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Relationship among soil properties, root-lesion nematode population, and soybean growth

Relação entre atributos de solo, população de nematoide das lesões radiculares e crescimento de plantas de soja

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ABSTRACT

Root-lesion nematode (RLN) (*Pratylenchus brachyurus*) is an important challenge to soybean production in Central Brazil due to its widespread occurrence, along with the absence of resistant cultivars and strategies for its management. The aim of this research was to evaluate the relationship among soil properties, RLN populations, and soybean crop growth using geostatistical analysis. The experiment was conducted in a soybean field located in the northern half of Mato Grosso state, in Brazil, with a history of damages by RLN. The results suggest a positive correlation between plant height and values of pH, Ca, Mg, and base saturation. On the other hand, RLN population was positively correlated with organic carbon, cation exchange capacity, and soil potential acidity. Moreover, our findings also indicate that soybean plant growth is reduced under acidic soil conditions, as susceptibility to RLN increases. Thus, the correction of soil acidity to suitable levels for soybean crop becomes an important strategy to minimize damages by RLN.

KEYWORDS: geostatistics, *Pratylenchus brachyrus*, soil chemistry, soil management.

RESUMO

O nematoide das lesões radiculares (NLR) (*Pratylenchus brachyurus*) representa um importante desafio para a produção de soja na região central do Brasil, devido a sua ocorrência generalizada e à ausência de cultivares resistentes e de estratégias adequadas para o seu manejo. O objetivo deste trabalho foi estudar as relações entre atributos de solo, a população de NLR e o crescimento de plantas de soja, usando ferramentas de geoestatística. O estudo foi realizado em área de produção comercial de soja na região do médio norte do Estado de Mato Grosso, com histórico de danos causados pelo NLR. Os resultados indicam que há correlação negativa entre a intensidade dos sintomas causados pela infestação do NLR e alguns atributos químicos do solo, tais como pH, Ca, Mg e saturação por bases. A população do NLR é positivamente correlacionada ao carbono orgânico, a capacidade de troca de cátions e a acidez potencial do solo. Há evidências de que a acidez do solo aumenta a suscetibilidade das plantas de soja ao ataque do NLR. Nesse sentido, a correção da acidez do solo para níveis adequados à cultura da soja é uma importante estratégia para minimizar os danos causados pelo NLR.

PALAVRAS-CHAVE: geoestatística, *Pratylenchus brachyrus*, química do solo, manejo do solo.

INTRODUCTION

Root-lesion nematode (RLN) [*Pratylenchus brachyurus* (Godfrey) Filipjev] is a soil organism naturally occurring in the region of Brazilian Cerrado (RIBEIRO et al. 2014). RLN attack symptoms in soybeans are characterized by excessive branching and darkening of the root system, resulting in low values of both plant height and grain yield (SANTANA-GOMES et al. 2014). In Brazilian Cerrado, damages caused by this nematode in crops of major economic importance have increased, especially in soybean (COSTA et al. 2014, SANTANA-GOMES et al. 2014, MACHADO et al. 2015). Only a few soybean cultivars are tolerant or even resistant to RLN; in addition, reproductive and harm effect variability among populations of

P. brachyurus may limit the performance of control practices such as the crop rotation (MACHADO et al. 2015).

Furthermore, the environmental factors might change the intensity of RLN symptoms in soybeans by enhancing the predisposition of plants to nematode penetration, colonization, survival, reproduction, and dissemination (KANDJI et al. 2001). Some studies have been carried out on this nematode attacking perennial crops such as pineapple [*Ananas comosus* L. (Merr.)] (SARAH et al. 1991). These authors noted that soil acidity correction, as well as plant nutrition, might contribute to reducing root infestation by RLN, increasing plant tolerance. These authors also reported that pH could influence the plant-parasite interaction only before or during its penetration into pineapple roots.

Given the above, the aim of this research was to evaluate the relationship among soil properties, RLN populations, and soybean growth using geostatistical analysis.

MATERIAL AND METHODS

The study was conducted during the 2010/11 growing season at a field located in Vera County, the northern half of the Mato Grosso state, in Central Brazil (12°08’26” S; 55°11’43” W; 340-m altitude). Local soil is classified as a dystrophic Red-yellow Latosol (EMBRAPA 2014), corresponding to a Typic Haplustox (SOIL SURVEY STAFF 2014) (130, 20, and 850 g kg^{-1} of clay, silt, and sand, respectively). The soybeans were annually fertilized with 80 kg ha^{-1} P_2O_5 and K_2O on average. The last liming was performed in April 2010, using a limestone with 10% MgO and 18% CaO; the liming was applied to the soil surface at a variable rate, in an average equivalent dose of 600 kg ha^{-1}.

Soil samples were collected at points regularly distributed within the area using a sampling grid of 20 m x 20 m, representing a total sampling area of 4 ha. Bulk samples were formed with five subsamples collected around each sampling point. One hundred deformed soil samples were collected from the layer 0.0 to 0.2 m. These samples were gathered on January 12, 2011, when soybean (cv. M9144RR) was at R3 reproductive stage (pod formation – 60 days after sowing). Soil chemical properties, as well as texture, were determined using the method described by EMBRAPA (1997). The R3 growth stage was chosen due to the presence of RLN symptoms, characterized by a lower plant height. Lower plants were distributed into patches ranging from 5 to 50 m in diameter, being widespread within all the experimental area.

Twenty soybean plants were evaluated for RLN injury intensity. The plant height was used as an indicator. At a given site, plants were considered low whether their heights were below the greatest height measured in this area (0.78 m), minus three times the standard deviation of all measurements (0.083 m). Therefore, the plant height value considered to distinguish between normal areas and areas with a reduced plant growth was 0.53 m (i.e., 0.78 – (3*0.083) = 0.53 m).

The RLN populations from soil samples were estimated through bioassays. The soil samples were collected five days after soybean harvest, placed into 1 kg pots, and then grown with soybean plants (cv. TMG 131 RR) in a greenhouse. Following the method described by COOLEN & D'HERDE (1972), nematode population was estimated by extracting and counting the number of individuals present in the roots of plants grown for 60 days after sowing, in each soil sample.

Data from soil properties, nematode population, and plant height were subjected to descriptive and geostatistical analyses. Experimental semivariograms were computed by using the same procedures and software described by VIEIRA et al. (2002). These variograms were based on a 150 m maximum distance, which was split into six lag class intervals of 25 m. Each point of the semivariogram was composed by a minimum of 175 point pairs and a maximum of 657 point pairs. The best fit to the experimental semivariogram generates a model chosen by determination and correlation coefficients between measured and krigged values by cross-validation (VIEIRA et al. 2002).

All data presenting spatial dependence were used to build maps. According to CAMBARDELLA et al. (1994), spatial dependence degree was computed separately to each variable. The parameters of models fit to the semivariograms were used to interpolate soil properties, plant height, and RLN population, according to procedures described by VIEIRA et al. (2002). Krigged values were applied to generate contour maps using Surfer 7.0 software. Thereby, krigged data for soil properties, plant height, and RLN population were correlated.

RESULTS AND DISCUSSION

All data obtained for soil properties, plant height, and RLN population presented skewness and kurtosis coefficients close to zero, evidencing a normal data distribution (Table 1). All the parameters presented a spatial dependence ranging from moderate to strong (Table 2). According to the classification of

CAMBARDELLA et al. (1994), plant height, P, H+Al, Ca, K, cation exchange capacity (CEC) and clay content showed a moderate spatial dependence, while RLN populations, C, pH, Al, Mg, and base saturation (V) had a strong spatial dependence (Table 2). Both plant height and RLN population were found to be under a strong influence of soil factors, with no correlation between each other (Table 3).

Table 1. Descriptive statistics for plant height, population of the nematode *Pratylenchus brachyurus* and soil attributes.

Parameter[1]	Unit	Minimum	Maximum	Mean	Class	Variance	CV (%)	Kurtosis	Skewness
Plant height	m	0.32	0.78	0.52		75.7	16.8	-0.16	0.11
Population density	specimens g^{-1} root	200	18,400	8.500	n.d.[2]	2.3E+07	55.8	-0.80	0.26
P	mg dm^{-3}	2.90	23.9	9.44	low	17.6	44.4	1.14	1.05
C	g dm^{-3}	6.93	16.7	10.8	low	4.23	19.1	-0.27	0.42
pH	log [H]	4.30	5.20	4.66	low	0.05	4.66	-0.79	0.27
H+Al	cmolc dm^{-3}	1.68	4.68	2.84	medium	0.37	21.3	0.63	0.53
Al	cmolc dm^{-3}	0.00	0.62	0.18	very low	0.02	80.4	-0.04	0.79
Ca	cmolc dm^{-3}	0.55	2.22	1.29	medium	0.15	30.0	-0.30	0.44
Mg	cmolc dm^{-3}	0.20	0.98	0.46	medium	0.04	41.7	0.30	0.95
K	cmolc dm^{-3}	0.05	0.20	0.12	medium	0.00	27.4	-0.04	0.20
CEC	cmolc dm^{-3}	3.29	7.65	4.70	medium	0.44	14.1	3.16	1.24
V	%	18.8	65.8	39.6	low	105.9	26.0	-0.44	0.37
Clay	%	9.43	15.2	12.8	sandy	1.11	8.23	0.56	-0.38

[1]P = phosphorus; C = organic carbon; pH = activity of hydrogen ions; H+Al= potential acidity; Al = aluminum; Ca = calcium; Mg = magnesium; K = potassium; CEC = cation exchange capacity [(H+Al)+Ca+Mg+K]; V = base saturation ((Ca+Mg+K)*100/CEC); [2] n.d. = non determinate.

Table 2. Theoretical semivariogram of spatial distribution of the plant height, population density of the nematode *Pratylenchus brachyurus* and soil attributes.

Parameter assessed	Function of the model[1]	Parameters of the theoretical model2			R2	C0/(C1+C0)[5]
		C0[2]	C1[3]	range[4]		
Plant height	GAU	50.0	25.0	25	0.24	0.67 M
Population density	EXP	5.0E+06	1.7E+07	48	0.31	0.23 S
P	EXP	9.39	15.00	119	0.92	0.39 M
C	ESF	0.00	2.80	38	0.76	0.00 S
pH	GAU	0.00	0.05	27	0.86	0.00 S
H+Al	EXP	0.26	0.11	70	0.52	0.70 M
Al	EXP	0.00	0.02	33	0.65	0.00 S
Ca	ESF	0.05	0.11	51	0.96	0.32 M
Mg	GAU	0.00	0.04	30	0.89	0.00 S
K	ESF	0.0003	0.0007	39	0.86	0.33 M
T	GAU	0.13	0.32	30	0.84	0.28 M
V	ESF	0.00	108.48	35	0.90	0.00 S
Clay	EXP	0.57	0.70	121	0.68	0.45 M

[1]EXP = exponential; ESF = aspheric; GAU = Gaussian; [2] C0 = nugget effect; [3] C1 = structured variance; [4] range = spatial dependence range; R2 = coefficient of determination; [5] = dependence degree. According to CAMBARDELLA et al. (1994), values of these parameters may be used to sort the spatial dependence as: strong (from 0 to 0.25); moderated (from 0.26 to 0.75), and weak (from 0.75 to 1).

The fitted models varied from 25 for plant height to 121 m for clay content (Table 2). These values were above the 20 m distance used in the sampling grid, which indicates an adequate sampling effort for modeling all the evaluated properties.

Soybean plant height ranged from 0.78 to 0.32 m (Table 1). When considering the sampling grid, 58 out of 100 sampling points presented plant heights lower than 0.53 m, which was established as a threshold between normal and reduced-height plants (Figure 1). The mean value for clustering plants below the threshold was 0.46 ± 0.05 m, while for normal plants it was 0.60 ± 0.05 m.

The RLN population showed an uneven distribution within the studied area since the number of individuals found in soybean plants ranged from 200 to 18,400 specimens g^{-1} root, with an average of 8,500 specimens g^{-1} root (Table 1, Figure 1).

The P content ranged from 2.90 to 23.90 mg dm^{-3}, with an average of 9.44 mg dm^{-3} (Table 1). According to the classification above, only 22 sampled points showed higher P values relative to the appropriate value for this element in this class of soil texture (12 mg dm^{3}), indicating a significant deficiency of P contents in the experimental area (Figure 2). The K levels ranged from 0.05 to 0.20 $cmol_c$ dm^{-3}, with a mean value of 0.12 $cmol_c$ dm^{-3} (Table 1). K levels ranged from 0.05 to 0.20 $cmol_c$ dm^{-3}, with a mean value of 0.12 $cmol_c$ dm^{-3} (Table 1). Even though K contents were not as critical as those of P, only 57% of the soil samples showed levels above 0.10 $cmol_c$ dm^{-3}, which is considered adequate for this nutrient.

Despite the lack correlation with nematode population, plant height was positively correlated with other parameters such as pH, Ca, Mg, and V, and negatively to H+Al and Al (Table 3). This evidence indicates the importance of soil acidity for the soybean development, mostly in presence of RLN. This assertion becomes more significant since higher pH levels are correlated to higher concentrations of Ca and Mg, which implies in higher V values and, therefore, lower H+Al and Al contents (SILVA et al. 2005). On the other hand, neither RLN population density nor plant height showed significant correlation with P and K levels in the soil (Table 3).

Table 3. Statistical significance of the correlations between the population of *Pratylenchus brachyurus* in soil and plant height, as well as to soil attributes.

	Soil attributes											
	Plant height	P	C	pH	H+Al	Al	Ca	Mg	K	CEC	V	Clay
Nematode population	-0.05	0.04	0.43*	-0.15	0.24*	0.19	0.16	0.04	-0.06	0.33*	0.02	-0.05
Plant height	-	-0.06	-0.11	0.43*	-0.36*	-0.57*	0.27*	0.32*	-0.06	-0.05	0.36*	0.07

*significant at 0.05% probability; n = 100.

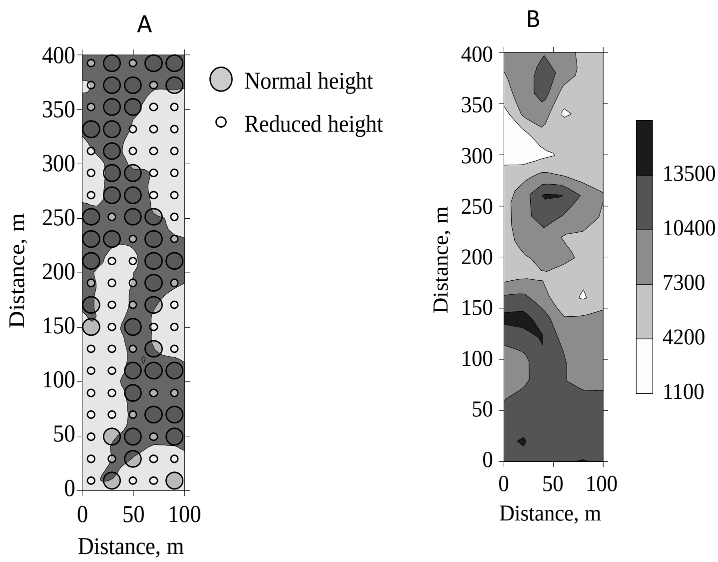

Figure 1. Spatial distribution of soybean plant height within an area infested with *Pratylenchus brachyurus*. Minor circle: points with reduced plant height; major circle: points with normal plants. White color: plants height < 0.53 m; gray color: plants height ≥ 0.53 m (A) spatial distribution of the nematode *Pratylenchus brachyurus* population (number of specimens g^{-1} root) (B).

In this study, RLN population was positively correlated only with C, CEC, and H+Al (Table 3). Nevertheless, this result seems to be inconsistent as it is expected that C and CEC increases would enhance soil capacity in retaining nutrients, which may improve plant growth and nematode tolerance (MELAKEBERHAN & AVENDAÑO 2008, COSTA et al. 2014). Moreover, higher contents of soil organic carbon are positively correlated to greater contents of microbial biomass and to a larger microbial activity (FRANCHINI et al. 2007), which might contribute to a suppressive environment to nematode growth, depending on the type of microorganisms existing in the soil (AVELINO et al. 2009, CHIAMOLERA et al. 2012, COSTA et al. 2014). However, increases in C content also expresses better environmental conditions to nematode survival and reproduction, as there is an increased water retention, modulation of soil temperature and better plant development. Altogether, these features increase nutrient availability for nematodes, which seems to outweigh the benefits to the crop.

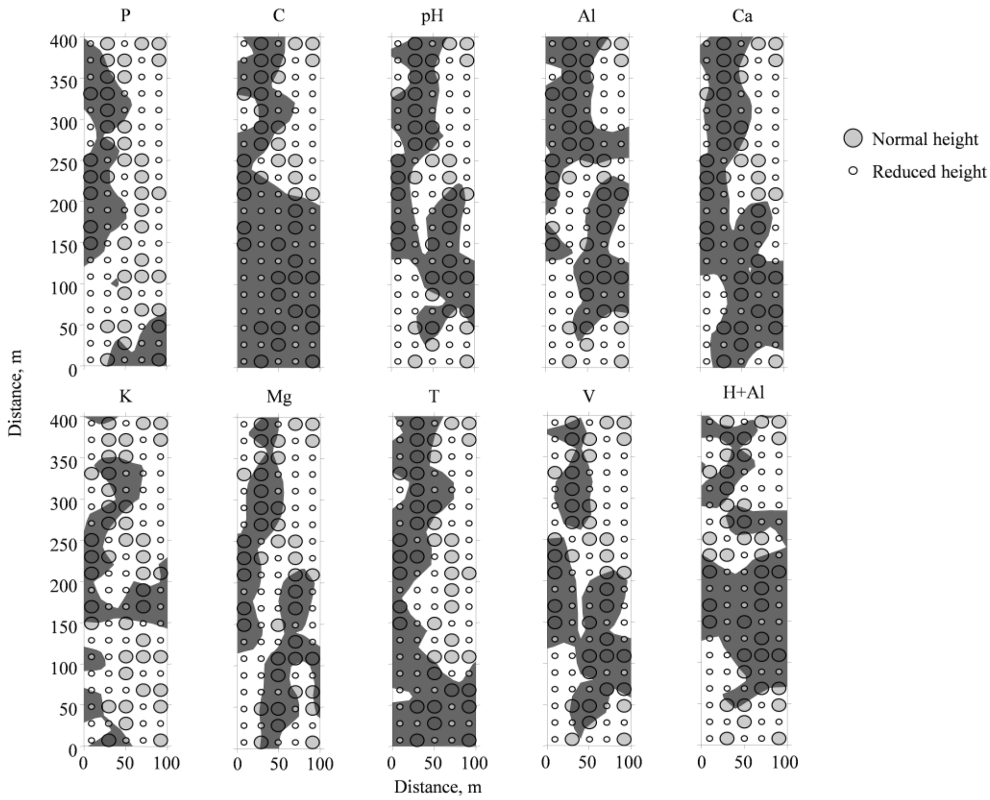

Figure 2. Spatial distribution of soil chemical attributes in the threshold value within the studied area. Threshold value for the attributes: P = 12.90, C = 9.72, pH = 4.70, Al = 0.08, Ca = 1.20, K = 0.14, Mg = 0.49, CEC = 4.69, V = 41.6, H+Al = 2.43. The white color indicates distribution of the chemical attributes with values below threshold value; gray color indicates distribution of the chemical attributes with values above the threshold value, except for the attributes Al and H+Al, where spatial distribution was inverse.

Potential acidity (H+Al) was the only soil parameter simultaneously correlated to plant height and RLN population; however, with negative interactions with plant height (-0.36) and positive ones with nematode population (0.24) (Table 3). This result is coherent since higher levels of potential acidity imply lower pH and nutrient availability in tropical soils, thereby hindering plant development. Additionally, positive correlations with nematode population can indicate that *P. brachyurus* is adapted to acidic soil conditions, with low nutrient availability.

No significant correlation was found between RLN population density and the soil parameters pH and V. The same was seen for contents of Ca, Mg, and Al in the soil (Table 3). These findings are partially divergent from previous studies, in which the population density of *Pratylenchus zeae* in sorghum roots (TREVATHAN et al. 1985) and *P. brachyurus* in pineapple roots (SARAH et al. 1991) decreased as soil acidity reduced. Likewise, KANDJI et al. (2001) found a negative correlation between the population of *Pratylenchus* spp. and contents of Ca and Mg in the soil. The lack of correlation between RLN population and pH, Ca, Mg, and V can be attributed to the fact that soil sampling was performed after soybean harvest. This may suggest that soil acidity influences only the relationship plant-parasite before and during nematode penetration into plant roots.

Depending on the nematode species (KANDJI et al. 2001) and on the considered trophic groups, nematode population may be correlated positively or negatively with nutrient contents in the soil. Within such context, the population density of free-living nematodes, including the species that feed on bacteria and fungi, display a positive correlation with nutrient content in the soil. Furthermore, KANDJI et al. (2001)

reported that population densities of plant-parasite nematodes such as *Meloidogyne* spp. and *Pratylenchus* spp. are negatively correlated with the nutrient concentration in the soil.

CONCLUSION

There is a positive association between soybean plant height and the values of pH, Ca, Mg, and base saturation. On the other hand, there is a negative correlation between plant height and Al and H+Al.

Root-lesion nematode (RLN) population was shown to be positively correlated with organic carbon, cation exchange capacity, and soil potential acidity.

Soil acidity correction to reach adequate levels for soybean cropping is an important strategy to minimize the damages by RLN.

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