	**CMBS**	**CCO_2**	**$qCCO_2$**	**GY**
I	F1	16.67	23.33	6.41	5.80	0.00	6.37	2.03	2.47	0.84	10.77	9.24	11.71	9.24	78.94	29.73	12.07	14.67	172.37	3.57	261.20	16.96	28.04	6466.44
	F5	0.00	3.33	5.88	5.20	0.00	4.90	1.67	4.82	0.47	5.80	7.04	11.86	7.04	59.36	50.73	8.67	27.70	76.40	0.83	347.27	23.65	38.59	7391.55
	F6	3.33	10.00	6.55	5.97	0.00	5.07	2.70	2.61	0.69	19.30	8.46	11.06	8.46	76.44	39.80	8.17	45.70	120.07	2.40	297.53	21.38	30.43	6160.57
	F7	16.67	93.33	5.94	5.27	0.00	5.03	1.30	3.79	0.76	13.80	7.10	10.88	7.10	65.28	36.95	8.30	28.73	83.33	3.63	310.01	16.67	22.74	7302.73
	F9	123.33	0.00	6.41	5.80	0.00	5.03	3.37	3.35	0.24	14.10	8.64	11.99	8.64	72.11	32.55	12.07	29.63	142.03	3.70	323.37	14.28	18.79	7738.94
	F10	70.00	6.67	6.26	5.63	0.00	5.37	2.50	3.16	0.84	43.53	8.70	11.87	8.70	73.30	39.84	7.63	18.30	84.03	3.97	310.87	19.29	25.82	6165.91
	F14	70.00	26.67	5.60	4.87	0.03	3.13	1.03	5.75	0.23	14.20	4.40	10.15	4.43	42.91	51.68	0.53	40.97	13.10	3.50	257.21	20.84	35.96	7192.94
	F19	6.67	0.00	4.13	3.70	0.00	2.13	0.57	1.97	0.20	9.13	2.90	4.87	2.90	39.74	15.91	0.40	7.20	46.57	2.70	178.84	11.46	21.04	4412.19
	F20	0.00	6.67	6.58	6.00	0.00	4.53	2.30	2.59	0.62	60.70	7.46	10.04	7.46	74.08	37.94	0.80	18.83	57.57	4.80	336.17	19.64	25.07	6975.93
	Mean	34.07	18.89	5.97	5.36	0.00	4.62	1.94	3.39	0.54	21.26	7.10	10.49	7.11	64.68	37.24	6.51	25.75	88.39	3.23	291.39	18.24	27.39	6645.25
II	F2	0.00	6.67	6.29	5.67	0.00	5.93	2.30	3.38	1.16	6.83	9.40	12.78	9.40	73.51	41.96	9.73	20.40	147.90	8.53	317.28	15.37	20.15	8952.51
	F3	3.33	20.00	6.32	5.70	0.00	8.97	2.40	3.46	1.21	43.70	12.58	16.03	12.58	77.04	52.41	7.33	37.47	153.33	16.10	318.73	13.66	18.24	10281.90
	F4	0.00	23.33	6.12	5.47	0.00	8.43	2.23	3.77	0.97	58.70	11.64	15.41	11.64	73.54	52.24	5.40	38.83	95.73	12.67	251.17	15.73	27.27	8140.69
	F8	20.00	3.33	6.66	6.10	0.00	7.77	2.07	2.21	1.07	51.40	10.90	13.11	10.90	83.07	39.11	10.20	21.70	228.17	7.73	325.89	20.94	28.19	9149.79
	F11	56.67	13.33	5.94	5.27	0.00	5.80	1.43	5.40	1.13	133.90	8.36	13.76	8.36	60.68	48.96	11.40	23.77	92.40	26.27	470.20	27.69	25.42	12505.03
	F12	240.00	20.00	5.71	5.00	0.00	3.13	1.03	4.55	0.30	38.90	4.47	9.02	4.47	49.87	50.88	0.53	34.60	16.07	4.17	417.83	19.98	21.32	8793.60
	F13	46.67	0.00	5.83	5.13	0.07	3.47	1.37	4.99	0.17	11.60	5.01	9.99	5.07	50.19	53.08	0.57	34.33	14.13	3.83	457.72	22.16	20.31	8335.65
	F15	340.00	0.00	5.80	5.10	0.00	4.00	1.33	5.46	0.32	18.70	5.66	11.11	5.66	51.08	55.99	1.33	26.40	20.57	5.03	308.15	19.25	29.84	8312.80
	F16	16.67	0.00	6.49	5.90	0.00	4.63	1.43	2.65	0.36	24.27	6.43	9.08	6.43	70.66	38.49	0.87	24.67	22.50	5.77	324.31	18.35	24.45	10592.51
	F17	0.00	10.00	5.74	5.03	0.07	3.83	1.53	5.53	0.93	9.73	6.29	11.82	6.36	53.85	42.48	9.83	27.77	135.37	3.70	395.17	24.32	24.74	8568.80
	F18	0.00	30.00	5.33	4.57	0.13	1.97	0.40	4.65	0.27	31.20	2.64	7.29	2.77	35.63	21.01	1.27	17.13	72.90	4.80	157.04	17.99	49.88	8526.74
	F21	0.00	20.00	5.74	5.03	0.23	2.60	0.77	4.34	0.29	20.47	3.66	8.00	3.89	56.03	30.09	2.13	34.77	14.93	2.30	269.73	12.80	21.87	8324.09
	Mean	60.28	12.22	6.00	5.33	0.04	5.04	1.52	4.20	0.68	37.45	7.25	11.45	7.29	61.26	43.89	5.05	28.49	84.50	8.41	334.44	19.02	25.97	9207.01

pH1: Hydrogenionic potential in water; pH2: Hydrogenionic potential in calcium chloride; Al: Aluminum (cmol dm^{-3}) Ca: Calcium (cmol dm^{-3}); Mg: Magnesium (cmol dm_{-3}) H + AL: Potential acidity (cmol dm^{-3}); K: Potassium (cmol dm^{-3}); P: Phosphorus (mg dm^{-3}); SB: Sum of Bases; CEC: Cation exchange capacity; CECef: Effective cation exchange capacity; V: Base saturation in percentage; OM: Organic matter (g kg^{-1}); Cu: Copper (mg dm^{-3}); Fe: Iron (mg dm^{-3}) Mn: Manganese (mg dm^{-3}); Zn: Zinc (mg dm^{-3}); MBSC: Microbial biomass carbon (mg g^{-1}); CCO_2: Basal respiration (mg c-co_2 g soil $^{-1}$$day^{-1}$); qCO2 - Metabolic quotient (mg C-Co_2µ $Cmic^{-1}h^{-1}$); Rothy - Number of nematodes *Rothylenculus* ssp; Prathy - Number of nematodes *Prathylencus* ssp.; GY- Grain Yield (kg ha^{-1})

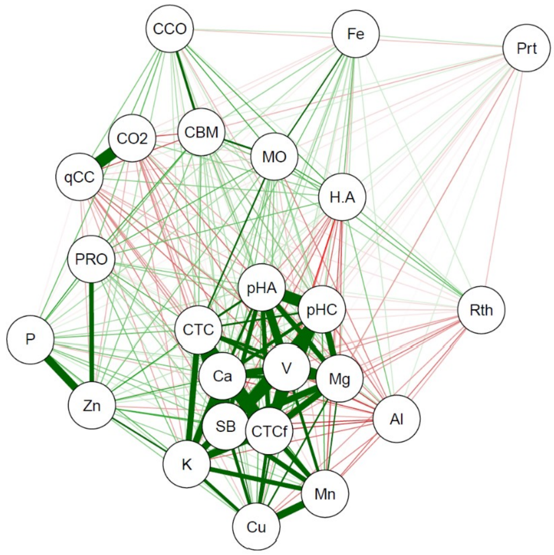

Figure 3. Correlations network of nematode occurrence, grain yield, and soil chemical and biological attributes evaluated in different crops in Mato Grosso do Sul. Positive correlations are highlighted in green and negative correlations are highlighted in red. The thickness of traces is proportional to the correlation magnitude. pH1 - Hydrogenionic potential in water; pH2 - Hydrogenionic potential in calcium chloride; Al - Aluminum; Ca - Calcium; Mg- Magnesium; H.A- Potential acidity; K- Potassium; P- Phosphorus in mg dm^{-3}; SB- Sum of Bases; CEC - Cation exchange capacity; CECef - Effective cation exchange capacity; V%- Saturation of bases; OM- Organic matter; Cu - Copper; Fe- Iron; Mn - Manganese; Zn - Zinc; MBSC - Microbial biomass carbon; CCO - Basal respiration; CO2 - mineralized carbon and microbial biomass carbon ratio; qCO2 - Metabolic quotient; Prt - nematode *Prathylencus* ssp .; Roth - nematode *Rothylenculus* ssp .; YIELD - Yield in kg ha^{-1}

Despite its importance, the Pearson's correlation coefficient may mislead results interpretation regarding the ratio between two variables. Therefore, it may not be a real measure of cause and effect. A high or low correlation coefficient between two variables may represent the effect of a third variable or a group of variables on the two variables and may not demonstrate the exact relative importance of the direct and indirect effects of these factors (CRUZ et al., 2012). Thus, the path analysis was carried out to investigate the relation of cause and effect. According to Teodoro et al. (2014), this method provides detailed knowledge about the influence of the variables involved and justifies the existence of positive and negative correlations, of high and low magnitude, between the studied variables.

Path analysis was carried out to unfold the correlations between soil chemical and biological attributes with the occurrence of *Prathylencus* (Table 4) and *Rothylenculus* (Table 5). Considering the basic variables, soil magnesium content was the variable that most influenced the occurrence of *Prathylencus* (Table 3), in an inversely proportional relation (-0.46). Therefore, the higher the content of this nutrient, the lower was the occurrence of this nematode. Franchini et al. (2014) found the same result when studying the population density of *Pratylenchus brachyurus* in function of the increase of the Ca+Mg contents. Blanco (2008) analyzed the relationship between nematodes and micro and macronutrients and verified that P, Mg, Ca, and K directly influence the population of *Pratylenchus* by reducing their quantity. According to Santana-Gomes et al. (2013), studies on the influence of mineral nutrition on diseases caused by nematodes are still scarce. The few existing studies do not clarify the mechanisms by which nutrients reduce the population of plant pathogens. However, in plant-nematode interactions, the accumulation of cellulose, lignin, and other elements originated from plant nutrition confer resistance to the nematode in the host plant (SANTANA-GOMES et al., 2013).

Concerning the occurrence of *Rotylenchulus* (Table 5), the organic matter content (0.35) and the H+Al content (potential acidity) (0.29) had the highest positive effect, while the aluminum content (-031) and potassium content (-0.30) showed negative relation. Asmus and Ishimi (2007) verified that soil macro and micronutrient content little influenced the population of *Rotylenchulus reniformi*s at the two depths studied. However, the potassium content revealed a negative correlation with the number of nematodes at the 0-20 cm depth. Franchini et al. (2014) observed that the reduction of the potential acidity (H+Al) resulted in an exponential decrease in the population density of *Pratylenchus*, confirming the effect of the potential acidity on the phytopathogen nematode population.

Organic matter from non-nematode-host crops, besides improving soil fertility and its physical and chemical attributes, has a nematicidal effect, *i.e.*, it reduces the number of individuals and delays the hatching of juveniles. However, its efficiency may be decreased due to the changes in soil fertility, moisture, organic matter content, and the nematode population. The nematicidal effect is related to the presence of substances released in the decomposition, which depend on the C/N ratio. Thus, the effect of the organic matter on the management of phytonematodes may be unfavorable when the C/N ratio, the dry and green matter production, and the soil pH alterations of the cover plants are unknown.

Asmus and Ishimi (2007) state that soil moisture little influences the population of *Rotylenchulus reniformis*. When the area infestation is high, two to four cycles of non-host crops are required to reduce the nematode population. This strategy minimizes the damage to the susceptible crop of economic interest to be grown in the area (CUNHA et al., 2015b).

A third path analysis was performed to verify the effects of the occurrence of nematodes and the soil chemical and biological attributes on maize grain yield (Table 6). Zinc (Zn) was the variable that most influenced grain yield (0.49). According to Gonçalves Junior et al. (2006), Zn is related to the enzymes responsible for plant growth. The influence of Zn on grain yield is due to its function, which is associated with the metabolism of carbohydrates, proteins, phosphates, and the formation of auxins, RNA and ribosomes. Domingues et al. (2004) verified that the Zn application increased maize grain yield and reported that the plants' response to the Zn application varied based on the soil type and the geographic region.

Likewise, Jamami et al. (2006) state that, as it occurs with boron, the availability of Zn in the soil depends on the soil chemical and physical attributes, as well as liming and P fertilization. Domingues et al. (2004) found similar results in Zn concentrations and the Zn shoot content, which varied with the pH in the two studied soils. The highest concentrations occurred in plants cultivated in the more acid soil, without liming. According to Nascimento et al. (2002), liming reduces the exchangeable Zn contents and increases the fractions organic matter, amorphous and crystalline iron oxides, and manganese oxides. The factors related to soil fertility, besides influencing maize grain yield, also affect the nematode population in the soil. The analysis of the correlations between soil attributes and grain yield or the factor that influences grain yield, such as phytoparasite nematodes, is a useful tool to establish cause and effect relations.

Table 4. Path analysis of the soil chemical and biological attributes on the occurrence of *Prathylencus* in different crops in Mato Grosso do Sul.

Effect	pH(H2O)	pH(CaCl)	Al	Ca	Mg	H+Al	K	P	SB	CEC	CECef	V	OM	Cu	Fe	Mn	Zn	MBSC	CCO2	CO2/MBSC	qCO2
Direct on Prathy	0.13	0.00	-0.17	0.07	-0.46	0.20	0.30	0.06	-0.04	0.05	-0.05	0.03	-0.24	0.24	0.29	-0.14	-0.14	-0.10	-0.22	0.01	0.01
indirect via pH(H2O)	---	0.13	-0.04	0.09	0.10	-0.04	0.06	0.03	0.10	0.09	0.10	0.11	0.04	0.06	0.04	0.06	0.02	0.05	0.03	-0.02	-0.02
indirect via pH(CaCl)	0.00	---	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
indirect via Al	0.05	0.06		0.09	0.09	-0.06	0.06	0.03	0.09	0.07	0.09	0.08	0.05	0.05	-0.02	0.05	0.04	0.04	0.03	-0.04	-0.04
indirect via Ca	0.04	0.05	-0.03	---	0.05	-0.02	0.05	0.02	0.07	0.06	0.07	0.05	0.02	0.04	0.01	0.05	0.04	0.01	0.00	-0.02	-0.02
indirect via Mg	-0.34	-0.36	0.23	-0.31	---	0.19	-0.22	-0.04	-0.37	-0.31	-0.37	-0.38	-0.09	-0.28	-0.08	-0.28	-0.06	-0.09	0.02	0.15	0.15
indirect via H+Al	-0.05	-0.07	0.07	-0.07	-0.08	---	-0.04	0.01	-0.07	0.01	-0.07	-0.12	0.11	-0.03	0.07	-0.08	0.03	0.07	0.10	0.06	0.06
indirect via K	0.14	0.15	-0.10	0.24	0.14	-0.06	---	0.13	0.24	0.23	0.24	0.20	0.07	0.20	-0.01	0.22	0.18	0.06	0.04	-0.06	-0.06
indirect via P	0.01	0.01	-0.01	0.02	0.00	0.00	0.03	---	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.01	0.05	0.02	0.02	0.00	0.00
indirect via SB	-0.03	-0.03	0.02	-0.04	-0.03	0.01	-0.03	-0.01	---	-0.04	-0.04	-0.04	-0.01	-0.03	-0.01	-0.03	-0.02	-0.01	0.00	0.01	0.01
indirect via CTC	0.03	0.03	-0.02	0.04	0.03	0.00	0.04	0.02	0.04	---	0.04	0.03	0.03	0.03	0.02	0.03	0.03	0.02	0.01	-0.01	-0.01
indirect via CTCef	-0.03	-0.03	0.02	-0.04	-0.04	0.02	-0.04	-0.01	-0.05	-0.04	---	-0.04	-0.02	-0.03	-0.01	-0.03	-0.02	-0.01	0.00	0.01	0.01
indirect via V	0.03	0.03	-0.01	0.03	0.03	-0.02	0.02	0.01	0.03	0.02	0.03	---	0.00	0.02	0.00	0.02	0.01	0.01	0.00	-0.01	-0.01
indirect via MO	-0.08	-0.07	0.07	-0.09	-0.05	-0.13	-0.05	-0.05	-0.08	-0.15	-0.08	-0.03	---	0.00	-0.14	0.03	-0.08	-0.15	-0.12	0.03	0.03
indirect via Cu	0.11	0.12	-0.07	0.14	0.15	-0.04	0.16	0.03	0.16	0.15	0.16	0.15	0.00	---	-0.01	0.20	0.07	0.05	0.04	-0.03	-0.03
indirect via Fe	0.08	0.06	0.03	0.05	0.05	0.11	-0.01	-0.01	0.05	0.10	0.05	0.02	0.18	-0.02	---	-0.05	0.01	0.08	0.04	-0.02	-0.02
indirect via Mn	-0.07	-0.07	0.05	-0.10	-0.09	0.06	-0.11	-0.01	-0.11	-0.09	-0.11	-0.10	0.02	-0.12	0.02	---	-0.04	0.00	0.00	0.01	0.01
indirect via Zn	-0.02	-0.02	0.03	-0.08	-0.02	-0.02	-0.09	-0.12	-0.07	-0.08	-0.07	-0.03	-0.05	-0.04	-0.01	-0.03	---	-0.05	-0.03	0.03	0.03
indirect via MBSC	-0.03	-0.03	0.02	-0.02	-0.02	-0.04	-0.02	-0.04	-0.02	-0.04	-0.02	-0.02	-0.06	-0.02	-0.03	0.00	-0.03	---	-0.06	0.04	0.04
indirect via CCO2	-0.05	-0.03	0.04	0.01	0.01	-0.11	-0.03	-0.09	0.00	-0.05	0.00	0.02	-0.11	-0.04	-0.03	0.00	-0.05	-0.15	---	-0.07	-0.07
indirect via CCO2/BMSC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	---	0.01
indirect via qCCO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.01	---
Total (correlation)	-0.06	-0.10	0.09	0.03	-0.24	0.12	0.14	-0.03	-0.02	0.03	-0.02	-0.05	-0.09	0.08	0.16	-0.01	0.00	-0.18	-0.14	0.09	0.09

pH (H2O) - Hydrogenionic potential in water, pH (CaCl) - Hydrogenionic potential in calcium chloride; Al - Aluminum; Ca - Calcium; Mg- Magnesium; H + Al - Potential Acidity; K- Potassium; P- Phosphorus; SB- Sum of Bases; CEC - Cation exchange capacity; CECef - Effective cation exchange capacity; V% - Base saturation; OM- Organic matter; Cu - Copper; Fe- Iron; Mn - Manganese; Zn - Zinc; CMBS - microbial biomass carbon; CCO2 - Basal respiration; CO2/MBSC qCO2 - Metabolic quotient; Prathy - *Prathylencus* ssp.

Table 5. Path analysis of the soil chemical and biological attributes on the occurrence of *Rothylencus* in different crops in Mato Grosso do Sul.

Effect	pH(H2O)	pH(CaCl)	Al	Ca	Mg	H+Al	K	P	SB	CEC	CECef	V	OM	Cu	Fe	Mn	Zn	MBSC	CCO2	CO2/MBSC	qCO2
Direct on Rothy	0.11	0.06	-0.31	-0.10	0.04	0.29	-0.30	0.16	-0.10	0.02	-0.11	-0.10	0.35	0.00	-0.12	0.06	-0.07	-0.02	-0.20	-0.07	-0.07
Indirect via pH(H2O)	---	0.11	-0.03	0.07	0.09	-0.03	0.06	0.02	0.08	0.07	0.08	0.10	0.04	0.05	0.03	0.05	0.02	0.04	0.02	-0.02	-0.02
Indirect via pH(CaCl)	0.06	---	-0.02	0.04	0.05	-0.02	0.03	0.01	0.05	0.04	0.05	0.06	0.02	0.03	0.01	0.03	0.01	0.02	0.01	-0.01	-0.01
Indirect via Al	0.09	0.11	---	0.16	0.16	-0.11	0.11	0.05	0.17	0.13	0.16	0.14	0.10	0.10	-0.04	0.10	0.07	0.07	0.05	-0.06	-0.06
Indirect via Ca	-0.07	-0.07	0.05	---	-0.07	0.03	-0.08	-0.04	-0.10	-0.09	-0.10	-0.09	-0.04	-0.06	-0.02	-0.07	-0.06	-0.02	0.00	0.03	0.03
Indirect via Mg	0.03	0.03	-0.02	0.03	---	-0.02	0.02	0.00	0.03	0.03	0.03	0.03	0.01	0.03	0.01	0.02	0.01	0.01	0.00	-0.01	-0.01
Indirect via H+Al	-0.08	-0.11	0.10	-0.09	-0.12	---	-0.06	0.02	-0.10	0.02	-0.10	-0.17	0.15	-0.05	0.11	-0.12	0.04	0.10	0.14	0.08	0.08
Indirect via K	-0.1449	-0.15	0.10	-0.24	-0.14	0.06	---	-0.13	-0.24	-0.23	-0.24	-0.20	-0.07	-0.20	0.01	-0.22	-0.18	-0.06	-0.05	0.06	0.06
Indirect via P	0.03	0.03184	-0.03	0.06	0.01	0.01	0.07	---	0.05	0.06	0.05	0.03	0.04	0.02	-0.01	0.02	0.14	0.06	0.06	-0.01	-0.01
Indirect via SB	-0.07	-0.08	0.05	-0.10	-0.08	0.04	-0.08	-0.03	---	-0.09	-0.10	-0.09	-0.03	-0.07	-0.02	-0.07	-0.05	-0.02	0.00	0.03	0.03
Indirect via CEC	0.02	0.02	-0.01	0.02	0.02	0.00	0.02	0.01	0.02	---	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Indirect via CECef	-0.08	-0.08	0.05	-0.10	-0.08	0.04	-0.09	-0.03	-0.11	-0.10	---	-0.09	-0.04	-0.07	-0.02	-0.08	-0.05	-0.02	0.00	0.03	0.03
Indirect via V	-0.08	-0.09	0.04	-0.08	-0.08	0.06	-0.06	-0.02	-0.09	-0.06	-0.09	---	-0.01	-0.06	-0.01	-0.07	-0.02	-0.02	0.01	0.04	0.04
Indirect via MO	0.12	0.10	-0.11	0.13	0.07	0.19	0.08	0.08	0.12	0.21	0.12	0.04	---	0.00	0.21	-0.05	0.12	0.22	0.17	-0.04	-0.04
Indirect via Cu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	---	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indirect via Fe	-0.03	-0.03	-0.01	-0.02	-0.02	-0.05	0.00	0.00	-0.02	-0.04	-0.02	-0.01	-0.08	0.01	---	0.02	-0.01	-0.03	-0.02	0.01	0.01
Indirect via Mn	0.03	0.03	-0.02	0.04	0.04	-0.03	0.04	0.01	0.04	0.04	0.04	0.04	-0.01	0.05	-0.01	---	0.01	0.00	0.00	0.00	0.00
Indirect via Zn	-0.01	-0.01	0.02	-0.04	-0.01	-0.01	-0.04	-0.06	-0.03	-0.04	-0.03	-0.02	-0.02	-0.02	0.00	-0.02	---	-0.02	-0.02	0.01	0.01
Indirect via MBSC	-0.01	-0.01	0.00	0.00	0.00	-0.01	0.00	-0.01	0.00	-0.01	0.00	-0	-0.01	0.00	-0.01	0.00	-0.01	---	-0.01	0.01	0.01
Indirect via CCO2	-0.04	-0.03	0.03	0.01	0.01	-0.10	-0.03	-0.08	0.00	-0.04	0.00	0.01	-0.1	-0.03	-0.03	0.00	-0.04	-0.13	---	-0.06	-0.06
Indirect via CCO2/ MBSC	0.01	0.01	-0.01	0.02	0.02	-0.02	0.01	0.00	0.02	0.01	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.03	-0.02	---	-0.07
Indirectvia qCCO2	0.01	0.01	-0.01	0.02	0.02	-0.02	0.01	0.00	0.02	0.01	0.02	0.02	0.01	0.01	0	0.01	0.01	0.03	-0.02	-0.07	---
Total (correlação)	-0.08	-0.11	-0.20	-0.21	-0.08	0.37	-0.35	0.01	-0.21	-0.06	-0.22	-0.26	0.40	-0.24	0.11	-0.35	-0.06	0.24	0.10	-0.07	-0.07

pH (H2O) - Hydrogenionic potential in water, pH (CaCl) - Hydrogenionic potential in calcium chloride; Al - Aluminum; Ca - Calcium; Mg- Magnesium; H + Al - Potential Acidity; K- Potassium; P- Phosphorus; SB- Sum of Bases; CEC - Cation exchange capacity; CECef - Effective cation exchange capacity; V% - Base saturation; OM- Organic matter; Cu - Copper; Fe- Iron; Mn - Manganese; Zn - Zinc; CMBS - microbial biomass carbon; CCO2 - Basal respiration; CO2/MBSC qCO2 - Metabolic quotient; Rothy - *Rothylencus* ssp.

Table 6. Path analysis of nematode occurrence and soil chemical and biological attributes on maize grain yield evaluated in different crops in Mato Grosso do Sul.

Effect	Rothy	Prathy	pH1	pH2	Al	Ca	Mg	H+Al	K	P	SB	CEC	CECef	V	OM	Cu	Fe	Mn	Zn	MBSC	CCO2	CO2/MBSC	qCO2
Direct on Yield	0.03	-0.07	0.24	0.20	0.13	0.07	-0.31	0.17	-0.01	0.04	-0.03	0.04	-0.03	-0.06	0.01	-0.02	0.00	0.08	0.49	0.22	-0.08	0.00	0.00
Indirect via Rothy	---	0.00	0.00	0.00	-0.01	-0.01	0.00	0.01	-0.01	0.00	-0.01	0.00	-0.01	-0.01	0.01	-0.01	0.00	-0.01	0.00	0.01	0.00	0.00	0.00
Indirect via Prarhy	0.01		0.00	0.01	-0.01	0.00	0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.01	-0.01	-0.01	0.00	0.00	0.01	0.01	-0.01	-0.01
Indirect via pH(H2O)	-0.02	-0.01	---	0.24	-0.07	0.16	0.18	-0.06	0.12	0.05	0.17	0.15	0.17	0.20	0.08	0.11	0.07	0.11	0.04	0.08	0.05	-0.04	-0.04
Indirect via pH(CaCl)	-0.02	-0.02	0.19	---	-0.07	0.13	0.15	-0.07	0.10	0.04	0.15	0.12	0.15	0.18	0.05	0.09	0.04	0.10	0.03	0.06	0.03	-0.04	-0.04
Indirect via Al	-0.03	0.01	-0.04	-0.04	---	-0.06	-0.06	0.04	-0.04	-0.02	-0.07	-0.05	-0.06	-0.06	-0.04	-0.04	0.01	-0.04	-0.03	-0.03	-0.02	0.03	0.03
Indirect via Ca	-0.02	0.00	0.05	0.05	-0.04	---	0.05	-0.02	0.06	0.03	0.07	0.07	0.07	0.06	0.03	0.04	0.01	0.05	0.04	0.01	0.00	-0.02	-0.02
Indirect via Mg	0.02	0.07	-0.23	-0.24	0.16	-0.21	---	0.13	-0.14	-0.02	-0.25	-0.20	-0.25	-0.25	-0.06	-0.19	-0.06	-0.19	-0.04	-0.06	0.01	0.10	0.10
Indirect via H+Al	0.06	0.02	-0.05	-0.06	0.06	-0.06	-0.07	---	-0.03	0.01	-0.06	0.01	-0.06	-0.10	0.09	-0.03	0.06	-0.07	0.02	0.06	0.08	0.05	0.05
Indirect via K	0.00	0.00	-0.01	-0.01	0.00	-0.01	-0.01	0.00	---	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	-0.01	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00
Indirect via P	0.00	0.00	0.01	0.01	-0.01	0.01	0.00	0.00	0.02	---	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.03	0.01	0.01	0.00	0.00
Indireto via SB	0.01	0.00	-0.02	-0.03	0.02	-0.03	-0.03	0.01	-0.03	-0.01	---	-0.03	-0.03	-0.03	-0.01	-0.02	-0.01	-0.03	-0.02	-0.01	0.00	0.01	0.01
Indirect via CEC	0.00	0.00	0.03	0.03	-0.02	0.04	0.03	0.00	0.03	0.02	0.04	---	0.04	0.03	0.03	0.03	0.02	0.03	0.03	0.02	0.01	-0.01	-0.01
Indirect via CECef	0.01	0.00	-0.02	-0.03	0.02	-0.03	-0.03	0.01	-0.03	-0.01	-0.03	-0.03	---	-0.03	-0.01	-0.02	-0.01	-0.03	-0.02	-0.01	0.00	0.01	0.01
Indirect via V	0.02	0.00	-0.05	-0.05	0.03	-0.05	-0.05	0.04	-0.04	-0.01	-0.05	-0.04	-0.05	---	-0.01	-0.04	0.00	-0.04	-0.01	-0.01	0.00	0.02	0.02
Indirect via OM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Indirect via Cu	0.00	0.00	-0.01	-0.01	0.01	-0.01	-0.01	0.00	-0.01	0.00	-0.01	-0.01	-0.01	-0.01	0.00	---	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00
Indirect via Fe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---	0.00	0.00	0.00	0.00	0.00	0.00
Indirect via Mn	-0.03	0.00	0.04	0.04	-0.02	0.05	0.05	-0.03	0.06	0.01	0.06	0.05	0.06	0.05	-0.01	0.06	-0.01	---	0.02	0.00	0.00	-0.01	-0.01
Indirect via Zn	-0.03	0.00	0.08	0.08	-0.11	0.27	0.06	0.07	0.30	0.41	0.24	0.29	0.24	0.11	0.16	0.15	0.02	0.12	---	0.17	0.11	-0.09	-0.09
Indirect via MBSC	0.05	-0.04	0.08	0.07	-0.05	0.03	0.04	0.08	0.05	0.08	0.04	0.08	0.04	0.04	0.14	0.05	0.06	0.00	0.08	---	0.14	-0.09	-0.09
Indirect via CCO2	-0.01	0.01	-0.02	-0.01	0.01	0.00	0.00	-0.04	-0.01	-0.03	0.00	-0.02	0.00	0.01	-0.04	-0.01	-0.01	0.00	-0.02	-0.05	---	-0.02	-0.02
Indirect via CCO2/MBSC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---	0.00
Indirect via qCCO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---
Total (correlação)	0.08	-0.05	0.32	0.27	0.06	0.31	-0.04	0.37	0.35	0.57	0.25	0.44	0.25	0.11	0.43	0.15	0.19	0.08	0.73	0.53	0.35	-0.10	-0.10

pH1 - Hydrogenionic potential in water, pH2 - Hydrogenionic potential in calcium chloride; Al - Aluminum; Ca - Calcium; Mg- Magnesium; H + Al - Potential Acidity; K- Potassium; P- Phosphorus; SB- Sum of Bases; CEC - Cation exchange capacity; CECef - Effective cation exchange capacity; V% - Base saturation; OM- Organic matter; Cu - Copper; Fe- Iron; Mn - Manganese; Zn - Zinc; CMBS - microbial biomass carbon; CCO2 - Basal Respiration; qCO2 - Metabolic quotient; Rothy - *Rothylenculus* ssp. ; Prathy - *Prathylencus* ssp .; YIELD- Yield in kg ha-1

CONCLUSIONS

The organic matter and the microbial biomass carbon positively influence the grain yield of maize crops.

Magnesium negatively influences the population of *Pratylenchulus* spp. in maize crops.

The population of *Rotylenchulus* spp. in the maize crops is related to the soil potential acidity and organic matter.

The presence of zinc in the soil is a limiting factor of grain yield.

RESUMO: Sistemas de cultivo e uso do solo influenciam diretamente o rendimento das culturas, interferindo nos atributos químicos, físicos e biológicos do solo. Este trabalho teve como objetivo avaliar a correlação entre a produtividade de grãos de milho, os atributos químicos e biológicos do solo e a ocorrência de nematoides em milho cultivado no período de entressafra, no estado do Mato Grosso do Sul. Amostras de solo de 21 safras de milho fora de temporada foram coletadas em 2015. As amostras foram usadas para identificar e quantificar os nematóides, determinar a atividade microbiana e o carbono da biomassa, e para análises químicas. Os atributos foram agrupados com base nas variáveis avaliadas usando a distância euclidiana média e o método de agrupamento de Ward. A inter-relação entre as variáveis foi analisada por meio de correlações, e seu desdobramento nas investigações de causa e efeito foi avaliado pela análise de trilha. A matéria orgânica e o carbono da biomassa microbiana influenciam positivamente o rendimento de grãos. O magnésio influencia negativamente a população de *Pratylenchulus* spp. nas culturas de milho. A acidez potencial e a matéria orgânica estão relacionadas à presença de *Rotylenchulus* spp.

PALAVRAS-CHAVE: Análise de trilha. Microbiologia do solo. Matéria orgânica do solo.

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