Revista Brasileira de Ciência do Solo

Division - Soil Processes and Properties | Commission – Soil Biology

Spatial Variability of Soil Fauna Under Different Land Use and Managements

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ABSTRACT: Geostatistics allows the evaluation of the distribution pattern of data with high spatial variability in agricultural systems. This study aimed to evaluate the spatial variability of biological diversity indices of soil fauna under different land (agriculture and forest). Samples were collected in seven areas (millet, soybean, corn, eucalyptus, pasture crops, and preserved and disturbed Cerrado), in Maranhão state, Brazil. The soil fauna was caught trapped in pitfall traps, installed 3 m away from each other. In each area, 130 traps were maintained for seven days. After this period, they were removed and their content transferred to bottles and taken to the laboratory, where the insects were screened and identified at the level of orders and families. Eight indices were calculated, namely: individuals trap^{-1} day^{-1}, Jackknife richness estimator, the Simpson, McIntosh, Shannon, and total diversity, and Simpson dominance, and Pielou equitability indices. The spatial variability was derived from the semivariograms fitted to Gaussian, spherical, and exponential geostatistical models. Statistical analysis showed medium values of the coefficient of variation for millet, except for the indices individuals trap^{-1} day^{-1} and McIntosh diversity, which were considered high. The values of the correlation matrix were negative for some indices, suggesting an inverse relationship. For millet, corn, eucalyptus, disturbed Cerrado, and pasture areas, the Shannon diversity index exhibited a pure nugget effect. For the areas of millet, corn, disturbed Cerrado and pasture, the total diversity index was adjusted to the Gaussian model. The degree of spatial dependence was considered high for the individuals trap^{-1} day^{-1} and Pielou equitability indices for millet. Only for soybean and pasture similarity in the scaled semivariograms was observed for the spatial variability of the indices, indicating similarity of performance. Soil management and land use affect the patterns of soil fauna abundance, richness, and diversity. The presence of groups such as Araneae, Diplura, and Poduromorpha are related to ecological equilibrium, quality, and sustainability of the agricultural systems studied.

Keywords: soil biodiversity, soil properties, geostatistics.

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Received: April 13, 2017
Approved: November 5, 2017

How to cite: Silva RA, Siqueira GM, Costa MKL, Guedes Filho O, Silva EFF. Spatial variability of soil fauna under different land use and managements. Rev Bras Cienc Solo. 2018;42:e0170121.
https://doi.org/10.1590/18069657rbcs20170121

INTRODUCTION

The use of geostatistics in analysis of soil properties variability has increased significantly over the last decades. In a given area, geostatistical techniques can identify properties that are treated as homogeneous but would need a differentiated management (Ribeiro et al., 2016). Moreover, by these techniques, soil properties can be understood, modelled, and mapped to identify specific management zones and reduce the effects of soil variability on crop yields (Siqueira et al., 2009; Chiba et al., 2010; Montanari et al., 2010; Carvalho et al., 2014; Zonta et al., 2014; Aquino et al., 2015; Montanari et al., 2015; Siqueira et al., 2015a, 2017).

Soil variability occurs due to the interaction of formation factors, climate, temperature, and management (Bonnin et al., 2010; Siqueira et al., 2017), which directly affects agricultural productivity (Basso et al., 2011). The different planting systems can alter the soil quality, due to constant fertilization and liming, resulting in changes in the physical, chemical, and biological soil properties (Baretta et al., 2003; Carvalho et al., 2014).

The no-tillage system plays an important role in the conservation and maintenance of soil biota (Crusciol et al., 2010; Pedroso et al., 2016), due to the reduced soil disturbance, residue accumulation (Cunha et al., 2011), and crop rotation (Paul et al., 2013), which stabilize habitats and food supply (Bottega et al., 2013). In terms of soil benefits, the no-tillage system minimizes evaporation and erosion and can increase soil water infiltration and microbial activity rates, favoring nutrient incorporation in the soil and improving the physical, chemical, and biological quality.

Several studies have addressed soil fauna as a soil quality promoter (Vasconcellos et al., 2013; Rousseau et al., 2014; Moura et al., 2015). The soil biota comprises organisms of the most diverse sizes, which have been studied to evaluate changes in the environments (Rousseau et al., 2014). In general, changes in group abundance, diversity, and composition reflect disturbances of the ecosystem (Domínguez et al., 2014). Agricultural practices cause numerous changes in the composition and distribution of soil biota, directly affecting soil processes such as nutrient cycling, organic matter decomposition, porosity, and water infiltration (Vries et al., 2013; Wagg et al., 2014; Siqueira et al., 2016).

Since the distribution of soil properties in the areas is irregular, an evaluation of the spatial distribution of the physical, chemical, and biological properties is essential to improve decision making with regard to crop management and production. The objective was to evaluate the spatial variability of biological diversity indices of the soil fauna under different land uses (millet, corn, soybean, eucalyptus, and pasture) and soil cover (preserved Cerrado and disturbed Cerrado).

MATERIALS AND METHODS

The study was carried out on the *Fazenda Unha de Gato*, municipality of Mata Roma, Maranhão, Brazil (3° 70’ 80.88” S and 43° 18’ 71.27” W). According to the Köppen classification system, the regional climate is humid tropical, with mean annual temperatures from 27 to 30 °C, a dry season from June to November, and a rainy season from December to May. Rainfall ranges from 1,400 to 1,600 mm and annual evapotranspiration is 1,144 mm (data measured at the meteorological station in the experimental area). The soil of the region is an Oxisol (Soil Survey Staff, 1999).

The soil fauna was sampled in May 2015, in pitfall traps, during the summer growing season of soybean and corn. In each of the five land use areas (millet, corn, soybean, eucalyptus, and pasture) and two areas with different soil cover (preserved cerrado and disturbed cerrado), 130 traps were installed (Figure 1). Each trap contained 4 %

formaldehyde (200 mL) for the preservation of organisms, according to the methodology described by Aquino et al. (2001) and Siqueira et al. (2014).

The traps were installed at a distance of 3.0 m from each other and left in the field for seven days. After this period, all contents were preserved in 70 % alcohol and screened. The groups were separated in large groups and family based on identification keys, according to Lawrence (1994). Subsequently, the biodiversity indices were generated, based on the identification of groups.

Soil samples were collected in each transect (0.00-0.20 m layer) to evaluate the relationships between soil chemical (organic carbon, P, pH, K, Ca, Mg, and CEC) and physical properties (sand, silt, clay, bulk density, total porosity, macroporosity, and microporosity) and the soil macrofauna in the study areas. The mean values of the soil chemical and physical properties in the areas are listed in table 1.

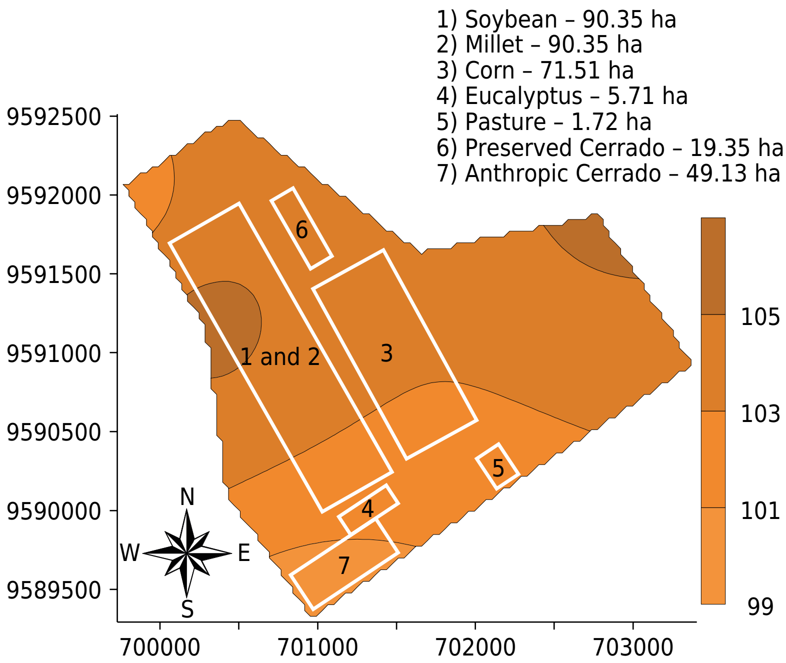

Figure 1. Location of study areas. 1 and 2 = soybean and millet; 3 = corn; 4 = eucalyptus; 5 = pasture; 6 = preserved Cerrado; and 7 = disturbed Cerrado.

Table 1. Soil physical and chemical properties in the study areas

Land uses and soil cover	Clay	Silt	Sand	Bd	Tp	Microp	Macrop	OC	P	pH($CaCl_2$)	K^+	Ca^{2+}	Mg^{2+}	CEC
	g kg^{-1}			Mg m^{-3}	m^3 m^{-3}	m^3 m^{-3}		g dm^{-3}			mmol$_c$ dm^{-3}			
Millet	120.0	110.0	770.0	1.56	0.37	0.15	0.22	29.0	18.0	4.6	2.2	20.0	4.0	51.2
Corn	147.0	107.0	746.0	1.47	0.34	0.14	0.20	19.0	14.0	5.0	2.4	26.0	5.0	56.4
Soybean	180.0	70.0	750.0	1.72	0.35	0.13	0.22	22.0	49.0	5.0	0.7	18.0	3.0	46.7
Eucalyptus	257.0	56.0	687.0	1.32	0.35	0.15	0.20	27.0	10.0	4.7	0.3	14.0	5.0	54.3
Preserved Cerrado	261.0	58.0	681.0	0.97	0.32	0.15	0.17	15.0	7.0	4.1	0.2	2.0	1.0	35.2
Disturbed Cerrado	256.0	77.0	667.0	1.22	0.33	0.15	0.18	21.0	8.0	4.2	0.5	3.0	3.0	42.5
Pasture	232.0	68.0	700.0	1.16	0.34	0.16	0.18	18.0	12.0	5.3	2.2	22.0	8.0	55.2

Bd = bulk density; Tp = total porosity; Microp = microporosity; Macrop = Macroporosity; OC = organic carbon; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; CEC = cationic exchange capacity. The properties were determined according to the methodology described by Camargo et al. (2009).

Diversity indices

To determine the biodiversity indices, software DivEs (Rodrigues, 2015) was used. The index individuals trap^{-1} day^{-1} was calculated from the number of individuals collected per trap and divided by the number of days in which the trap remained in the field, in this case, seven days.

The first-order Jackknife richness index estimates the richness of a community. It is defined as a function of the number of species that occur in only one sample, termed single species. Thus, the larger the number of species in a single sample, the higher the estimate for the total number of species in the community (Equation 1):

$$E_D = S_{obs} + S_1\left(\frac{f-1}{f}\right) \qquad \text{Eq. 1}$$

in which: E_d is Jackknife richness index; S_{obs} is the number of observed species; S_1 the number of species present in a single cluster; and f the number of samples.

Simpson's diversity index is used to quantify infinite communities, that is, in cases which the total number of individuals in a sample is different from the total number of individuals in the community (Equation 2). This index is appropriate to estimate diversity when sampling involves the counting of individuals:

$$D_s = \Sigma\ \frac{ni\ (ni - 1)}{N\ (N - 1)} \qquad \text{Eq. 2}$$

in which: *Ds* is Simpson diversity index; *ni* is the number of individuals of species *i* in the sample; *N* is the total number of individuals in the sample.

The McIntosh diversity index is a more complex index because, apart from considering the total number of individuals, it takes square root of the sum of the number of individuals of each species into account (Equations 3 and 4):

$$D = \frac{\mathrm{N - U}}{\mathrm{N} - \sqrt{\mathrm{N}}} \qquad \text{Eq. 3}$$

$$\mathrm{U} = \sqrt{\Sigma_{i=1}^{n} n_i^2} \qquad \text{Eq. 4}$$

in which: *D* is the McIntosh diversity index; *N* is the total number of individuals in the sample(s); *U* the square root of the sum of the squared number of individuals per species.

The Shannon-Wiener diversity index is the most commonly used index in community studies. Shannon values range from 0 to 3.5, rarely exceeding 4.5 (Magurran, 1988). The index will be zero if a sample contains only one species and reaches the maximum value when all species of a sample have the same number of individuals (Equation 5):

$$\mathrm{H'} = \Sigma_{i=1}^{n}\ pi \times \log_{10} pi \qquad \text{Eq. 5}$$

in which: *H'* is Shannon-Wiener diversity index; *ni* is the number of individuals of species *i* in the sample; *N* is the total number of individuals in the sample; log_{10} is the logarithm (base 10).

The diversity of a region, i.e., total diversity, can be estimated as a function of the species variation (Equation 6):

$$\mathrm{TD} = \Sigma_{i=1}^{n}\ wi\ [pi\ (1 - pi)] \qquad \text{Eq. 6}$$

in which: *TD* is diversity total; *wi* is the weight given to the function, which expresses the desired importance of species *i* in the global quantification of regional diversity; *pi* is the relative frequency.

Simpson's dominance is determined by the Simpson diversity index (Equation 7):

$$D_S = 1 - \left(\frac{\Sigma_i^n \ n_i \times (n - 1)}{N \ (N - 1 \ )} \right) \qquad \text{Eq. 7}$$

in which: D_s is the Simpson dominance; *ni* is the number of individuals of each species; and *N* the number of individuals.

The Pielou equitability indicates the distribution of individuals among species and is proportional to diversity and inversely proportional to dominance. Equitability compares the Shannon-Wiener diversity with the observed species distribution that maximizes diversity (Equation 8):

$$U = \frac{H'}{\log_{10} S} \qquad \text{Eq. 8}$$

in which: U is the Pielou equitability; *H'* is the Shannon-Wiener index; *S* is the number of groups present in each area; and log_{10} is the logarithm to base 10.

Geostatistical and statistical analysis

Descriptive statistics were determined using the statistical program R (R Development Core Team, 2009), where the values of maximum, minimum, mean, standard deviation, coefficient of variation (CV), skewness, kurtosis, and normality were calculated by the Kolmogorov-Smirnov test at 0.01 % probability. The linear correlation matrix of Pearson was calculated for all soil properties, according to the classification of Santos (2007), considering r values up to 0.5 as low and above 0.5 as high.

Multivariate statistics were applied to data of physical, chemical, and biological soil properties, using the factorial exploration technique to identify relationships between them. For the factorial analysis, collinearity-free data were selected and standardized (null mean and unit variance). The factors were extracted by principal component analysis calculated from the correlation matrix between variables. The properties with factor loadings above 0.7 in absolute value were selected (Jeffers, 1978). Multivariate analysis was carried out using software Statistica 7.0.

The spatial variability was analyzed through the construction of a semivariogram γ (h) of a spatially distributed variable, as proposed by Vieira (2000) (Equation 9).

$$\gamma \ (h) = \frac{1}{2N \ (h)} \ \Sigma_{i=1}^{N(h)} \ [z(xi) - z(xi + h)]^2 \qquad \text{Eq. 9}$$

in which: *γ(h)* is the spatial variability; *N(h)* is the number of observations separated by distance *h*. All semivariograms were fitted to a mathematical model according to the range (a), sill (C_0+C_1), and nugget effect parameters (C_0).

The intrinsic hypothesis of geostatistics was considered, which requires no finite variance, *Var*(*z*) but only stationarity of the mean and second-order stationarity of the differences *[(z (x) -z (x + h)]* (Journel and Huijbregts, 1978). The semivariograms were scaled as described by Vieira et al. (1997) (Equation 10).

$$\gamma^{sc} \ (h) = \ \frac{\gamma(h)}{Var(z)} \qquad \text{Eq. 10}$$

in which: $y^{sc}(h)$ is the scaled semivariogram; *y(h)* is the original semivariogram, and *Var(h)* is the data variance.

The advantage of the scaled semivariogram is that several semivariograms can be drawn on the same graph, otherwise, the scales on the semivariance axis would be different. When grouping the semivariograms, similar spatial variability of the relevant variables was observed (Vieira et al., 1997) The experimental semivariogram was fitted by adjusting the spherical, exponential and Gaussian models and choosing the best fit by jack-knifing, as proposed by Carvalho et al. (2002).

The spatial dependence ratio was calculated according to the equation 11.

$$RD = \left(\frac{C_0}{C_0 + C_1}\right) \times 100 \qquad \text{Eq. 11}$$

in which: RD is the ratio of dependency; C_0 is the nugget effect; C_0+C_1 is the sill.

And classified as proposed by Cambardella et al. (1994), in strong (0-25 %); moderate (25-75 %); and weak (75-100 %).

RESULTS AND DISCUSSION

The sampled arthropods were classified into 20 taxonomic orders and one family. The representativeness was highest in the millet area, with 9,974 individuals, followed by eucalypt with 3,841 individuals. The lowest abundance was in the area with soybean (222 individuals) (Table 2).

Poduromorpha tends to be better represented in areas with organic residues in the soil, where it is also captured in greater abundance (Baretta et al., 2003; Rafael et al., 2012). These organisms are used as bioindicators of soil quality and environmental disturbances, being key organisms for the detection of degraded areas. In the eucalyptus area, although there is a thick layer of organic matter, the contribution of the class Poduromorpha is relevant, because they are important as consumers, for nutrient cycling, and responsible for soil enrichment.

Table 2. Composition of the soil fauna under different use and management in the Cerrado Biome

Taxonomic groups	Millet	Corn	Soybean	Eucalyptus	Preserved Cerrado	Disturbed Cerrado	Pasture
Acari	5,772	311	71	594	202	7	749
Araneae	2	13	33	192	1,592	853	84
Coleoptera	602	134	30	81	43	32	138
Diplura	51	19	9	354	182	197	16
Dermaptera	3,317	76	41	2	-	-	525
Diptera	4	2	12	2	1	-	101
Diplopoda	-	2	-	13	4	-	-
Formicidae	106	215	11	428	248	588	225
Hymenoptera	11	4	14	49	38	23	36
Gastropoda	-	-	-	1	1	-	-
Isopoda	-	-	-	16	-	-	-
Isoptera	-	-	-	-	11	54	-
Lepidoptera larvae	2	2	-	2	1	-	50
Orthoptera	5	1	-	-	2	-	9
Entomobryomorpha	49	11	-	-	-	-	-
Psocoptera	43	5	-	-	-	-	-
Trichoptera	2	1	-	3	-	2	-
Poduromorpha	8	1	1	2,098	45	6	-
Scorpionida	-	-	-	2	5	14	-
Sternorrhyncha	-	27	-	4	9	-	-
Tysanura	-	-	-	-	-	1	-
Total	9,974	824	222	3,841	2,384	1,777	1,933

-: without individuals.

The correlation matrix between soil fauna taxa and soil chemical and physical properties was null (<0.05) (data not shown). In a study on the spatial relationship between macrofauna and soil properties, Gholami et al. (2016) stated that this correlation is difficult to describe. The reasons are the sensitivity and dynamics of the soil macrofauna, depending on soil use and management, once these organisms respond to the slightest environment alterations.

Multivariate analysis grouped the data in three classes, which together explain 88.75 % of the original data (Table 3). The factors 1, 2, and 3 explained 40.27, 26.39, and 22.07 %, respectively, of the total variation.

Factor 1 describes the ecological equilibrium and soil chemical quality in the studied environment. It involves the groups of predators, recyclers of organic matter and groups involved in soil decomposition processes such as Araneae (0.77065), Scorpionida (0.76860), Diplura (0.75912), and Coleoptera (-0.97741). This factor had a strong negative correlation with the following soil properties: silt (-0.80897), P (-0.96085), pH (-0.91209), K (-0.96407), Ca (-0.96709), Mg (-0.75495), and CEC (-0.79704).

Table 3. Factor analysis with the first three factors and factorial charge that represent the correlation coefficients between soil properties and each factor

Properties	Factor 1	Factor 2	Factor 3
	40.27 %*	26.39 %*	22.07 %*
Coleoptera	-0.97741	-0.115935	0.176653
Ca	-0.96709	0.058151	0.224349
K	-0.96407	-0.053323	-0.233894
P	-0.96085	0.171819	0.126568
pH($CaCl_2$)	-0.91209	-0.269774	0.262025
Clay	0.82529	-0.524333	0.209074
Silt	-0.80897	0.531781	-0.244777
CEC	-0.79704	0.033083	0.470337
Araneae	0.77065	-0.029316	-0.413791
Scorpionida	0.76860	0.066500	-0.450302
Diplura	0.75912	0.157689	0.626440
Mg	-0.75495	-0.436175	0.312288
Sand	0.08910	0.974856	-0.142351
Microporosity	0.14812	-0.935675	0.316191
Total Porosity	0.39344	-0.856098	-0.328434
Diptera	-0.52303	-0.849638	-0.029507
Larva Lepidoptera	-0.53449	-0.843265	-0.016709
Orthoptera	-0.51780	-0.835033	-0.127818
Dermaptera	-0.62639	-0.773847	-0.068883
Sternorrhyncha	-0.53294	0.765612	-0.151998
Entomobryomorpha	-0.67900	0.705438	-0.199904
Psocoptera	-0.67900	0.705438	-0.199904
Isopoda	0.21146	0.127796	0.962091
Poduromorpha	0.22371	0.128339	0.961003
Diplopoda	0.26534	0.243106	0.918383
OC	0.14397	0.212435	0.781333
Macroporosity	0.01470	0.430730	0.758906
Interpretation	Ecological equilibrium and chemical quality	Regulators of food chain and porosity	Soil builders

* Variation percent of the variation of original data set retained by the respective factors. Ca: calcium; K: potassium; P: phosphorus; CTC: cationic exchange capacity; Mg: magnesium; OC: organic carbon. Values highlighted in bold: values greater than 0.7 % in the analysis of factors.

Factor 2 grouped the food chain regulators and soil porosity, with a strong positive correlation with the groups Entomobryomorpha (0.705438), Psocoptera (0.705438), and Sternorrhyncha (0.765612). This indicates that these groups are related to macroporosity (-0.935675), sand (0.974856), and total porosity (-0.856098), which demonstrates their contribution to organic matter decomposition and soil structuring.

Factor 3 grouped the soil properties called soil builders, with a strong positive correlation to all properties. The groups Diplopoda (0.918383), Isopoda (0.962091), and Poduromorpha (0.961003) are related to organic matter input and relevant in nutrient recycling and soil enrichment (Bedano et al., 2016). The presence of the groups of soil builders and organic matter decomposers contributed positively to the sustainability of the productivity of agricultural systems. In this way, the soil fauna is the transforming agent of chemical, physical, and biological properties of the soil (Correia, 2002; Blanchart et al., 2006; Bottinelli et al., 2015; Franco et al., 2016).

The main statistical parameters for biodiversity indices are described in table 4. In millet, according to the classification of Warrick and Nielsen (1980), the coefficient of variation (CV) values are considered medium, except for the indices individuals trap^{-1} day^{-1} (CV = 66.29) and McIntosh diversity (CV = 124.67), which are considered high. For corn, all CV values are considered high (>60 %). In the soybean area, the CV values of the Simpson, McIntosh, Shannon diversity, total diversity, Simpson dominance, and Pielou equitability indices were above 100 %, which was also the case for the McIntosh index in all areas. High CV values are related to high standard deviations, explained by the aggregate behavior of the soil fauna and by intrinsic processes such as reproduction, feeding, migration, and dispersion of organisms. Thus, according to Warrick and Nielsen (1980), the CV values of soil properties can reach 1000 %.

Several authors report high CV values for soil variables. In a study on weed variability under different managements, Schaffrath et al. (2007) reported CV between 86.05 and 168.85 %. In an evaluation of the volumetric content of water in the soil, Siqueira et al. (2015a) reported a high CV range (97.60 - 106.8 %) for the different depths. However, Machado et al. (2006) attributed the high CV values to the sampling grid used.

There was variation regarding the minimum and maximum value of individuals in the areas. Only corn and soybean obtained a minimum value of zero in all indices. The highest mean was for individuals trap^{-1} day^{-1} in the eucalyptus area (29.55), followed by individuals trap^{-1} day^{-1} in the preserved Cerrado (18.34); in both areas, the CV was greater than 100 %. According to Carvalho et al. (2002), skewness and kurtosis values between 0 and 3 indicate normal frequency. In this case, some indices presented no skewness and kurtosis values close to 0 and 3, indicating a lognormal distribution of these indices. For Isaaks and Srivastava (1989) and Cressie (1991), data normality is not a prerequisite for the use of geostatistics, whereas the stationarity of the semivariance is required.

The linear correlation matrix showed negative values for some indices in all areas (Table 5). In millet, total diversity × individuals trap^{-1} day^{-1} (r = -0.010) and Simpson diversity × Jackknife richness (r = -0.059) obtained very low and negative values, indicating an inverse association, that is, while an index grows other decreases. With the exception of preserved Cerrado, the correlation between Shannon index × Simpson diversity index for the other areas (millet r = 0647; corn r = 0.885, soybeans r = 0943; eucalyptus r = 0.976; disturbed Cerrado r = 0.942; pasture r = 0.920) remained high and positive, according to Santos classification (2007). The high correlation between Shannon diversity and Simpson diversity occurs because both indices take into account the total number of individuals within the sample, being these indices adequate to work with infinite communities, where it is only possible to determine diversity by sample means. The other correlations, with values between r = 0.1-0.5 or r = <0.1 are considered low.

The parameters of the semivariograms adjustment are presented in table 6. It is observed that for the richness indices, Simpson and Shannon diversity and Simpson dominance in the area of millet, the data evidenced pure nugget effect. The same occurred for the Simpson,

Table 4. Statistical parameters for biodiversity indices in the studied areas

Diversity index	Sum	Min	Max	Mean	Variance	SD	CV	Skew	Kurtosis	D
							%			
					Millet					
individuals trap^{-1} day^{-1}	1424.86	0.43	35.86	10.96	52.80	7.27	66.29	1.16	1.45	0.11 n
Jackknife Richness	577.00	2.00	8.00	4.44	1.36	1.17	26.32	0.92	1.02	0.23 ln
Simpson Diversity	66.94	0.06	0.71	0.51	0.02	0.13	25.60	-1.14	1.47	0.11 n
McIntosh Diversity	191.81	0.00	8.68	1.48	3.38	1.84	124.67	1.36	1.31	0.27 ln
Shannon Diversity	51.76	0.06	0.60	0.40	0.01	0.10	24.57	-0.75	1.02	0.06 n
Total Diversity	112.63	0.35	1.00	0.87	0.02	0.16	17.92	-1.04	0.06	0.23 ln
Simpson Dominance	62.86	0.29	0.94	0.48	0.02	0.13	27.43	1.14	1.44	0.10 n
Pielou Equitability	82.45	0.00	0.99	0.63	0.03	0.17	27.26	-0.63	1.24	0.07 n
					Corn					
individuals trap^{-1} day^{-1}	117.71	0.00	5.00	0.90	0.70	0.83	92.61	2.04	6.61	0.14 n
Jackknife Richness	326.00	0.00	6.00	2.50	2.31	1.52	60.65	-0.00	-0.70	0.13 n
Simpson Diversity	68.72	0.00	1.00	0.52	0.11	0.33	63.95	-0.61	-1.02	0.19 ln
McIntosh Diversity	835.50	0.00	39.97	6.42	69.23	8.32	129.46	2.08	4.58	0.22 ln
Shannon Diversity	41.06	0.00	0.72	0.31	0.04	0.21	68.73	-0.25	-1.10	0.18 ln
Total Diversity	65.97	0.00	0.93	0.50	0.11	0.33	66.61	-0.50	-1.26	0.18 ln
Simpson Dominance	38.27	0.00	1.00	0.29	0.07	0.26	91.47	1.17	1.25	0.13 n
Pielou Equitability	84.83	0.00	1.00	0.65	0.15	0.39	61.15	-0.95	-0.93	0.28 ln
					Soybean					
individuals trap^{-1} day^{-1}	222.00	0.00	6.00	1.71	1.14	1.07	62.48	1.66	3.00	0.30 ln
Jackknife Richness	192.00	0.00	4.00	1.48	0.58	0.76	51.43	1.10	0.99	0.35 ln
Simpson Diversity	45.53	0.00	1.00	0.35	0.21	0.46	131.00	0.59	-1.60	0.4 ln
McIntosh Diversity	885.44	0.00	35.51	6.81	90.76	9.53	139.87	1.37	1.36	0.32 ln
Shannon Diversity	17.15	0.00	0.58	0.13	0.03	0.18	135.30	0.83	-0.81	0.39 ln
Total Diversity	26.18	0.00	0.83	0.20	0.07	0.27	133.99	0.75	-1.11	0.39 ln
Simpson Dominance	11.47	0.00	1.00	0.09	0.06	0.25	282.84	3.10	8.61	0.47 ln
Pielou Equitability	48.20	0.00	1.00	0.37	0.23	0.48	129.18	0.52	-1.75	0.40 ln
					Eucalyptus					
individuals trap^{-1} day^{-1}	3841.00	0.00	181.00	29.55	1098.08	33.14	112.15	2.33	6.20	0.22 ln
Jackknife Richness	447.00	1.00	6.00	3.44	1.50	1.23	35.67	-0.07	-0.50	0.17 ln
Simpson Diversity	36.26	0.00	0.83	0.28	0.04	0.20	72.52	0.37	-0.74	0.08 n
McIntosh Diversity	102.21	0.00	6.45	0.79	0.92	0.96	122.25	2.61	9.90	0.23 ln
Shannon Diversity	28.92	0.00	0.67	0.22	0.02	0.15	65.63	0.27	-0.53	0.08 n
Total Diversity	114.98	0.00	0.99	0.89	0.06	0.24	27.08	-3.21	9.19	0.35 ln
Simpson Dominance	93.74	0.18	1.00	0.72	0.04	0.20	28.05	-0.37	-0.74	0.08 n
Pielou Equitability	52.31	0.00	1.00	0.40	0.06	0.24	60.07	0.19	-0.61	0.06 n
					Preserved Cerrado					
individuals trap^{-1} day^{-1}	2384.00	0.00	234.00	18.34	800.52	28.29	154.29	4.26	26.57	0.25 ln
Jackknife Richness	447.00	1.00	6.00	3.44	1.50	1.23	35.67	-0.07	-0.50	0.17 ln
Simpson Diversity	93.74	0.18	1.00	0.72	0.04	0.20	28.05	-0.37	-0.74	0.08 n
McIntosh Diversity	112.99	0.00	13.45	0.87	2.13	1.46	168.09	5.69	43.89	0.27 ln
Shannon Diversity	29.13	0.00	0.67	0.22	0.02	0.15	64.95	0.25	-0.52	0.08 n
Total Diversity	115.78	0.00	0.99	0.89	0.06	0.24	27.01	-3.21	9.22	0.34 ln
Simpson Dominance	93.74	0.18	1.00	0.72	0.04	0.20	28.05	-0.37	-0.74	0.08 n
Pielou Equitability	52.31	0.00	1.00	0.40	0.06	0.24	60.07	0.19	-0.61	0.06 n
					Disturbed Cerrado					
individuals trap^{-1} day^{-1}	1777.00	1.00	96.00	13.67	238.01	15.43	112.86	2.80	9.46	0.26 ln
Jackknife Richness	365.00	1.00	6.00	2.81	1.24	1.11	39.69	0.08	-0.37	0.19 ln
Simpson Diversity	64.20	0.00	1.00	0.49	0.08	0.28	56.01	-0.51	-0.69	0.10 n
McIntosh Diversity	716.50	0.00	35.51	5.51	44.90	6.70	121.58	2.12	5.50	0.20 ln
Shannon Diversity	41.68	0.00	0.60	0.32	0.03	0.18	55.25	-0.53	-0.71	0.11 n
Total Diversity	75.56	0.00	0.99	0.58	0.11	0.33	57.06	-0.61	-1.03	0.14 ln
Simpson Dominance	58.80	0.00	1.00	0.45	0.07	0.27	60.25	0.46	-0.35	0.08 n
Pielou Equitability	86.59	0.00	1.00	0.67	0.11	0.33	49.39	-1.13	-0.04	0.19 ln
					Pasture					
individuals trap^{-1} day^{-1}	276.14	0.00	12.43	2.12	3.59	1.89	89.20	2.81	10.15	0.20 ln
Jackknife Richness	342.00	1.00	5.00	2.63	1.15	1.07	40.75	0.25	-0.54	0.19 ln
Simpson Diversity	72.10	0.00	0.90	0.55	0.05	0.23	42.03	-0.88	0.04	0.13 n
McIntosh Diversity	83.99	0.00	3.91	0.65	0.51	0.71	110.56	2.39	6.57	0.21 ln
Shannon Diversity	49.46	0.00	0.78	0.38	0.03	0.17	43.95	-0.43	-0.10	0.10 n
Total Diversity	86.82	0.00	0.99	0.67	0.09	0.30	44.30	-0.97	-0.32	0.18 ln
Simpson Dominance	59.91	0.00	1.00	0.46	0.08	0.27	59.55	0.36	-0.47	0.08 n
Pielou Equitability	86.10	0.00	1.00	0.66	0.11	0.33	49.69	-1.10	-0.10	0.17 ln

Min = minimum; Max = maximum; SD = standard deviation; CV = coefficient of variation; D = data normality by the Kolmogorov-Smirnov test at 0.01 % probability; n = Normal; ln = lognormal.

Table 5. Linear correlation matrix for the biodiversity indexes in the studied areas

Diversity index	Ind.trap	Jack. ric.	Simp.div.	McInt.div	Shan.div	Tot. div	Simp.dom	Piel.eq.
				Millet				
Individuals trap^{-1} day^{-1}	1.000							
Jackknife Richness	0.160	1.000						
Simpson Diversity	0.077	0.028	1.000					
McIntosh Diversity	0.041	-0.476	0.136	1.000				
Shanon Diversity	0.205	0.295	0.647	0.173	1.000			
Total Diversity	-0.010	0.514	-0.148	-0.988	-0.185	1.000		
Simpson Dominance	-0.177	-0.059	-0.706	-0.306	-0.946	0.316	1.000	
Pielou Equitability	0.092	-0.344	0.527	0.521	0.715	-0.548	-0.815	1.000
				Corn				
Individuals trap^{-1} day^{-1}	1.000							
Jackknife Richness	0.701	1.000						
Simpson Diversity	0.364	0.778	1.000					
McIntosh Diversity	-0.239	-0.244	-0.099	1.000				
Shanon Diversity	0.584	0.957	0.885	-0.293	1.000			
Total Diversity	0.609	0.847	0.796	-0.353	0.862	1.000		
Simpson Dominance	0.219	0.001	-0.220	0.636	-0.148	-0.005	1.000	
Pielou Equitability	0.400	0.744	0.945	-0.117	0.850	0.814	-0.103	1.000
				Soybean				
Individuals trap^{-1} day^{-1}	1.000							
Jackknife Richness	0.862	1.000						
Simpson Diversity	0.661	0.857	1.000					
McIntosh Diversity	0.422	0.307	0.492	1.000				
Shanon Diversity	0.820	0.965	0.943	0.379	1.000			
Total Diversity	0.788	0.943	0.962	0.401	0.989	1.000		
Simpson Dominance	0.346	-0.029	-0.108	0.716	-0.058	-0.077	1.000	
Pielou Equitability	0.722	0.869	0.990	0.491	0.952	0.963	-0.065	1.000
				Eucalyptus				
Individuals trap^{-1} day^{-1}	1.000							
Jackknife Richness	-0.084	1.000						
Simpson Diversity	0.098	0.573	1.000					
McIntosh Diversity	0.211	-0.497	-0.019	1.000				
Shanon Diversity	0.085	0.703	0.976	-0.142	1.000			
Total Diversity	-0.019	0.545	0.214	-0.358	0.279	1.000		
Simpson Dominance	-0.098	-0.573	-1.000	0.019	-0.976	-0.214	1.000	
Pielou Equitability	0.197	0.411	0.943	0.146	0.893	0.235	-0.943	1.000
				Preserved Cerrado				
Individuals trap^{-1} day^{-1}	1.000							
Jackknife Richness	0.403	1.000						
Simpson Diversity	-0.239	-0.340	1.000					
McIntosh Diversity	-0.195	-0.452	0.063	1.000				
Shanon Diversity	0.439	0.692	-0.664	-0.212	1.000			
Total Diversity	0.167	0.546	-0.037	-0.467	0.283	1.000		
Simpson Dominance	-0.427	-0.573	0.690	0.123	-0.968	-0.213	1.000	
Pielou Equitability	0.335	0.411	-0.665	-0.033	0.890	0.229	-0.943	1.000
				Disturbed Cerrado				
Individuals trap^{-1} day^{-1}	1.000							
Jackknife Richness	0.455	1.000						
Simpson Diversity	-0.113	0.653	1.000					
McIntosh Diversity	-0.328	-0.506	-0.341	1.000				
Shanon Diversity	0.043	0.820	0.942	-0.426	1.000			
Total Diversity	0.485	0.755	0.558	-0.668	0.661	1.000		
Simpson Dominance	0.278	-0.339	-0.660	0.510	-0.596	-0.218	1.000	
Pielou Equitability	-0.064	0.546	0.897	-0.314	0.845	0.537	-0.507	1.000
				Pasture				
Individuals trap^{-1} day^{-1}	1.000							
Jackknife Richness	0.083	1.000						
Simpson Diversity	-0.365	-0.030	1.000					
McIntosh Diversity	-0.116	0.008	-0.333	1.000				
Shannon Diversity	-0.186	-0.048	0.920	-0.433	1.000			
Total Diversity	0.265	0.051	0.481	-0.547	0.602	1.000		
Simpson Dominance	-0.011	-0.310	0.062	-0.120	0.128	0.086	1.000	
Pielou Equitability	0.037	0.546	-0.040	0.116	-0.118	-0.111	-0.493	1.000

Ind.trap: Individuals trap^{-1} day^{-1}; Jack. ric: Jackknife Richness; Simp.div: Simpson Diversity; McInt.div: McIntosh Diversity; Shan.div: Shannon Diversity; Tot. div: Total Diversity; Simp.dom: Simpson Dominance; Piel.eq: Pielou Equitability.

McIntosh, Shannon diversity, Simpson dominance, and Pielou equitability in the corn area; Simpson, McIntosh diversity, total diversity in soybean area; Simpson, McIntosh, Shannon diversity, total diversity, Simpson dominance, and Pielou equitability in the eucalyptus area; individuals $trap^{-1}$ day^{-1}, jackknife richness, Simpson diversity, McIntosh diversity, total diversity, and Pielou equitability in the preserved Cerrado area; Simpson diversity, Shannon diversity, Simpson dominance, and Pielou equitability in the disturbed Cerrado; individuals $trap^{-1}$ day^{-1}, Simpson, McIntosh, Shannon index, and Pielou equitability in the pasture area. Siqueira et al. (2016) evaluating the variability of weeds in a no-tillage system obtained a pure nugget effect for the Shannon diversity index, the same occurred in the present study for millet, corn, eucalyptus, disturbed Cerrado, and pasture areas. The pure nugget effect indicates that 3 m spacing was not sufficient to detect spatial variability (Vieira, 2000).

The other indices with spatial variability were fitted to a geostatistical model, Gaussian, spherical or exponential. For the millet only the Pielou equitability was adjusted to the spherical model, individuals $trap^{-1}$ day^{-1} and McIntosh diversity were fitted to the exponential model and total diversity to the Gaussian model (Table 6). Gholami et al. (2016) studying the spatial variability of the soil macrofauna associated to abiotic factors in a riparian forest in south-western Iran, it adjusted the exponential model to the index of uniformity, richness and diversity, and the spherical model to soil macrofauna abundance. Several authors describe that the spherical model is the one that best fits the soil and plants data (Cambardella et al., 1994; Vieira, 2000; Siqueira et al., 2008; Siqueira et al., 2009; Chiba et al., 2010; Silva et al., 2014; Siqueira et al., 2015b).

According to the classification of Cambardella et al. (1994), the spatial dependence degree for the individuals $trap^{-1}$ day^{-1} index and Pielou equitability in the millet area is high (above 75 %). For soybean and preserved Cerrado area, the spatial dependence remained the median (25 to 75 %). The highest value of nugget effect (C_0) was for individuals $trap^{-1}$ day^{-1} in eucalyptus (C_0 = 400), and the lowest value was for total diversity (C_0 = 0.008) in the pasture, which indicates good representativeness of the semivariogram fitting parameter. According to Carvalho et al. (2001), high values of nugget effect indicate discontinuity between the samples.

The range of values (a) ranged from 20 m individuals $trap^{-1}$ day^{-1} in eucalyptus to 78 m individuals $trap^{-1}$ day^{-1} in millet. The determination of the range values is needed to know to what point the samples are correlated with each other and the maximum spatial dependence distance between the samples (Vieira, 2000). For Carvalho et al. (2003), based on the range of spatial dependence, future samplings can be delineated, provided the same conditions are repeated. In a study on the spatial variability of the diversity indices of soil macrofauna, Gholami et al. (2016) found range values varying from 952 m for diversity to 2,967 m for the uniformity index.

Soil arthropods play a relevant role with regard to the ecosystem quality. However, their abundance and richness may be affected by land use and soil management (Lima et al., 2010), and by physical and chemical properties (Majer et al., 2007; Rousseau et al., 2014; Bedano et al., 2016). According to Birkhofer et al. (2010), the biotic relations also contribute to the formation of spatial patterns. In this sense, the presence of cover crops favors species of the soil epigeal fauna that are specialized and sensitive to abiotic alterations, e.g., Acari, Araneae, Diplura, Formicidae, and Poduromorpha. This occurs due to food offer, microclimate, and natural shelter (Batista et al., 2014; Gholami et al., 2014; Franco et al., 2016).

Soil use and management are directly related to spatial patterns of soil fauna (Ettema and Wardle, 2002; Bardgett and van der Putten, 2014). Therefore, it is possible to describe the greatest differences in the spatial distribution of soil macrofauna, mainly in preserved and disturbed Cerrado because the soil fauna is sensitive to minimal alterations caused by inappropriate soil use and management.

The scaled semivariogram was used to allow a comparison between diversity indices that express the difference of the scalar magnitude of soil fauna (Figure 2). In addition,

Table 6. Semivariogram fitting parameters for biodiversity indices in the studied areas

Diversity index	Model	C_0	C_1	a	r^2	SD
						%
		Millet				
individuals $trap^{-1}$ day^{-1}	Exponential	45	13	78	0.999	77.58
Log Jackknife richness			Pure nugget effect			
Log Simpson Diversity			Pure nugget effect			
Log McIntosh Diversity	Exponential	0.33	0.28	52	0.999	54.09
Log Shannon Diversity			Pure nugget effect			
Total Diversity	Gaussian	0.0167	0.0065	27	0.999	71.98
Simpson Dominance			Pure nugget effect			
Pielou Equitability	Spherical	0.0232	0.0074	60	0.999	75.81
		Corn				
individuals $trap^{-1}$ day^{-1}	Exponential	0.104	0.043	26	0.999	70.74
Jackknife richness	Gaussian	1.7	0.6	35	0.999	82.26
Log Simpson Diversity			Pure nugget effect			
McIntosh Diversity			Pure nugget effect			
Shannon Diversity			Pure nugget effect			
Total Diversity	Gaussian	0.089	0.025	33	0.999	78.07
Simpson Dominance			Pure nugget effect			
Log Pielou Equitability			Pure nugget effect			
		Soybean				
individuals $trap^{-1}$ day^{-1}	Exponential	0.5	0.5	40	0.999	50.00
Jackknife richness	Spherical	0.34	0.2	50	0.999	62.96
Simpson Diversity			Pure nugget effect			
McIntosh Diversity			Pure nugget effect			
Log Shannon Diversity	Exponential	0.019	0.012	56	0.999	65.91
Log Total Diversity			Pure nugget effect			
Log Simpson Dominance	Exponential	0.018	0.013	40	0.999	58.06
Pielou Equitability	Exponential	0.14	0.08	35	0.999	63.63
		Eucalyptus				
individuals $trap^{-1}$ day^{-1}	Gaussian	400	700	20	0.999	36.36
Jackknife richness	Gaussian	1.23	0.35	75	0.999	77.84
Log Simpson Diversity			Pure nugget effect			
McIntosh Diversity			Pure nugget effect			
Shannon Diversity			Pure nugget effect			
Total Diversity			Pure nugget effect			
Simpson Dominance			Pure nugget effect			
Pielou Equitability			Pure nugget effect			
		Preserved Cerrado				
Log individuals $trap^{-1}$ day^{-1}			Pure nugget effect			
Log Jackknife richness			Pure nugget effect			
Simpson Diversity			Pure nugget effect			
McIntosh Diversity			Pure nugget effect			
Shannon Diversity	Guassian	0.0086	0.0045	50	0.999	65.64
Log Total Diversity			Pure nugget effect			
Log Simpson Dominance	Exponential	0.0118	0.0055	45	0.999	68.20
Log Pielou Equitability			Pure nugget effect			
		Disturbed Cerrado				
individuals $trap^{-1}$ day^{-1}	Exponential	0.12	0.06	22	0.999	66.66
Jackknife richness	Gaussian	0.98	0.38	30	0.999	72.05
Log Simpson Diversity			Pure nugget effect			
McIntosh Diversity	Gaussian	0.34	14	31	0.999	70.83
Shannon Diversity			Pure nugget effect			
Log Total Diversity	Gaussian	0.08	0.035	30	0.999	69.56
Log Simpson Dominance			Pure nugget effect			
Log Pielou Equitability			Pure nugget effect			
		Pasture				
individuals $trap^{-1}$ day^{-1}			Pure nugget effect			
Log Jackknife richness	Exponential	0.8	0.45	36	0.999	67.93
Simpson Diversity			Pure nugget effect			
McIntosh Diversity			Pure nugget effect			
Shannon Diversity			Pure nugget effect			
Log Total Diversity	Gaussian	0.008	0.016	30	0.999	83.33
Log Simpson Dominance	Exponential	0.055	0.026	45	0.996	67.90
Log Pielou Equitability			Pure nugget effect			

C_0: nugget effect; C_1: Structural variance; a: range; r^2: Correlation coefficient; SD: Spatial dependence (%).

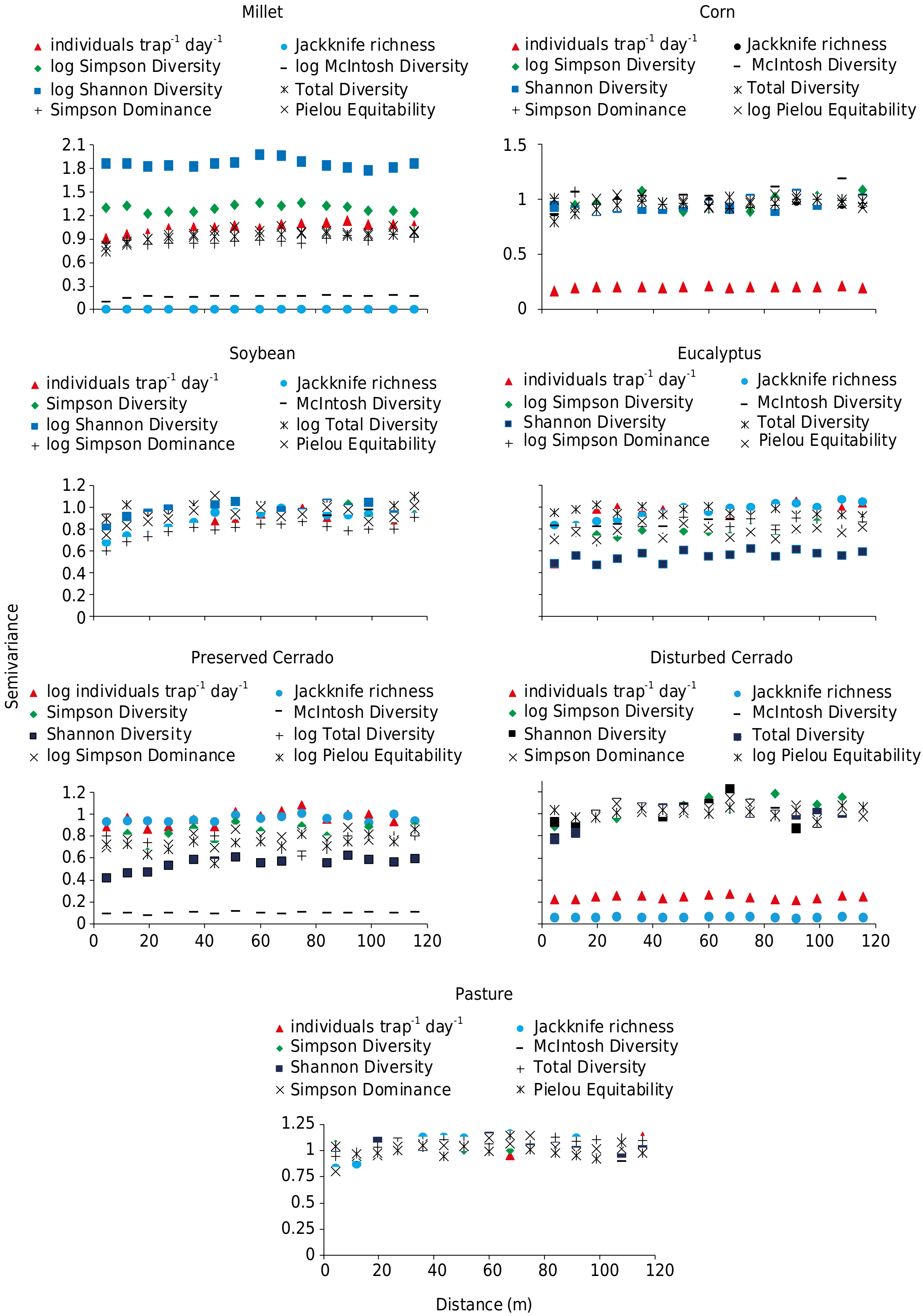

Figure 2. Scaled semivariograms for biodiversity indices in the studied areas.

it favors the comparison and comprehension of the spatial variability of the studied diversity indices.

For the areas of soybean and pasture, biodiversity indices suggested similarity of spatial variability. However, the Shannon diversity, Simpson diversity, McIntosh diversity, and jackknife richness indices in millet were more dispersed than the other indices of this crop area. The same was observed for individuals trap^{-1} day^{-1} in the corn area; Shannon diversity in eucalyptus; McIntosh diversity in the preserved Cerrado; and individuals trap^{-1} day^{-1} and Jackknife richness in the disturbed Cerrado. The greatest differences described for soil macrofauna diversity indices by the scaled semivariogram are a result of the soil management, disturbance degree, and sensitivity of macrofauna groups to food availability.

Therefore, the semivariance of the Shannon index was higher for millet than the other semivariance values of the other indices for the area, separating this index from the others. In the other cases, the semivariance was close to zero, and lower than the indices with similar variability.

This dispersion may be explained by the parameters used to determine the indices. The individuals trap^{-1} day^{-1} indices take the number of individuals collected in a sample of seven days into consideration, so this value always tends to be higher or equal to the others. With regard to the Shannon, Simpson, and McIntosh indices, the total number of species in a given sample is considered, and, specifically in the case of McIntosh diversity, the square root of the sum of the number of individuals, which explains the high values of semivariance in the Shannon and Simpson indices and the low semivariance of McIntosh's index in millet.

Another explanation for the variation in semivariance values may be related to the number of individuals collected in each area and their distribution among the samples. In an evaluation of the Shannon and Simpson diversity indices in weeds, Siqueira et al. (2016) observed similar spatial variability of these indices.

CONCLUSIONS

Soil management and land use affected the patterns of soil fauna abundance, richness and diversity. The presence of groups such as Araneae, Diplura, and Poduromorpha indicated the ecological equilibrium, quality and sustainability of the agricultural systems studied. Geostatistical techniques satisfactorily analyzed the spatial dynamics of soil fauna in the seven studied areas. The spatial variability of all indices in the soybean and pasture area is similar, with close semivariance values.

ACKNOWLEDGMENTS

The authors are indebted to the Fapema (Foundation for Research and Scientific and Technological Development of Maranhão, Brazil) for the financial support of the project (Apcinter-02587/14, BATI-02985/14, Universal-00735/15, BEPP-01301/15, APEC 01697/15, BM-01267/15, Fapema/05232/15 and BD-01343/15). Authors would like to thank CNPq (*Conselho Nacional de Desenvolvimento Científico e Tecnológico*) for the grant awarded to the second and fifth author.

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