UNIVERSIDADE FEDERAL DO MARANHÃO
CENTRO DE CIÊNCIAS AGRÁRIAS E AMBIENTAIS
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIA ANIMAL
CHAPADINHA-MA

DISSERTATION

MATHEMATICAL MODELLING OF SOIL DIVERSITY INDICES UNDER DIFFERENT USES AND MANAGEMENTS

RAIMUNDA ALVES SILVA

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Orientation: Glécio Machado Siqueira

Dissertation submitted to the Graduate Program in Animal Science as a partial requirement to obtain a master's degree in Animal Science.

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Love and you shall be loved.

With love MARIA GRAZIELLA (In memorium).

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ABSTRACT: Soil is the habitat for a number of living organisms that perform essential functions to the ecosystem. The present work aimed to determine the edaphic diversity in large groups under different uses and management of the soil in Cerrado Biome. The study was developed in the city of Mata Roma (3º 70 '80.88' 'S and 43º 18' 71.27 " W), in the eastern region of Maranhão state, Brazil. It were installed 130 pitfall traps in five areas with different management (millet, soybean, maize, eucalyptus, and pasture) and two reference areas with natural vegetation with different uses (anthropized Cerrado and preserved Cerrado). The traps remained in the field for a period of seven days, after this, the contents were maintained in plastic bottles and taken to the laboratory, where they were sampled and identified in large groups (orders and family). After identification, the biodiversity indexes were determined: (Shanon index, Pielou, Average and total richness and abundance). The data were analyzed using descriptive statistics and multivariate techniques using group dissimilarity. The geostatistical analysis was evaluated by a semivariogram, adjusted to a geostatistical, spherical, gaussian or exponential model. The multifractality was analyzed by the current method, in successive segments of different sizes of 2^k, k=0 a k= 7 in the range of q = +10 to q = -10. 20,995 arthropods were collected throughout the study. The highest abundance was found for millet (9,974 individuals), and the lowest abundance values were reported for soybean (222) and maize (824), respectively. The highest biodiversity index is reported for the soybean area (2.69), although there is less abundance, in this area, the groups are evenly distributed due to the homogeneous management in the study area. The main axis in the analysis of the main components (PCA) explained 50.9% of the correlation of the groups with the sampled areas. The dendrogram had demonstrated that the area of soybean and maize are similar and had isolated the area of millet with the most dissimilar in relation to the others. The use and management of the soil in the study areas determine the occurrence of soil arthropods in function of food availability. For the areas of millet, maize, eucalyptus, anthropized Cerrado and pasture the Shanon diversity index obtained pure nugget effect. For the areas of millet, maize, anthropized Cerrado and pasture, the total diversity index was adjusted to the gaussian model. Only for the areas of soybean and pasture the staggered semivariograms showed similarity in the spatial variability of indexes, indicating that they behave similarly. The multifractality generated generalized dimension, D_0, for all the indexes in the millet area, with invariant values, $D_0 = 1.000 \pm 0.000$. The singularity spectra were curves in concave parables with greater or smaller asymmetry for all areas sampled. In general, the fauna of soil presented spatial variability and multifractal parameters.

Keywords: Edaphic Arthropods, Soil Quality, Soil Invertebrates, Geostatistics, Multifractal Analysis.

1. INTRODUCTION

The *Cerrado* is the second largest biome in Brazil, behind only the Amazon forest in extension (Silva and Bates, 2002; Sano et al., 2010). It is composed of a mosaic of natural landscapes, configured by several ecosystems with different physiognomies such as Cerradão, Cerrado *sensu stricto*, Campo Rupreste, Palm Grove, Vereda, Galeria Mata, Ciliary Forest and Mesophytic Forest (Oliveira-Filho and Ratter, 2002; Junior and Haridasan, 2005). Having several characteristics in fauna and flora as endemic species (Fiedler et al., 2004), is considered one of the 25 points in the world for conservation *"hotspot*" (Myers et al., 2000).

In the Brazilian Northeast, the *Cerrado* covers approximately 31,8 million hectares, comprising the states of Piauí, Bahia and Maranhão. In the State of Maranhão, the *Cerrado* covers a total of 9.8 million hectares, 30% of the state total area. It is a region with soils of low fertility, high acidity, high concentrations of aluminum and with low water availability fo for plants, but adequate for mechanization and agriculture use (Conceição and Castro, 2009). The precipitations have a high degree of homogeneity with the highest averages of the Northeastern *Cerrado*, varying from 1,200 mm to the extreme of 1,500 mm (França, 1996).

A significant demographic increase, an increasing demand for food and the search for areas with productive potential in the last 50 years, has led to the occupation of the brazilian *Cerrado* by monocultures such as soybean and sugarcane, turning this region in the country main agricultural frontier. According to the National Supply Company (CONAB), the grain cultivated area in the years 2015/2016 was 210.5 million hectares, which represents an increase of 1.4% compared to the last harvest in 2014. Associated to the cultivation of this vast area, a great investment on high-cost specialized machinery has also been observed in this area lately, which might lead to some modifications in the soil, such as compaction, erosion, contamination by agrochemicals as well as losses of edaphic biological diversity.

In agricultural terms, the state of Maranhão is being considered a new agricultural frontier in the last years. This expansion started in the south of the state, in the municipalities of Tasso Fragoso, Riachão and Balsas. Lately, the production of commodities such as soybean in the East region of Maranhão has grown, mainly in the municipalities of Alto Parnaíba, São Raimundo das Mangabeiras, Sambaíba, Fortaleza dos Nogueiras and Chapadinha. According to Presoti (2008), the microregion of Chapadinha is responsible for 78% of Maranhão East production, where the municipalities of Anapurus has an area corresponding to 4,379 ha, Brejo 7,920 ha, Buriti 7,383 ha and Mata Roma 2,670 ha. Regarding the production of maize, the state ranks as the tenth, with a total of 731,300 tons in the first two harvests of 2016 (IBGE, 2016).

In this perspective, it has been observed that the state of Maranhão has expanded its agricultural sector, although the advances in studies had not followed this growth. Thus, it is possible that the biological diversity in these newly opened areas is still unknown and eliminates the ecosystem services provided to the soil by edaphic organisms. The objective of this work was to evaluate the diversity, spatial variability and fractal pattern of soil fauna under different uses and management of soil.

2. LITERATURE REVIEW

2.1 Biological diversity

Brazil has the largest number of vertebrate fauna and high plant diversity and of endemic species. However, regarding the invertebrate fauna, which represents a large mass of living biological species, the informations are still incomplete. The last surveys for the Hexapoda, describe 90,269 species determined for Brazil, while the estimate is 400,070 species (Rafael et al., 2012), this denotes how much the knowledge of invertebrate fauna still insipient.

In this context, the Arthropoda phylum is represented for about 800 thousand species, being the most numerous of the animal kingdom and surpassing all the other phyla together (Rafael et al., 2012). It has adaptability to different environments, high reproductive capacity, and in some cases, high abundance by constituting social organization. In ecological terms, some groups are considered agricultural and urban pests, pollinators of diverse species of plants (Giannini et al., 2015), environmental bioindicators (Tylianakis et al., 2004, 2005, 2006, Vezzani and Mielniczuk, 2009), decomposers (Sulkava et al., 2001; Decaens et al., 2003), herbivores, predators, parasites (Soares et al., 2010), ecosystem engineers (Lavelle, 1977; Blouin et al., 2013), besides being prey of vertebrates and invertebrates in the trophic chain.

The studies of distribution, richness, abundance, diversity and structural organization of groups can be influenced by the variation in climatic conditions, being the climate a determinant factor for the population fluctuation (Marinoni and Ganho, 2003), type of vegetation and food resources (Siqueira et al., 2014), precipitation (Bispo et al., 2006), interspecific competition (Silva et al., 2011). Faunal analyzes represent a starting point for more specific studies. The determination of species abundance is a benchmark for the comparison of communities, since it allows delimiting the characterization of a community, to measure the environmental impact, to determine the predominance of ecological groups and indicators, to describe the dynamics of the ecosystem and to establish criteria for management programs (Frizzas et al., 2003).

The soil biota comprises a range of organisms with a variety of sizes and numerous functions in the soil (Araújo et al., 2007). Regarding to the invertebrates, almost all classes develop a phase or are completely edaphic. Some organisms constitute the soil microfauna, since the body diameter varies from 4 μm to 100 μm (Swift et al., 1979), are directly involved in the cycling of nutrients, as they ingest bacteria and fungi, which can intensify the mineralization of the microbial mass (Correia and Oliveira, 2000), causing changes in the biochemical processes of soil.The mesofauna is composed of organisms of 100 μm to 2 mm, characterized by a totally terrestrial habitat and their dependency on the environment humidity. They are trophic regulators of the microfauna and act as shredders of decomposing plant material (Correia and Andrade, 1999).

The macrofauna is composed of organisms with a body diameter of 2 mm to 100 mm and are considered engineers of the ecosystem, since their body is large enough to break down the mineral and organic structures when feeding, moving and building galleries in the soil (Correia and Oliveira, 2000). Functionally, macrofauna redistributes microbial organic matter, creates biopores, promotes humification and produces fecal acorns that maintain soil fertility (Oliveira, 2008).

2.2 Uses and Soil Management

The proper management of the soil provided numerous benefits to the planted crop, besides favoring the edaphic organisms in general. Depending on the type of soil preparation, there may be the formation of compacted layers, reduction of micropores which hinders the entry of air, water and root development (Nascente et al., 2011).

The no-tillage system favors microbiological activities, increase in organic matter content, as well as the incorporation of residues in the soil, which incorporates nutrients into the system. Conservation systems, result in the significant improvement of soil physical and chemical attributes (Siqueira Neto et al., 2010; Vezzani and Mielniczuk, 2011). The improvement in soil quality is due to the soil protection that this management system offers. There is still a reduction in waste fragmentation, because there is no upturn in the soil.

In no-tillage system, the soil fauna is in thesis benefited. Because there is no soil turnover, organisms are able to complete development by performing all functions in the environment. The presence of soil cover throughout the year provides habitats and feed the edaphic fauna in all stages. Allied to this, the reduction in the application of agrochemical, and crop rotation favors diversity and allows the fauna to develop.

2.3 Diversity indexes

The term biodiversity is a contraction of the expression biological diversity. It refers to the existing number of *taxa* in a given location (alpha diversity), or to a diversity in a region (beta diversity). Some parameters are taken into account for expressing the biological diversity, such as richness (number of species) and relative abundance (number of individuals belonging to the species) (Ricklefs, 2003).

The changes in invertebrate fauna can be accessed through quantitative approaches (abundance, density and richness); which has lately been the potential parameters for the selection of bio indicators of soil quality, providing information on changes occurred in the environment over time. In this way, it is targeted a greater diversity, aiming the balance, a basic condition for the maintenance of ecosystems quality.

The ecological indixes enable the quantification of diversity (Shanon Index), the equitability or uniformity (Pielou Index), richness (Jackknife richness) and dominance (Simpson Dominance Index). Each index has its peculiarity. The Shanon index is the most used in biological diversity analysis. It was developed in 1949, and expresses the uncertainty of which species belongs an individual randomly taken from a community, containing "S" species and "N" individuals. In this case, the higher the index value, the more diverse the sample in question. The values assumed vary from 0 to a maximum value, usually around 3.5 (Magurran, 1988; Zanzini, 2007).

The Pielou equitability expresses the distribution of individuals among different species of a sample. The values of Pielou vary from 0 to 1 and values close to 1 denote that the species are well distributed, having no predominance of a group in the sample (Zanzini, 2007).

Regarding the applicability of diversity indexes, studies such the one conducted by Bennazi et al. (2013), verified that the richness index was the most appropriate for characterizing the influence of different harvesting methods of sugarcane in soil macro fauna. These authors also identified the presence of a dominant group whose high abundance reduced the equitability and diversity of fauna. The index of richness and abundance were used by Lima et al. (2010) in different agro-systems, where areas with agroforestry systems had better soil chemical quality and, consequently, higher values of fauna richness and abundance. Similarly, the Shanon diversity and Pielou equitability indexes were best expressed by Moura et al. (2014) in systems with high quality legume residues (*Gliricidia sepium*) that improved soil quality and increased the diversity of edaphic fauna.

In Brazil, despite the existence of studies that quantify the biota of soil by the indices, they are still irrelevant as to the area and diversity of biomes occurring in the country. In Maranhão state, the few studies comprises the diversity of agro ecological systems (Oliveira, 2013, Moura et al., 2014, Moura et al., 2016), in chronosequence of capoeiras (Rousseau et al., 2014), and nematodes in several crops (Doihara, 2015).

2.4 Spatial variability

Geostatistics allows the understanding, observation, modeling and mapping of the spatial variability of different attributes (Siqueira et al., 2015). It is an important tool in detailed analysis of physical, chemical and biological attributes (Vieira, 2000; Filho et al., 2011). This approach results in less random errors because it encompasses a set of statistical methods for the analysis and mapping of data distributed in the time and / or space.

The studies on geostatistical started in 1951, with Daniel G. Krige, who could not find meaning in the values of variance without taking into account the distance between the samples (Vieira, 2000; Farias, 2002). Based on these first observations, this author developed the theory of regionalized variables, which comprehends the basis of geostatistics (Matheron, 1963, 1971). The concept used by Matheron (1963), defines variables as a numerical function, which varies from one place to another, with apparent continuity where the variation can not be represented by a simple mathematical function.

According to Vieira (2000), the geostatistical hypotheses comprehends: the second order stationarity hypothesis, the intrinsic hypothesis and the universal tendency or kriging hypothesis. The first hypothesis implies on the existence of finite variance related to the measured values, which is hardly satisfied, since it does not apply to phenomena that have an infinite dispersion capacity. The second hypothesis is less restrictive, requiring only the existence and stationarity of the semivariogram, without restriction in relation to the finite variance, being the most used hypothesis. Universal kriging has infinite dispersion capacity, it does not have finite variance and its covariance can not be determined.

In general, the geostatistical study assumes that the measurements localized nearer of each other are more similar than those separated by larger distances (Vieira et al., 1981; Vieira et al., 2002). According to Sturaro (1993), the basic difference between statistics and geostatistics is that the first requires that the sample values be spatially independent, on the other hand, geostatistics requires that the sample values be spatially correlated.

The attributes of soil are heterogeneously distributed on earth, as a consequence of the processes of soil formation (Paz González et al., 2000, Vieira and Paz González, 2002, Bonnin et al., 2010). Recently, the studies in soil science have taken into account the variability of soil attributes in time and space, considering soil heterogeneity as its intrinsic characteristic. This allows a localized management of soil (Paz González et al., 2000), less expenditures on inputs (Huang et al., 2006), changes in the management practices, reduction of environmental problems (Cambardella et al., 1994; Corá et al., 2004) and consequently crops with higher yielding (Grego and Vieira, 2005).

In order to reduce the effects of environmental degradation, it is important to note that there is a significant reduction in environmental degradation (Huang et al., 2006; Corá et al., 2004) and consequently higher crop yields (Grego and Vieira, 2005). Lately, the geostatistics has been used in agriculture in a series of different purposes. It has been applied in order to understand soil attributes such as its resistance to penetration (Souza et al., 2009; Tavares et al., 2015); its electrical conductivity (Siqueira et al., 2014, 2015, 2016); water content (Siqueira et al., 2008; Siqueira et al., 2015); density and porosity (Siqueira et al., 2009); and roughness. The geostatistics has also been used in the estimation of soil chemical attributes such as micronutrients (Dafonte Dafonte et al., 2010); PH (Morales et al., 2010); Nitrogen, phosphorus and potassium (Morales et al., 2014); (Guedes Filho et al., 2010), and biometric attributes of plants (Grego et al., 2010, Filho et al., 2011).

In terms of spatial variability of biological diversity, few studies have characterized this diversity by geostatistical techniques. Neves et al. (2010) used geostatistics to assess the biodiversity of natural reserves in the State of São Paulo. The variability of weeds was also characterized by Siqueira et al. (2005) and Siqueira et al. (2016), which correlated this variability with the apparent electrical conductivity of soil, and determined the distribution of weeds in reboleiras.

However, the edaphic fauna, an important component in the maintenance of soil quality, is only sampled aiming the estimation of diversity, abundance and distribution. There are no studies aiming the estimation of spatial variability of edaphic organisms, being necessary to evaluate how these organisms are distributed in space, in order to assure a proper management, when necessary.

2.5 Fractal theory

The term *fractus* means breaking, shattering. Thus, fractal is an object that presents invariance in its form as long as the scale in which this object is being analyzed is altered, this object keeps its original form. In other words, some objects can not be explained by conventional mathematics, being necessary a theory that might better explain. The term fractal is derived from the Latin term *fractus*, proposed by B. B. Mandelbrot, in order to gather objects that have continuous but non-differentiable forms (Mandelbrot, 1982). It is characterized by a potency law between the number and size of objects, to an exponent D, called fractal dimension (D_f) (Mandelbrot, 1982; Castrignano and Stelluti, 1999).

Thus, when an in-line length is evaluated, the measurement is given in spatial scale (δ), and the length of this line is L (δ) and estimated as a set of N segments of line lengths (δ). It is estimated that the small details in lines are not recognized in small spatial resolution, turning visible only at higher resolutions. In this case, the measured length of L (δ) increases as the measurement scale decreases. What was expressed by Mandelbrot (1967) when describe that the relationship between length and scale can be obtained by a potency law, where D_f is the key element for measuring irregularities of complex objects (Sun et al., 2006).

Fractal geometry, unlike euclidean geometry, is not necessarily an integer value. The fractal is a fractional number that represents the degree of occupation in space (Gouvea and Murari, 2004). From a line segment, which divided into three equal segments, forms a triangular image. In sequence, applying the same rule, the image formed is immediately equal to the previous one. Thus repeating the same process a succession of infinite lengths is obtained, which are defined by Mandelbrot as "internal infinity" (Gouvea and Murari, 2004).

However, an object is not always characterized in a single scale. In these cases, the variable presents complex behavior, being represented by a set of fractal, which is conceptualized as multifractal theory. The multifractal theory allows the quantitative evaluation of complex phenomena in spatial and temporal sphere. The patters of multifractal are considered the most appropriated for analyzing extreme variability over a range of scales (Lovejoy and Shertzer, 2007).

Thus, the fractal and multifractal geometry offer new concepts to define the heterogeneity of soils. The fractal dimension (D_f), in turn, becomes an indicative for autocorrelation of natural phenomena, allowing the quantification and integration of informations related to soil physical, chemical and biological attributes, measured at different temporal and spatial scales (Perfect and Kay, 1995; Eghball et al., 1999).

Fractal/multifractal analysis is already used for measuring and quantify physical characteristics (Caniego et al., 2005, Vidal-Vásquez et al., 2008), Siqueira et al., 2013, Valcárcel-Armesto et al. (1988); soil chemistry (La Scala et al., 2009, Panosso et al., 2012, Dafonte Dafonte et al., 2015); Soil properties that are constant over time as standards of particle size (Wang et al., 2009, Vidal Vázquez et al., 2013); Properties that are modified by soil management, such as soil carbon (Caniego et al., 2005); as well as soil penetration resistance (Siqueira et al., 2013, Wilson et al., 2015, López de Herrera et al., 2016). However, studies characterizing edaphic fauna by fractal / multifractal patterns are still unknown.

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Soil fauna diversity under different uses and managements

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ABSTRACT: Soil is the habitat for a number of living organisms that perform essential functions to the ecosystem. The present work aimed to determine the edaphic diversity in large groups under different uses and management of the soil in Cerrado Biome. The study was developed in the city of Mata Roma (3º 70 '80.88' 'S and 43º 18' 71.27 " W), in the eastern region of the State of Maranhão, Brazil. Were installed 130 pitfall traps in five areas with different management (Millet, Soybean, Maize, Eucalyptus, and Pasture) and two reference areas with natural vegetation with different uses (anthropized Cerrado and preserved Cerrado). The traps remained in the field for a period of seven days, after this, the contents were maintained in plastic bottles and taken to the laboratory, where they were sampled and identified in large groups (orders and family). After identification, the biodiversity indexes were determined: (Shanon index, Pielou, Average and total richness and abundance). The data were analyzed using descriptive statistics and multivariate techniques using group dissimilarity. 20,995 arthropods were collected throughout the study. The highest abundance was found for millet (9,974 individuals), and the lowest abundance values were reported for soybean (222) and maize (824), respectively. The highest biodiversity index is reported for the soybean area (2.69), although there is less abundance, in this area, the groups are evenly distributed due to the homogeneous management in the study area. The main axis in the analysis of the main components (PCA) explained 50.9% of the correlation of the groups with the sampled areas. The dendrogram had demonstrated that the area of soybean and maize are similar and had isolated the area of millet with the most dissimilar in relation to the others. The use and management of the soil in the study areas determine the occurrence of soil arthropods in function of food availability.

Keywords: Edaphic Arthropods, Soil Quality, Soil Invertebrates.

1. Introduction

The soil is a natural, live and dynamic system, which pursue uncountable functions to the ecosystems. The understanding of the soil must start from the understanding of the physical and chemical aspects and also from the interaction between the organisms (Bottinelli et al., 2015). The soil invertebrates play an important role in ecological processes, are directly involved in nutrient cycling (de Vries et al., 2013; Wagg et al., 2014), energy flow (Neher et al., 2012), organic matter decomposition and mineralization (Carrillo et al., 2011; Bernard et al. 2012) and bioturbation that is directly connected to the formation of channels, pores and aggregates in soil.

The epigaeous fauna communities provide the nutrients to the plants, cause mineralogical and microstructural transformations of the soil (de Oliveira et al., 2014). However, factors can change the soil fauna, directly interfering in the ecological services performed by them (Ruiz & Lavelle, 2008). The soil turning, succession of the employed culture, edaphoclimatic conditions, type of soil cover and agrochemicals use to decrease the activity of some individuals or reduce the most sensitive groups to environment changes.

The use and management of the soil are one of the factors that cause a drastic reduction in the fauna groups of the soil, leading to degradation, reduction or loss of agricultural production capacity (Wolters, 2001; Siqueira et al., 2014). The reduction or extinction of some soil invertebrates groups, as well as the beneficial activities, developed, contributes to the high rates of land deterioration, fertility decline, nutrient reduction and arthropod pests increase (Dominguez et al., 2014).

The study of invertebrate communities in the soil allows to evaluate the functionality of these organisms in the soil and the complexity of ecological processes (Aquino et al., 2008; Moço et al., 2010), the answers of these communities to the different types of management, environmental interaction or change of habitat (Rousseau et al., 2012; Vasconcellos et al., 2012). In this sense, highlights the importance of abundance and diversity that allows the knowledge of the dynamics and allows the development of biodiversity indicators and the use of the soil considering the ecological function, taking into account that the edaphic invertebrates are present in all levels of the trophic chain, directly affecting the primary production.

The biological diversity indexes are parameters that take into account the amount of specimens collected and the distribution of the individuals within the species. The values of diversity indexes are indicative of the structure or fragility of the community, clearly expressing the presence or absence of rare organisms. This study aimed to evaluate the diversity of the soil fauna in different production agrosystems in a Oxisol.

2. Materials & Methods

2.1. Site experiment

The study was conducted in the city of Mata Roma, in the eastern region of Maranhão State, Brazil, where the coordinates are 3º 70 '80.88" S and 43º 18 '71.27" W (Figure 1). The region climate, according to Köppen classification, is the tropical humid type, with two well-defined seasons, one rainy (December to June) and one dry (July to November), with average annual temperatures ranging between 27ºC and 30ºC. The precipitation varies from 1,400 mm to 1,600 mm, with annual evapotranspiration 1,144 mm^3 (Figure 2).

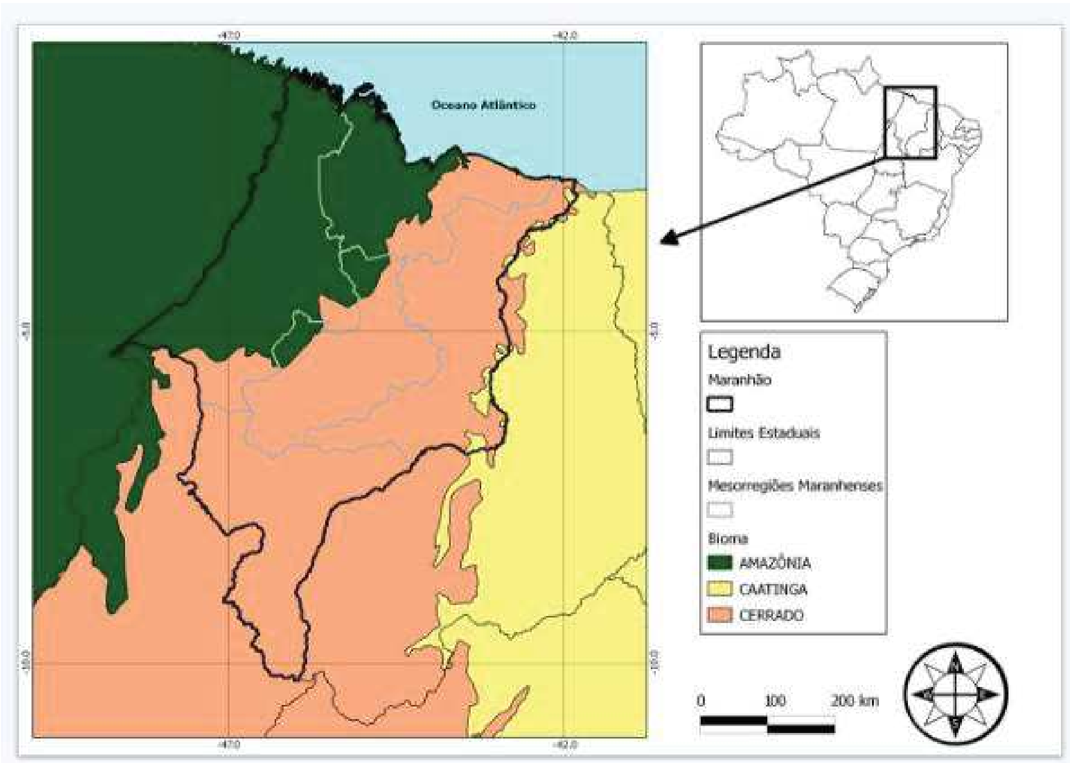

Fig. 1. Location of the study area in Brazil.

The soil of the area is classified as Oxisol, whose physical and chemical characteristics of 0.0-0.2 m depth layer were determined according to USDA (1999) (Table 1).

Seven areas of different uses and management were evaluated: 1) Millet (ME) (108 ha), species used on the cover of the soil in the off-season, due to its importance in nutrient cycling and soil conservation; 2) Maize (MA) (103 ha); 3) Soybean (SO) (113 ha), both areas were implanted to nine years in replacement of a typical cerrado and maintain a crop rotation system, the two areas use herbicide, fertilizers, a subsoiling of 32 cm at each five; in the soybean area is used desiccant at the end of the cycle (sampling occurred at the end of the soybean cycle and five days after dissects application); 4) Eucalyptus (EC) (3.79 ha) Cultivated for seven years and with high content of organic matter and litter; 5) preserved

Cerrado (CP) (33.08 ha)) Environmental preservation area in regeneration of the cerrado biome, with main plant species such as bark (*Stryphnodendron adstringens* Mart.), Copaiba (*Copaifera martii* Hayne), pequi fruit (*Caryocar brasiliense* Cambess); 6) Anthropic Cerrado (AC) (20.44 ha) constitutes a cerrado strip used for cattle grazing, wood removal in small-scale, due to this, has a heterogeneous vegetation with clearings; 7) Pasture (PA) (3 ha) is used for grazing of goats and sheep.

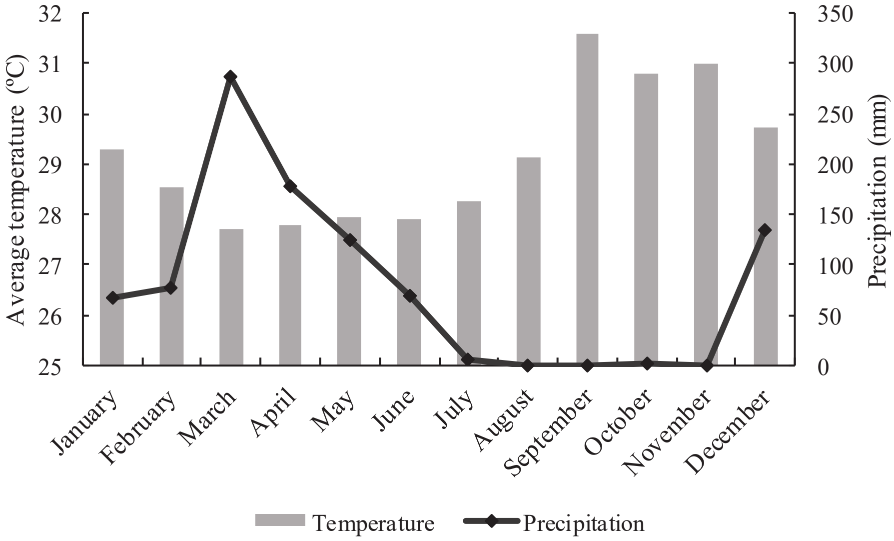

Fig. 2. Average monthly temperature and precipitation in the year 2015.

Table 1. Granulometric characterization and chemical characterization of the soil in the studied areas.

	Clay	Silt	Sand	Density	Total porosity	Microporosity	Macroporosity
	-------g/kg^{-1}--------			Mg m^{-3}	m^{3}m^3		
Millet	120.0	110.0	490.0	1.56	32.5	15.2	22.1
Maize	147.0	107	747.0	1.47	27.0	14.2	20.7
Soybean	80.0	70.0	590.0	1.72	38.6	13.2	22.7
Eucalyptus	257.0	56.0	657.0	1.32	30.0	15.9	20.9
Preserved Cerrado	261.0	58.9	681.0	0.97	33.6	15.5	17.8
Anthropic Cerrado	256.0	57.0	667.0	1.22	34.4	15.4	18.7
Pasture	232.0	68.0	540.0	1.16	35.6	16.7	18.6
	OC	P	pH	K	Ca	Mg	CEC
	---g/dm^3---		CaCl^2	----------------------mmolc/dm^3 -----------------------			
Millet	29.0	18.0	4.6	2.2	20.0	4.0	51.2
Maize	19.0	14.0	5.0	2.4	26.0	5.0	56.4
Soybean	22.0	49.0	5.0	0.7	18.0	3.0	46.7
Eucalyptus	27.0	10.0	4.7	0.3	14.0	5.0	54.3
Preserved Cerrado	15.0	7.0	4.1	0.2	2.0	1.0	35.2
Anthropic Cerrado	21.0	8.0	4.2	0.5	3.0	3.0	42.5
Pasture	18.0	12.0	5.3	2.2	22.0	8.0	55.2

OC= Organic carbon; P= Phosphorus; K= Potassium; Ca= Calcium; Mg= Magnesium; CEC= Cation exchange capacity.

The intensity determination of the soil use was conducted in function of each area historical, with attribution of 0 (zero) for an area with no use and the maximum value of 3 for an area with intense use (Table 2).

Table 2. Location, soil type, culture management and natural area studied.

Coordinates	Soil type	Vegetation	Soil cover (%)	Weeds	Pesticides	Soil use intensity
3º69'21.18''S 43º19'49.31''W	Oxisol	Millet	100	No	Yes	3
03º41'423''S 043º11'481''W	Oxisol	Maize	100	No	Yes	3
03º41'932"S 043º11'475"W	Oxisol	Soybean	100	No	Yes	3
3º70'91.90"S 43º18'86.83"W	Oxisol	Eucalyptus	90	No	No	3
03º41'902"S 043º11'477"W	Oxisol	Preserved Cerrado	100	Yes	No	0
3º71'09.76"S 43º18'84.02"W	Oxisol	Anthropic Cerrado	90	Yes	No	1.5
3º70'70.68"S 43º18'13.82"W	Oxisol	Pasture	80	Yes	No	3

2.2 Sampling and diversity of the soil fauna

The soil fauna was collected in the period from May of 2015, using pitfall traps, and consisted of the installation of plastic bottles approximately 9 cm of height and 8 cm in diameter allocated at soil level. When moving, animals accidentally fall into the traps and during the sample period remain preserved by the solution of 200ml at 4% formaldehyde deposited in the bottle (Aquino et al., 2001; Siqueira et al., 2014). 130 traps were allocated in a transept with a spacing of 3 m, these traps remained in the field for a period of seven days, after that period were removed from the field and all contents were transferred to bottles containing alcohol 70%.

In the laboratory, the content of each bottle was transferred to a petri dish and identified with clamp aid, binocular magnifying glass and identification key in functional groups (Order, family and larvae). In this study, the Formicidae family was separated from the Hymenoptera Order to the ecological importance exercised in the ecosystem. After identification, all contents were returned to their respective bottles and stored in the laboratory as control material.

2.3. Diversity Indexes

The biodiversity indexes determined were: Shanon-Wiener Index (H'), Pielou equitability average and total richness. The Shanon-Wiener index quantifies the diversity of an area, by the number of species and relative abundance and is expressed by the following formula:

$$H' = -\sum pi\,.Log.Pi \quad (1)$$

wherein, *H'* the diversity, *pi:ni* / N is the number of relative frequency of the species *i*, N the maximum number of species. In this case, the greater the H' value greater will be the diversity.

The Pielou index indicates the fauna uniformity in each area, in other words, indicates how the individuals are distributed among the different species present in the sample, and is calculated by the following equation:

$$U = \frac{H'}{Log_2 S} \quad (2)$$

wherein, *H'* represents the Shanon-Wiener index, *S* present group number in each area. In this case, values close to 0 indicates that some group keeps the dominance and values close to 1 indicate that the relative abundance of the groups is presented in a similar way.

The Jackknife first order wealth estimator is a function of the number of species that occur in a sample, denominated of single species, so the greater the number of species that occur in only one sample, among all samples collected in the community studied, the greater will be that estimate the total number of species present in the community.

$$E_D = S_{0bs} + S_1\left(\frac{f-1}{f}\right) \quad (3)$$

2.4. Statistics

Nonparametric tests were applied to analyze hierarchical groupings of the taxa in the different systems of use and native area. With the aid of the statistical program R (R Development Core Team, 2009), multivariate of the principal components analyses were made (PCA) with the sampled areas to determine the level of relation between the variables and grouping analysis (Cluster Analysis), using the Euclidian distance between the abundance of edaphic fauna groups as the measure of similarity for the seven areas.

3. Results

3.1 Structure and composition of Arthopods communities

A total of 20,955 individuals were collected distributed in 20 orders (Acari, Araneae, Coleoptera, Diplura, Dermaptera, Diptera, Diplopoda, Hymenoptera, Gastropoda, Isopoda, Isoptera, Lepidoptera larvae, Orthoptera, Entomobryomorpha, Psocoptera, Trichoptera, Poduromorpha, Scorpionida, Sternorrhyncha, Thysanura and one family (Formicidae) (Figure 3). There was a difference in the number of collected individuals by soil use, occurring a greater number of individuals in the millet (9,974 individuals, 14 taxa), eucalyptus (3,841 individuals, 16 taxa), preserved Cerrado (2,384 individuals, 15 taxa), pasture (1,933 individuals, 10 taxa), anthropic cerrado (1,777 individuals, 11 taxa), maize (824 individuals, 16 taxa) and soybean (222 individuals, 9 taxa) (Figure 3).

The most abundant groups were Acari (7,706 individuals), followed by Dermaptera (3,961 individuals), Araneae (2,769 individuals) and Poduromorpha (2,159 individuals) (Figure 3). Thysanura was the group with lowest abundance (1 individual), followed by Gastropoda (2 individuals).

Arthropods from the area with millet corresponded to 47.59% of the individuals sampled, to 18.32% in the area with eucalyptus, to 11.37% in preserved Cerrado, to 9.22%, in the pasture area, to 8.48% in anthropized Cerrado, 3.93% in maize and 1.05% in soybean area (Figure 3).

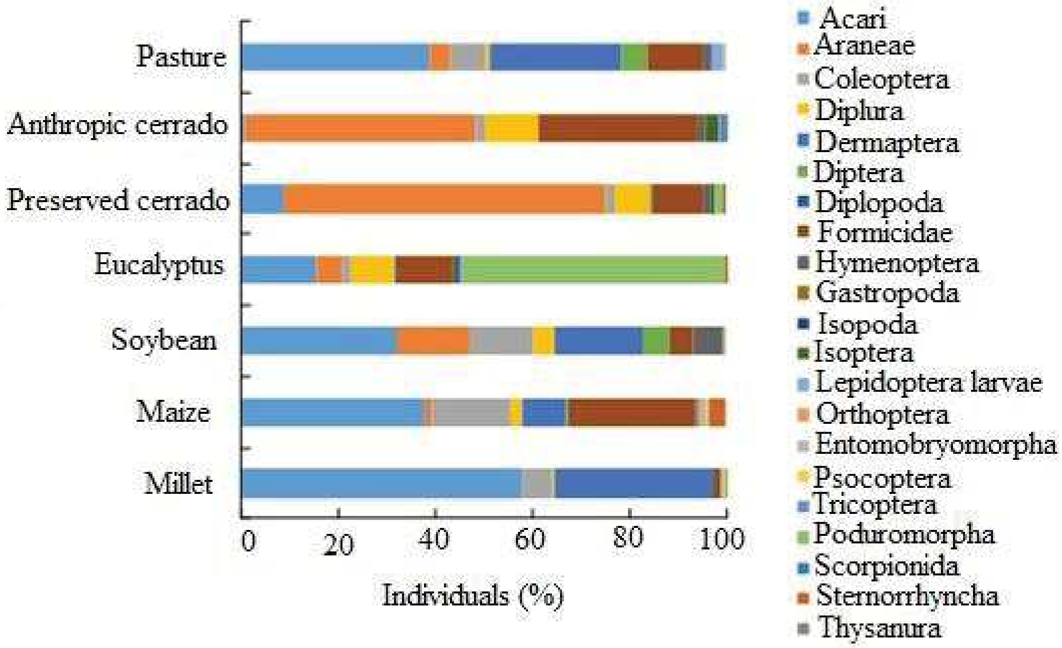

Fig. 3. Dominance and occurrence of orders and families in the study areas.

The abundance of arthropods per trap (Ind.pitfall.day) was the lower for soybean (31.71±3.10), followed by maize (117.71±13.07) and greater for millet (1424.85±242.93) and eucalyptus (548.71±75.47) (Table 3). In this case, the application of pesticides and the absence of weeds in soybean and maize contributed to a lower abundance. However, the higher organic matter content in millet and eucalyptus (29 g/dm^3 and 27 g/dm^3, respectively) favored the presence of some groups, such as Coleoptera, Dermaptera and Poduromorpha.

The highest diversity (Shanon Index) was recorded in soybean (2.69), followed by maize area (2.42), pasture (2.42), eucalyptus (2.08), anthropic Cerrado (1.85), millet (1.44) and preserved Cerrado (0.73) (Table 4). In all the areas, the average value of Shanon diversity was superior to 1, except for the preserved Cerrado.

The Pielou index showed a greater uniformity in the soybean areas (0.84), pasture (0.73) and maize (0.60), despite the low abundance in these areas, the individuals are found well distributed among the groups, unlike millet, for example. The highest average richness corresponded to the area with eucalyptus (4.04) and the total richness was higher in maize and eucalyptus (16), followed by the preserved Cerrado (15) and millet (14). The lowest richness corresponded to the area with soybean (9).

Table 3. Ecological parameters and indexes used to evaluate the arthropod communities in the sampled areas.

	Abundance ± std (Ind.pitfall.day^1)	CV (%)	Shanon index	Pielou index	Average richness	Total richness
Millet	1424.85±242.93	17.04	1.44	0.37	3.43	14
Maize	117.71±13.07	11.10	2.42	0.60	2.52	16
Soybean	31.71±3.10	9.78	2.69	0.84	1.48	9
Eucalyptus	548.71±75.47	13.75	2.08	0.52	4.04	16
Preserved Cerrado	340.57±57.85	16.98	0.73	0.44	2.43	15
Anthropic Cerrado	253.85±41.15	16.21	1.85	0.53	2.80	11
Pasture	276.14±35.44	12.83	2.42	0.73	3.30	10

In the principal component analysis (PCA) (Figure 4), the main axis explained 50.9% and the secondary axis explained 34.6. It is noted that there is a greater correlation of Poduromorpha, Diplopoda, Gastropoda, Isopoda, Diplura, Trichoptera and Hymenoptera with the eucalyptus area.

The grouping based on the abundance of the groups evidenced great similarity between soybean, maize, this due to the similar management adopted in both areas. The anthropic Cerrado and the Preserved Cerrado also formed a similar grouping.

Finally, cluster analysis isolated the Millet area from other areas, showing that due a major food supply available, there was a greater abundance of other areas (Figure 5).

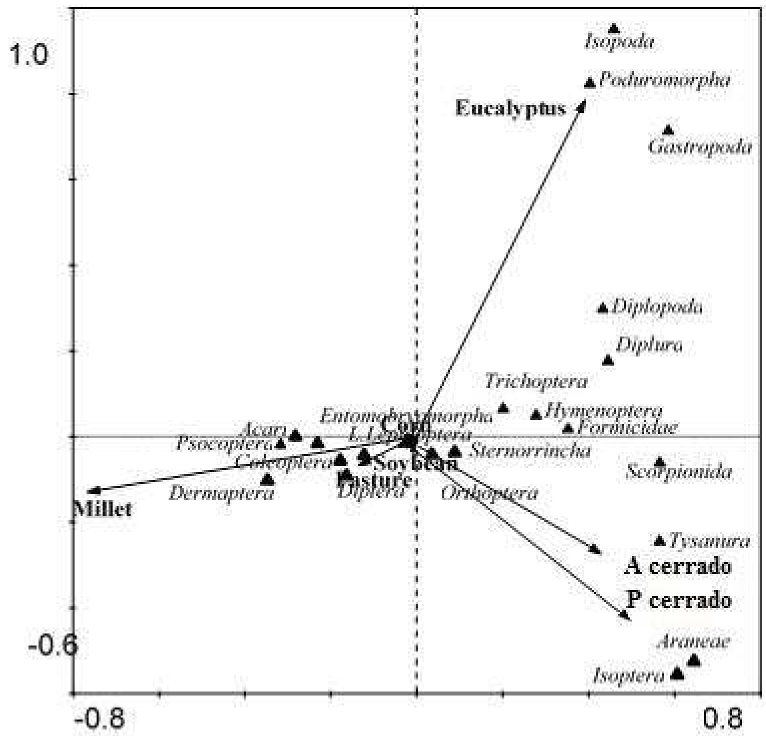

Fig. 4. The principal components analysis of the relation between groups of edaphic arthropods and the Planting areas: Millet, Maize, Soybean, Eucalyptus, Preserved Cerrado (P Cerrado), Anthropic Cerrado (A Cerrado) and pasture.

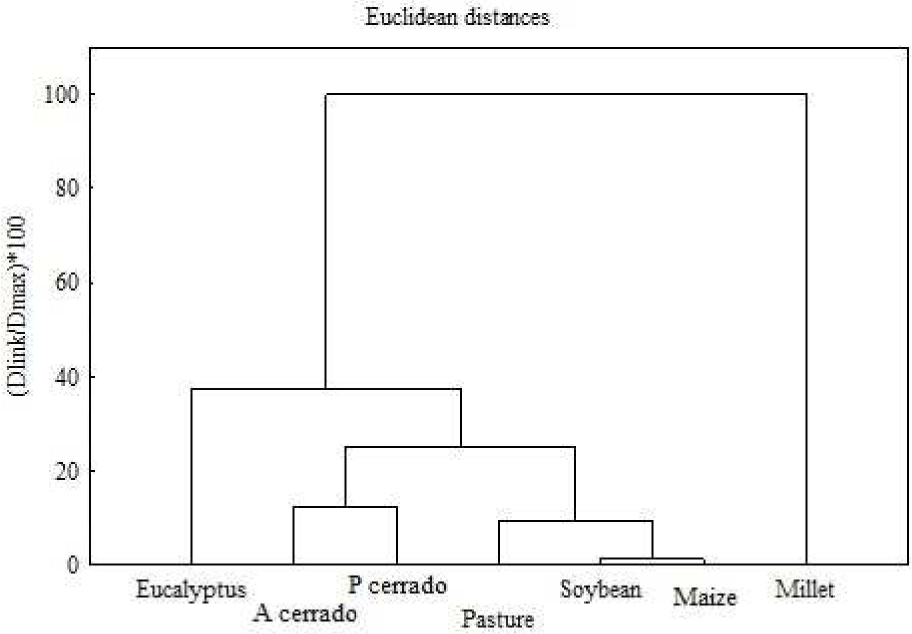

Fig. 5. Dendrogram presenting the connection distance for the sampled areas (Eucalyptus, Anthropic Cerrado (A Cerrado), Preserved Cerrado (P Cerrado), Pasture, Soybean, Maize, and millet).

4. Discussion

The soil prepare and cropping systems effect its biota, which is still little know (Perez et al., 2013). Some groups might be dramatically altered or eliminated, resulting in the dominance of groups more adapted.

The higher abundance in the area with millet might have resulted from the presence of straw in the soil from previous crops, this offered food for the edaphic fauna, favoring, this way, specific groups. The presence of vegetal cover or residues in the soil contributes to the increase of the availability of food and promotes the creation of habitats that allows a greater abundance of the population, which benefits the ecological sustainability of the production systems (Batista et al., 2014; Bedano et al., 2016; Franco et al., 2016). Associated to the absence of natural enemies, the high rate of female ovoposition and fast hatching in dermaptera, resulted in higher abundance of this group in millet and pasture.

The Dermaptera Group is associated with the vegetal biomass input, once that, in the millet, the straw left in the soil right after the soybean removal contributed to its abundance. Several factors can directly influence the arthropod community, as year period (dry or rainy season), microclimate that is favored by the environment, type of soil, use and management adopted (Bedano et al., 2016), food availability and predator population (Neto et al., 2012; de Araújo et al., 2013).

In the same way, a desiccant application in the soybean plantation, this explains the lower abundance in this area, allied with the constant use of the pesticide. The edaphic community is mainly influenced by the anthropic action, with respect to the use and management of the soil (Lima et al., 2010), which directly interferes in the abundance and diversity (Santos et al., 2008), associated with the physical disturbance and the changes in the quantity and quality of the organic matter (Majer et al., 2007).

Due to the low density of ants, a natural predator of mites, the population has dominance, mainly in millet. Damé et al., 1996, affirm that in tropical climates, the greater representativeness of Acari can be conditioned to the two well-defined seasons, a dry one and a rainy one, which would be a normal behavior. May also be the adaptation result to the variations of the temperature and water regime, according to Bergon et al. (1996).

Poduromorpha (54.62%) was the predominant group in eucalyptus, in this case, the presence of weeds, the absence of pesticide application, the formation of thick litter, higher canopy, compared to other environments, allowed the formation of microclimate, and greater availability of food. The litter constitutes the most favorable environment for the edaphic organisms for the development of the life cycle, possibly, this is related to the best conditions of humidity, aeration, temperature, pH, food resource (Bedano et al., 2016).

The higher Shanon diversity in the area with soybean results from the presence of groups equitativelly distributed, having not been observed dominance of group in this area. The values above 1, indicates that the fauna diversity in these areas is high (Magurran, 1988). The species diversity is interconnected to a relation between the species number and the individual's number distribution between the species, so when the samplings present the same number of individuals the index will assume its maximum value (Zanzini, 2005). In practical terms, the values assumed by the Shanon index are between 1.5 and 3.5 and only rarely exceed the value of 4.5 (Magurran, 1988).

The management and the intensification of land use only affected the abundance, not interfering with the diversity and richness. The intensity of land use leads to a reduction in the abundance and richness of predators, interfering with the ecological functions of the soil, being needed decades for these environments to recover (Rousseau et al., 2014).

The dissimilarity found in the area with millet is due its higher quantity of individuals, which differentiated it from the others areas. The Preserved Cerrado area is a secondary forest in the regeneration process, possibly the short time of preservation of this environment has not allowed yet that there was greater differentiation. However, the presence of animals in the Anthropic Cerrado area favored the abundance of some groups, making both areas closer.

According to Baretta et al., (2006) results obtained in cluster analyses allow us to know the differences between the soil management systems, taking into account the abundance and diversity of the taxonomic groups, being still important to discriminate soil systems of preparation and cultivation, as well as to understand the dynamics of the main edaphic groups.

5. Conclusion

The management adopted was decisive for the low abundance of arthropods in soybean and maize. In terms of diversity and equitability, the soybean (2.69 diversity and 0.84 equitability) had obtained the highest index, indicating that the individuals are well distributed among the groups when compared to the other areas. There was a predominance of specific groups, as Acari (millet), Poduromorpha (Eucalyptus) and Araneae (preserved cerrado), indicating the low abundance of predators from these groups.

Interest conflicts

The authors declare not having interest conflicts.

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SPATIAL VARIABILITY OF THE SOIL FAUNA UNDER DIFFERENT USE AND MANAGEMENTS

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ABSTRACT

Geostatistics allows the evaluation of the spatial variability of data that requires different management. This work aimed to evaluate the spatial variability of biological diversity indexes of the soil fauna under different use and management in the closed Biome. The soil fauna was sampled in five areas with different management (millet, soybean, maize, eucalyptus and pasture crops) and two areas with different uses (preserved cerrado and anthropic cerrado), in Mata Roma City, Maranhão State, Brazil. The edaphic fauna was collected in pitfall traps, which were installed at a spacing of 3m. In each area, 130 traps were installed, which remained in the field for a seven day period. After this period they were removed, packed in bottles and taken to the laboratory, where were made the screening and identifications at the level of orders and families. Eight indexes were generated: individuals' traps/day, Jackknife richness, Simpson diversity, McIntosh, Shannon, total diversity, Simpson dominance and Pielou equitability. The spatial variability was obtained through semivariograms adjusted to the geostatistical models: Gaussian, spherical and exponential. Statistical analysis showed that in the millet crop, the values of the coefficient of variation remained medians, except for the index of Individuals' trap/day and McIntosh diversity that were considered high. The correlation matrix showed negative values for some indexes, indicating that there is an inverse relationship. The areas of millet, maize, eucalyptus, anthropic cerrado and pasture, the Shannon diversity index had obtained a pure nugget effect. For the areas of millet, maize, anthropic 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/day index and Pielou equitability in millet. Only for the soybean and pasture that the scaled semivariograms presented similarity in the spatial variability of the indexes, indicating that these, behave in a similar way.

Keywords: Geostatistics, Soil Fauna, Soil Management.

INTRODUCTION

The use of geostatistics in the analysis of the variability of soil attributes has grown significantly in the last decades. The geostatistical techniques allow to identify in an area the characteristics that are treated as homogeneous and that need different management (Ribeiro et al., 2016), besides allowing the understanding, the modeling and the mapping of the soil attributes, allowing the identification of specifics zones of management and reducing the effects of soil variability under crops production (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., 2015).

The soil variability occurs due to the interaction of formation factors, climate, temperature and handling management (Bonnin et al., 2010), which directly reflects on agricultural productivity (Basso et al., 2011). The several planting systems can alter the quality of the soil, due to the constant incorporation of fertilizers and correctives, consequently alter the physical, chemical and biological properties (Baretta et al., 2003; Carvalho et al., 2014).

The soil tillage system of direct seeding exerts an important function in the conservation and maintenance of soil biota (Crusciol et al., 2010; Pedroso et al., 2016), because, the minimum of soil rotation, residue accumulation (Cunha et al, 2011) and crop rotation (Paul et al, 2013), provides stability of habitats and food supply (Bottega et al, 2013). In terms of soil benefits, the no-tillage system reduces the evaporation, reduces the erosion, increases the rate of soil water infiltration and microbial activity, which favors the incorporation of nutrients in the soil, improving the physical, chemical and biological quality.

Several studies have focused on edaphic fauna with a soil quality promoter (Vasconcellos et al., 2013, Moura et al., 2014, Rousseau et al., 2014). 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 the abundance, diversity, and composition of the groups reflect the disturbances of the ecosystem (Dominguez et al., 2014). Agricultural practices cause many changes in the composition and distribution of soil biota, which directly affects edaphic processes such as nutrient cycling, decomposition of organic matter, porosity and water infiltration (de Vries et al., 2013; Wagg et al., 2014; Siqueira et al., 2016).

The descriptive statistic describes the properties without taking into account the spatial position, once the soil does not present uniformly in all areas, it becomes important to evaluate the spatial distribution of the physical, chemical and biological attributes for better decision making about the management and crop production. This work aimed to evaluate the spatial variability of the biological diversity indexes in different management (Millet, maize, soybean, eucalyptus and pasture) and different use (preserved cerrado and anthropic cerrado).

MATERIAL AND METHODS

The study was carried out at Fazenda Unha de Gato, Mata Roma city, Maranhão, Brazil, whose coordinates are 3º 70' 80.88" S and 43º 18' 71.27" W. According to the Köppen classification, the climate of the region is humid tropical type, with annual temperatures mean ranging from 27ºC to 30ºC, dry season that goes from June to November and rainy from December to May. Precipitation ranges from 1,400 mm to 1,600 mm and annual evapotranspiration values of 1,144 mm^3. According to the USDA classification (1999), the soil of the region is a Oxisol.

The soil fauna was collected in May 2015 in pitfall traps. 130 traps were installed in each of the five areas of different soil management (millet, maize, soybean, eucalyptus and pasture) and two areas with a different use (preserved cerrado and anthropic cerrado). Each trap contained 200mL of formaldehyde at 4% for the preservation of organisms, according to the methodology described by Aquino et al. (2001), and Siqueira et al. (2014).

The traps were placed at a distance of 3m from the other and remained in the field for a period of seven days. After this period, all contents were preserved in alcohol 70% and screened. The identification of the groups occurred through identification keys in large groups and family, according to Lawrence (1991). Subsequently, the identification of the groups was generated the biodiversity indexes.

Diversity indexes

To determine the biodiversity indexes, the DivEs software (Rodrigues, 2015) was used. The individuals' trap/day index (Ind arm^{-1} day^{-1}) was obtained from the number of individuals collected in a given sample and divided by the period in which the sample remained in the field, in this case, seven days.

The first-order Jackknife richness index estimates the richness of a community. It is taken as a function of the number of species that occurs in one and only one sample, receiving the name of single species. Thus, the larger the number of species that occurs in a single sample the larger will be the estimate for the total number of species in the community.

$$E_D = S_{obs} + S_1(\frac{f-1}{f}) \quad (1)$$

wherein: S_{obs} Is the number of observed species; S_1 Is the number of species that is present only in a grouping; *f* grouping number that contains the *ith* species of a grouping.

Simpson's diversity index is used to quantify infinite communities, that is, cases where the total number of individuals in the sample is different from the total number of individuals in the community. It is an appropriate index to estimate diversity when the sampling occurs in individuals counting.

$$Ds = \sum \frac{ni\ (ni-1)}{N(N-1)} \quad (2)$$

wherein: *ni* = Number of individuals of the *ith* species in the sample; *N* = a total number of individuals in the sample.

McIntosh diversity index is a more complex index because in addition to considering the total number of individuals considers the square root of the sum of the squared individuals of each species.

$$D = \frac{N-U}{N-\sqrt{N}} \quad (3)$$

$$U = \sqrt{\sum_{i=1}^{n} n_i^2} \quad (4)$$

wherein: *N* Is the total number of individuals in the sample(s); *U* is the square root of the sum of the squared individuals of each species.

The Shanon-Wiener diversity index is the most used index in community studies. Shannon values range from 0 to 3.5, rarely exceeding 4.5 (Magurran, 1988). The index will be zero when having only one species in the sample and assumes maximum value when all the species present in the sample have the same number of individuals.

$$H' = \sum_{i=1}^{n} pi\ X\log_{10} pi \quad (5)$$

wherein: *ni* = Number of individuals of the ith species in the sample; *N* = total number of individuals in the sample; Log_{10} = neperian logarithm (base 10).

Total diversity estimates the diversity of a region and can be estimated as a function of species variation.

$$TD = \sum_{i=1}^{n} wi[pi(1 - pi)] \tag{6}$$

Wherein: *wi* is the weight given to the function, which expresses the importance that if want gives to the species *i* in the global quantification of regional diversity; *Pi* is the relative frequency.

The Simpson dominance is determined by the Simpson diversity index.

$$D_S = 1 - \left(\frac{\sum_{i}^{n} n_i X\,(n-1)}{N(N-1)}\right) \tag{7}$$

wherein: *ni* is the number of individuals of each species; *N* is the number of individuals.

Pielou equitability refers to the distribution of individuals among species, is proportional to diversity and inversely proportional to dominance. Equitability compares the Shanon-Wiener diversity with the observed species distribution that maximizes diversity.

$$U = \frac{H'}{Log_{10}S} \tag{8}$$

Wherein: *H*' is the Shanon-Wiener index; S number of groups present in each area; *Log* is the logarithm in base 10.

Descriptive statistics were determined using the R statistical program (R Development Core Team), where the values of maximum, minimum, mean, standard deviation, the coefficient of variation (CV), skewness, kurtosis, and normality were calculated by the Kolmogorov-Smirnov test at 0.01% probability.

Spatial Variability

The spatial variability was analyzed through the construction semivariograms according to Vieira (2000). The semivariogram, *γ (h)*, of a spatially distributed variable.

$$y(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(xi) - z(xi + h)]^2 \tag{9}$$

wherein: *N(h)* is the number of observations separated by the distance h. All semivariograms were adjusted to a mathematical model according to the nugget effect parameters (C_0), level (C_0+C_1) and range (a).

It was considered the intrinsic hypothesis of geostatistics in which there is no requirement of finite variance, $Var(z)$ and requires only the stationarity of the mean and second order stationarity of the differences [(z (x) -z (x + h)] (Journel and Huijbregts, 1978). The semivariograms were scaled according to Viera et al. (1997).

$$y^{sc}(h) = \frac{y(h)}{Var\ (z)} \tag{10}$$

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

The utility of the scaled semivariogram is to draw several semivariograms on the same graph, otherwise, would have different scales on the semivariance axis. When there is the grouping of semivariograms, can be said that the relevant variables present similar spatial variability (Viera et al., 1997). The adjustment of the experimental semivariogram was performed by adjusting the spherical, the exponential and the gaussian models, being the best fit chosen in function of the jack-knifing technique, as presented by Carvalho et al. (2002).

The spatial dependence ratio was calculated according to the equation below:

$$RD = \left(\frac{C_0}{C_0+C_1}\right) * 100 \tag{11}$$

As proposed by Cambardella et al. (1994), being strong (0-25%); Moderate (25-75%); Weak (75-100%).

RESULTS AND DISCUSSION

The sampled arthropods were classified into 20 taxonomic orders and one family. The most representative area was the millet with 9,974 individuals, eucalyptus with 3,841 individuals. The soybean presented a smaller abundance with 222 individuals sampled (Table 1).

According to Baretta et al. (2007) and Rafael et al. (2012), Poduromorpha tends to be more sampled in areas that present organic residues in the soil, besides being captured in greater abundance. These organisms are used as bioindicators of soil quality and environmental disturbances, which are generally key organisms for the detection of degraded areas. In the case of the eucalyptus area, although there is a thick layer of organic matter, the contribution of the class Poduromorpha is relevant, because they are important consumers, important in the cycling of nutrients and responsible for soil enrichment.

Table 1: Composition of the edaphic fauna under different use and management in the Cerrado Biome.

	Millet	Maize	Soybean	Eucalyptus	Preserved Cerrado	Anthropic 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**

The main statistical parameters for biodiversity indexes are described in Table 2. In millet crop, according to Warrick and Nielsen (1980) classification, the coefficient of variation (CV) values are considered mean, except for the index of Individuals trap day (CV = 66.29) and McIntosh diversity (CV = 124.67), which are considered high. For maize crop, all CV values are considered high, values above 60%. In the soybean area, the Simpson, McIntosh, Shanon diversity indexes, total diversity, Simpson dominance and Pielou equitability obtained CV values above 100%, the same occurred with the McIntosh index in all areas. High CV values are related to high values of standard deviation, which is 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), soil attributes can obtain CV reaching 1000%.

Several authors report high CV values for soil variables, Schaffrath et al. (2007) studying weed variability in different managements found CV between 86.05% and 168.85%. Siqueira et al. (2015) evaluating the volumetric content of water in the soil, describe high CV ranging from 97.60% to 106.8% for the different depths. However, Machado et al. (2006) attribute the high CV values to the sampling grid used.

There was variation regarding the minimum and maximum value of individuals in the areas. Only maize and soybean obtained a minimum value of zero in all indexes. The highest mean was for individuals trap day in the eucalyptus area (29.55), followed by individuals trap day 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 are indicative of normal frequency. In this case, some indexes did not present skewness and kurtosis values close to 0 and 3, indicating that these indexes have a lognormal distribution. For Isaaks and Srivastava (1989); Cressie (1991) the data normality is not a requirement for the use of geostatistics before is necessary the stationarity of semivariance.

Table 1: Statistical parameters for biodiversity indexes in the studied areas.

					Millet					
	Sum	Min	Max	Mean	Variance	SD	CV (%)	Skew	Kurtosis	D
Individuals trap day	1424.86	0.43	35.86	10.96	52.80	7.27	66.29	1.16	1.45	0.11n
Jackknife Richness	577.00	2.00	8.00	4.44	1.36	1.17	26.32	0.92	1.02	0.23Ln
Simpson Diversity	66.94	0.06	0.71	0.51	0.02	0.13	25.60	-1.14	1.47	0.11n
McIntosh Diversity	191.81	0.00	8.68	1.48	3.38	1.84	124.67	1.36	1.31	0.27Ln
Shanon Diversity	51.76	0.06	0.60	0.40	0.01	0.10	24.57	-0.75	1.02	0.06n
Total Diversity	112.63	0.35	1.00	0.87	0.02	0.16	17.92	-1.04	0.06	0.23Ln
Simpson Dominance	62.86	0.29	0.94	0.48	0.02	0.13	27.43	1.14	1.44	0.10n
Pielou Equitability	82.45	0.00	0.99	0.63	0.03	0.17	27.26	-0.63	1.24	0.07n
					Maize					
	Sum	Min	Max	Mean	Variance	SD	CV (%)	Skew	Kurtosis	D
Individuals trap day	117.71	0.00	5.00	0.90	0.70	0.83	92.61	2.04	6.61	0.14n
Jackknife Richness	326.00	0.00	6.00	2.50	2.31	1.52	60.65	-0.00	-0.70	0.13n
Simpson Diversity	68.72	0.00	1.00	0.52	0.11	0.33	63.95	-0.61	-1.02	0.19Ln
McIntosh Diversity	835.50	0.00	39.97	6.42	69.23	8.32	129.46	2.08	4.58	0.22Ln

	Sum	Min	Max	Mean	Variance	SD	CV (%)	Skew	Kurtosis	D
Shanon Diversity	41.06	0.00	0.72	0.31	0.04	0.21	68.73	-0.25	-1.10	0.18Ln
Total Diversity	65.97	0.00	0.93	0.50	0.11	0.33	66.61	-0.50	-1.26	0.18Ln
Simpson Dominance	38.27	0.00	1.00	0.29	0.07	0.26	91.47	1.17	1.25	0.13n
Pielou Equitability	84.83	0.00	1.00	0.65	0.15	0.39	61.15	-0.95	-0.93	0.28Ln

Soybean

	Sum	Min	Max	Mean	Variance	SD	CV (%)	Skew	Kurtosis	D
Individuals trap day	222.00	0.00	6.00	1.71	1.14	1.07	62.48	1.66	3.00	0.30Ln
Jackknife Richness	192.00	0.00	4.00	1.48	0.58	0.76	51.43	1.10	0.99	0.35Ln
Simpson Diversity	45.53	0.00	1.00	0.35	0.21	0.46	131.00	0.59	-1.60	0.4Ln
McIntosh Diversity	885.44	0.00	35.51	6.81	90.76	9.53	139.87	1.37	1.36	0.32Ln
Shanon Diversity	17.15	0.00	0.58	0.13	0.03	0.18	135.30	0.83	-0.81	0.39Ln
Total Diversity	26.18	0.00	0.83	0.20	0.07	0.27	133.99	0.75	-1.11	0.39Ln
Simpson Dominance	11.47	0.00	1.00	0.09	0.06	0.25	282.84	3.10	8.61	0.47Ln
Pielou Equitability	48.20	0.00	1.00	0.37	0.23	0.48	129.18	0.52	-1.75	0.40Ln

Eucalyptus

	Sum	Min	Max	Mean	Variance	SD	CV (%)	Skew	Kurtosis	D
Individuals trap day	3841.00	0.00	181.00	29.55	1098.08	33.14	112.15	2.33	6.20	0.22Ln
Jackknife Richness	447.00	1.00	6.00	3.44	1.50	1.23	35.67	-0.07	-0.50	0.17Ln
Simpson Diversity	36.26	0.00	0.83	0.28	0.04	0.20	72.52	0.37	-0.74	0.08n
McIntosh Diversity	102.21	0.00	6.45	0.79	0.92	0.96	122.25	2.61	9.90	0.23Ln
Shanon Diversity	28.92	0.00	0.67	0.22	0.02	0.15	65.63	0.27	-0.53	0.08n
Total Diversity	114.98	0.00	0.99	0.89	0.06	0.24	27.08	-3.21	9.19	0.35Ln
Simpson Dominance	93.74	0.18	1.00	0.72	0.04	0.20	28.05	-0.37	-0.74	0.08n
Pielou Equitability	52.31	0.00	1.00	0.40	0.06	0.24	60.07	0.19	-0.61	0.06n

Preserved Cerrado

	Sum	Min	Max	Mean	Variance	SD	CV (%)	Skew	Kurtosis	D
Individuals trap day	2384.00	0.00	234.00	18.34	800.52	28.29	154.29	4.26	26.57	0.25Ln
Jackknife Richness	447.00	1.00	6.00	3.44	1.50	1.23	35.67	-0.07	-0.50	0.17Ln
Simpson Diversity	93.74	0.18	1.00	0.72	0.04	0.20	28.05	-0.37	-0.74	0.08n
McIntosh Diversity	112.99	0.00	13.45	0.87	2.13	1.46	168.09	5.69	43.89	0.27Ln
Shanon Diversity	29.13	0.00	0.67	0.22	0.02	0.15	64.95	0.25	-0.52	0.08n
Total Diversity	115.78	0.00	0.99	0.89	0.06	0.24	27.01	-3.21	9.22	0.34Ln
Simpson Dominance	93.74	0.18	1.00	0.72	0.04	0.20	28.05	-0.37	-0.74	0.08n
Pielou Equitability	52.31	0.00	1.00	0.40	0.06	0.24	60.07	0.19	-0.61	0.06n

Anthropic Cerrado

	Sum	Min	Max	Mean	Variance	SD	CV (%)	Skew	Kurtosis	D
Individuals trap day	1777.00	1.00	96.00	13.67	238.01	15.43	112.86	2.80	9.46	0.26Ln
Jackknife Richness	365.00	1.00	6.00	2.81	1.24	1.11	39.69	0.08	-0.37	0.19Ln
Simpson Diversity	64.20	0.00	1.00	0.49	0.08	0.28	56.01	-0.51	-0.69	0.10n
McIntosh Diversity	716.50	0.00	35.51	5.51	44.90	6.70	121.58	2.12	5.50	0.20Ln
Shanon Diversity	41.68	0.00	0.60	0.32	0.03	0.18	55.25	-0.53	-0.71	0.11n
Total Diversity	75.56	0.00	0.99	0.58	0.11	0.33	57.06	-0.61	-1.03	0.14Ln
Simpson Dominance	58.80	0.00	1.00	0.45	0.07	0.27	60.25	0.46	-0.35	0.08n
Pielou Equitability	86.59	0.00	1.00	0.67	0.11	0.33	49.39	-1.13	-0.04	0.19Ln

Pasture

	Sum	Min	Max	Mean	Variance	SD	CV (%)	Skew	Kurtosis	D
Individuals trap day	276.14	0.00	12.43	2.12	3.59	1.89	89.20	2.81	10.15	0.20Ln
Jackknife Richness	342.00	1.00	5.00	2.63	1.15	1.07	40.75	0.25	-0.54	0.19Ln
Simpson Diversity	72.10	0.00	0.90	0.55	0.05	0.23	42.03	-0.88	0.04	0.13n
McIntosh Diversity	83.99	0.00	3.91	0.65	0.51	0.71	110.56	2.39	6.57	0.21Ln
Shanon Diversity	49.46	0.00	0.78	0.38	0.03	0.17	43.95	-0.43	-0.10	0.10n
Total Diversity	86.82	0.00	0.99	0.67	0.09	0.30	44.30	-0.97	-0.32	0.18Ln
Simpson Dominance	59.91	0.00	1.00	0.46	0.08	0.27	59.55	0.36	-0.47	0.08n
Pielou Equitability	86.10	0.00	1.00	0.66	0.11	0.33	49.69	-1.10	-0.10	0.17Ln

Min: Minimum; Max: Maximum; SD: Standard deviation; CV= Coefficient of variation; D: Normality of the date for test of Kolmogorov-Smirnov 0,01% probability; n: Normal; Ln: Lognormal

The linear correlation matrix showed negative values for some indexes in all areas. In millet, total diversity x individuals trap day (r = -0.010) and Simpson diversity x 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 Shanon index x Simpson diversity index for the other areas (millet r = 0647; maize r = 0.885, soybeans r = 0943; eucalyptus r = 0.976; anthropic 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 indexes take into account the total number of individuals within the sample, being these indexes 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.

Table 3: Linear correlation matrix for the biodiversity indexes in the studied areas.

	Millet							
	Ind.trap	Jack.div.	Simp.div.	McInt.div	Shan.div	Tot. div	Simp.dom	Piel.eq.
Individuals trap day	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
	Maize							
	Ind.trap	Jack.div.	Simp.div.	McInt.div	Shan.div	Tot. div	Simp.dom	Piel.eq.

Individuals trap day	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

	Ind.trap	Jack.div.	Simp.div.	McInt.div	Shan.div	Tot. div	Simp.dom	Piel.eq.
Individuals trap day	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

	Ind.trap	Jack.div.	Simp.div.	McInt.div	Shan.div	Tot. div	Simp.dom	Piel.eq.
Individuals trap day	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

	Ind.trap	Jack.div.	Simp.div.	McInt.div	Shan.div	Tot. div	Simp.dom	Piel.eq.
Individuals trap day	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

Anthropic cerrado

	Ind.trap	Jack.div.	Simp.div.	McInt.div	Shan.div	Tot. div	Simp.dom	Piel.eq.
Individuals trap day	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								
	Ind.trap	Jack.div.	Simp.div.	McInt.div	Shan.div	Tot. div	Simp.dom	Piel.eq.
Individuals trap day	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				
Shanon 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

The parameters of the semivariograms adjustment are presented in Table 2. It is observed that for the richness indexes, Simpson and Shanon diversity and Simpson dominance in the area of millet the data evidenced pure nugget effect. The same occurred for the Simpson, McIntosh, Shanon diversity, Simpson dominance and Pielou equitability in the maize area; Simpson, McIntosh diversity, total diversity in soybean area; Simpson, McIntosh, Shanon diversity, total diversity, Simpson dominance and Pielou equitability in the eucalyptus area; Individuals trap day, jackknife richness, Simpson diversiy, McIntosh diversity, total diversity and Pielou equitability in the preserved cerrado area; Simpson diversity, Shanon diversity, Simpson dominance and Pielou equitability in the anthropic cerrado; Individuals trap day, Simpson, McIntosh, Shanon 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 Shanon diversity index, the same occurred in the present study for millet, maize, eucalyptus, anthropic cerrado and pasture areas. The pure nugget effect indicates that 3 m spacing was not sufficient to detect spatial variability (Vieira, 2000).

The other indexes that presented spatial variability were adjusted to a geostatistical model, Gaussian, spherical or exponential. For the millet only the Pielou equitability was adjusted to the spherical model, individuals traps day and McIntosh diversity were adjusted to the exponential model and total diversity to the Gaussian model (Table). 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; Chiba et al., 2010; Silva et al., 2014; Siqueira et al., 2015).

According to the classification of Cambardella et al. (1994), the spatial dependence degree for the individuals trap day 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 (C0) was for individuals trap day 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 adjustment 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 day in the eucalyptus) to 78 m Individuals trap day in the millet). The determination of the range values is needed to know to what point the samples are correlated with each other and presenting the maximum spatial dependence distance between the samples (Vieira, 2000). For Carvalho et al. (2003) establish the range of spatial dependence allows to delineate future samplings, taking into account the same conditions of the previous study.

Table 4: Semivariogram adjustment parameters for biodiversity indexes in the studied areas.

			Millet			
	Model	C_0	C_1	a	r^2	SD (%)
Individuals trap day	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 Shanon 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
			Maize			
	Model	C_0	C_1	a	r^2	SD (%)
Individuals Trap Day	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				
Shanon 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			
	Model	C_0	C_1	a	r^2	SD (%)
Individuals trap day	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				

	Model	C_0	C_1	a	r^2	SD (%)
McIntosh Diversity	Pure nugget effect					
Log Shanon 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						
	Model	C_0	C_1	a	r^2	SD (%)
Individuals trap day	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					
Shanon Diversity	Pure nugget effect					
Total Diversity	Pure nugget effect					
Simpson Dominance	Pure nugget effect					
Pielou Equitability	Pure nugget effect					
Preserved cerrado						
	Model	C_0	C_1	a	r^2	SD (%)
Log Individuals trap day	Pure nugget effect					
Log Jackknife richness	Pure nugget effect					
Simpson Diversity	Pure nugget effect					
McIntosh Diversity	Pure nugget effect					
Shanon 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					
Anthropic cerrado						
	Model	C_0	C_1	a	r^2	SD (%)
Log Individuals trap day	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
Shanon 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						
	Model	C_0	C_1	a	r^2	SD (%)
Log Individuals trap day	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					
Shanon 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 (%)

In figure 2 the scaled semivariograms are presented for the seven studied areas. For the areas of soybean and pasture, biodiversity indexes showed similarity in spatial variability. However, for the millet Shanon diversity, Simpson diversity, McIntosh diversity index, and jackknife richness presented dispersed comparing to other indexes of the area. The same occurred for individuals' trap day in the maize area; Shanon diversity in eucalyptus; McIntosh diversity in the preserved cerrado; Individuals trap day and Jackknife richness in the anthropic cerrado.

In this case, semivariance values for Shanon index in the millet were higher than the other values of semivariance of the other indexes for the area, making this index distant from the others. In the other cases, the semivariance values were close to zero, below the index values with similarity in the variability.

This dispersion can be explained by the parameters used in determining the indexes. The individuals day trap indexes take into consideration the number of individuals collected in a sample in the period of seven days, so this value tends to be always higher or similar to the others. When to Shanon, Simpson, and McIntosh indexes, there consider the total number of species in a given sample, or in the case of McIntosh diversity, the square root of the squared individuals sum, this explains the high values of semivariance in the Shanon and Simpson index and the low value of McIntosh's semivariance in millet.

Another explanation for the variation in the semivariance values may be related to a number of individuals collected in each area and their distribution among the samples. Siqueira et al. (2016) evaluating diversity indexes of Shanon and Simpson in weeds perceived that these indexes presented similar spatial variability.

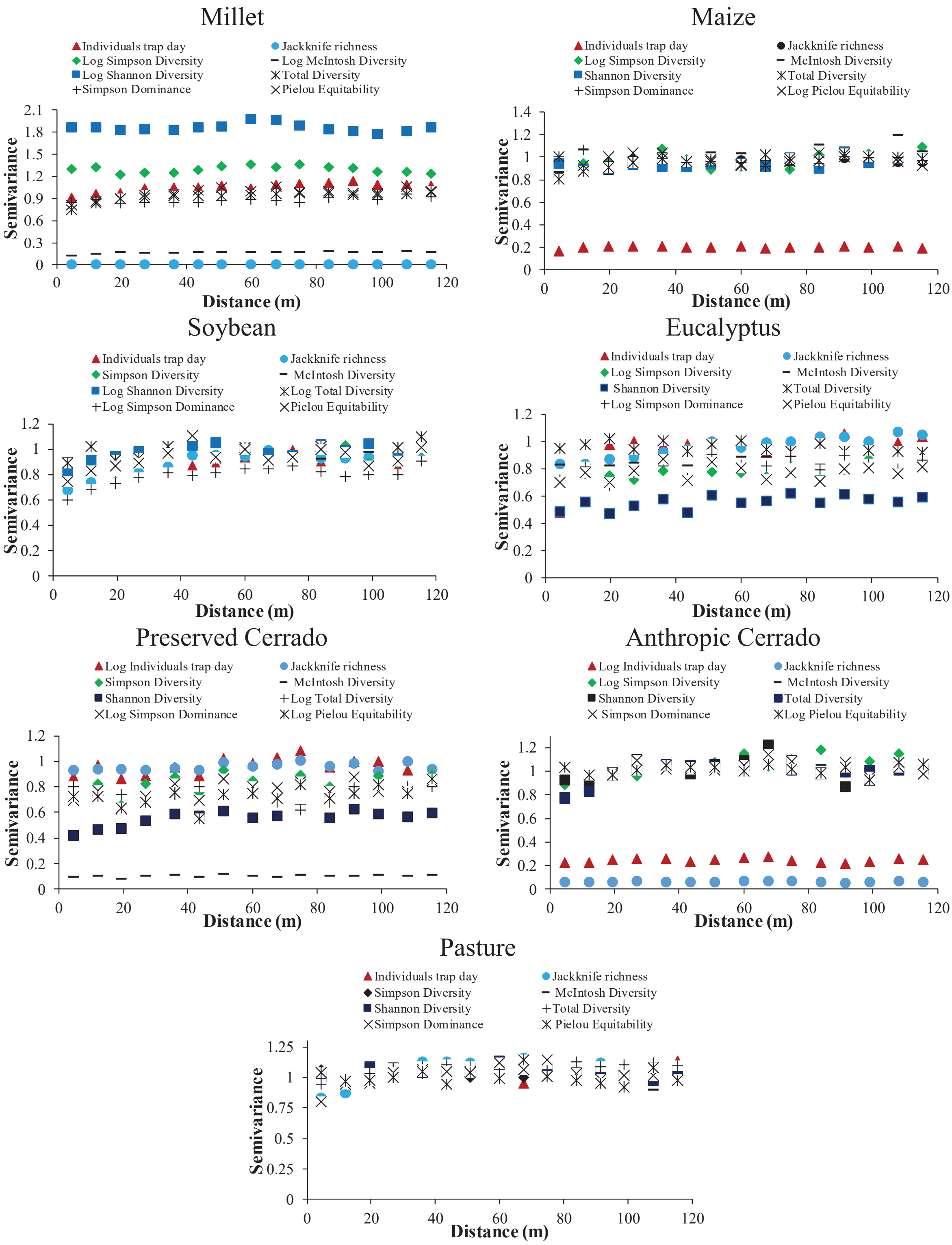

Figure 2: Scaled semivariograms for biodiversity indexes in the studied areas.

CONCLUSION

The C_0 values ranged from 0.008 m for the total diversity index in soybean in the pasture area to 400 m for the individuals trap day index in eucalyptus. Already the range values (a) ranged from 20 m (individuals trap day in eucalyptus) to 78 m trap individuals day in millet). For some diversity indexes, the spacing of 3 m between samples was not enough to detect spatial variability, being another sample grid needed. All indexes in the soybean and pasture area present similar spatial variability, thus presenting close semivariance values.

Interest conflicts

The authors declare to have no interest conflicts.

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Supplementary material

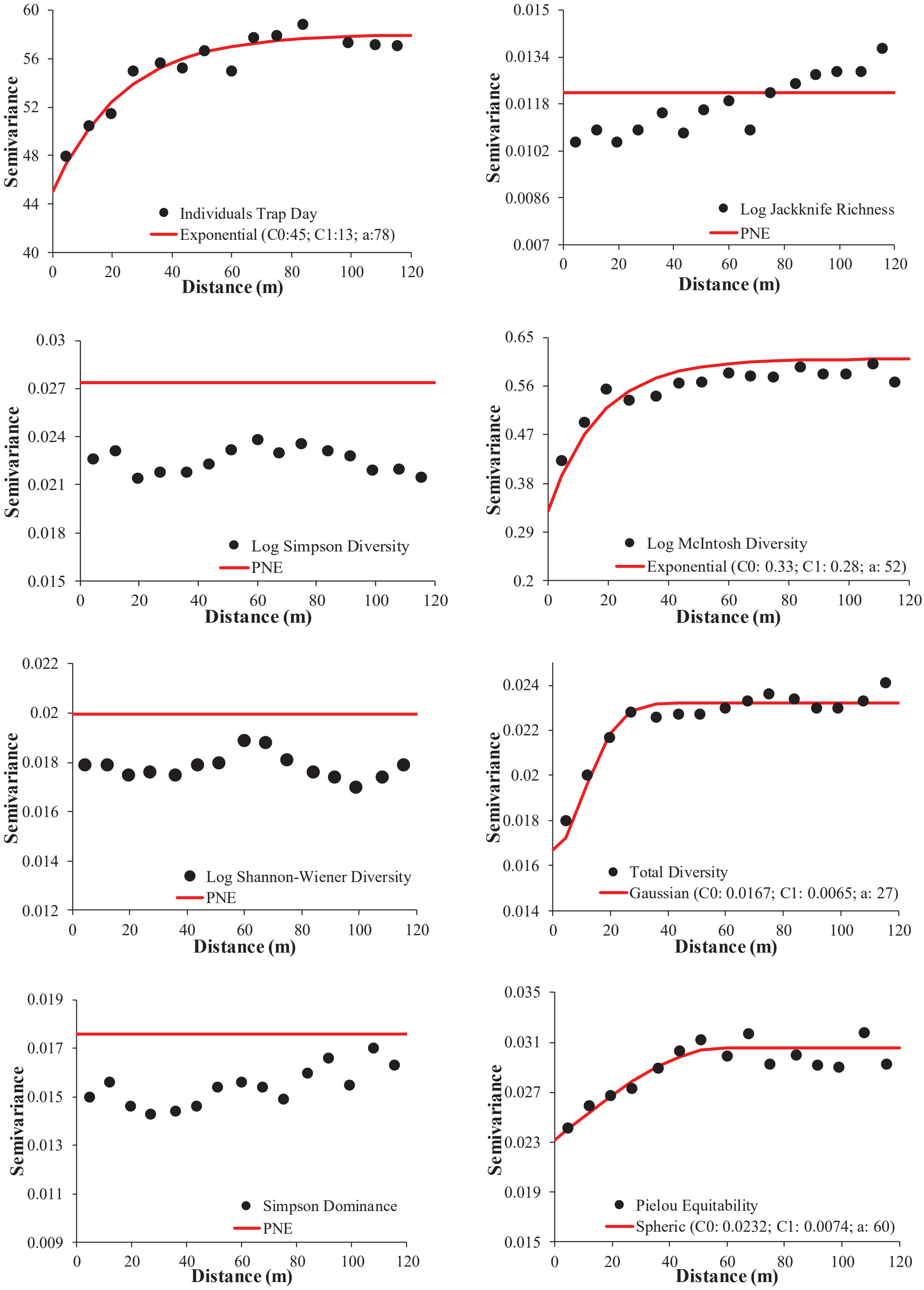

Figure 1S: Semivariograms for biodiversity indexes in the millet area.

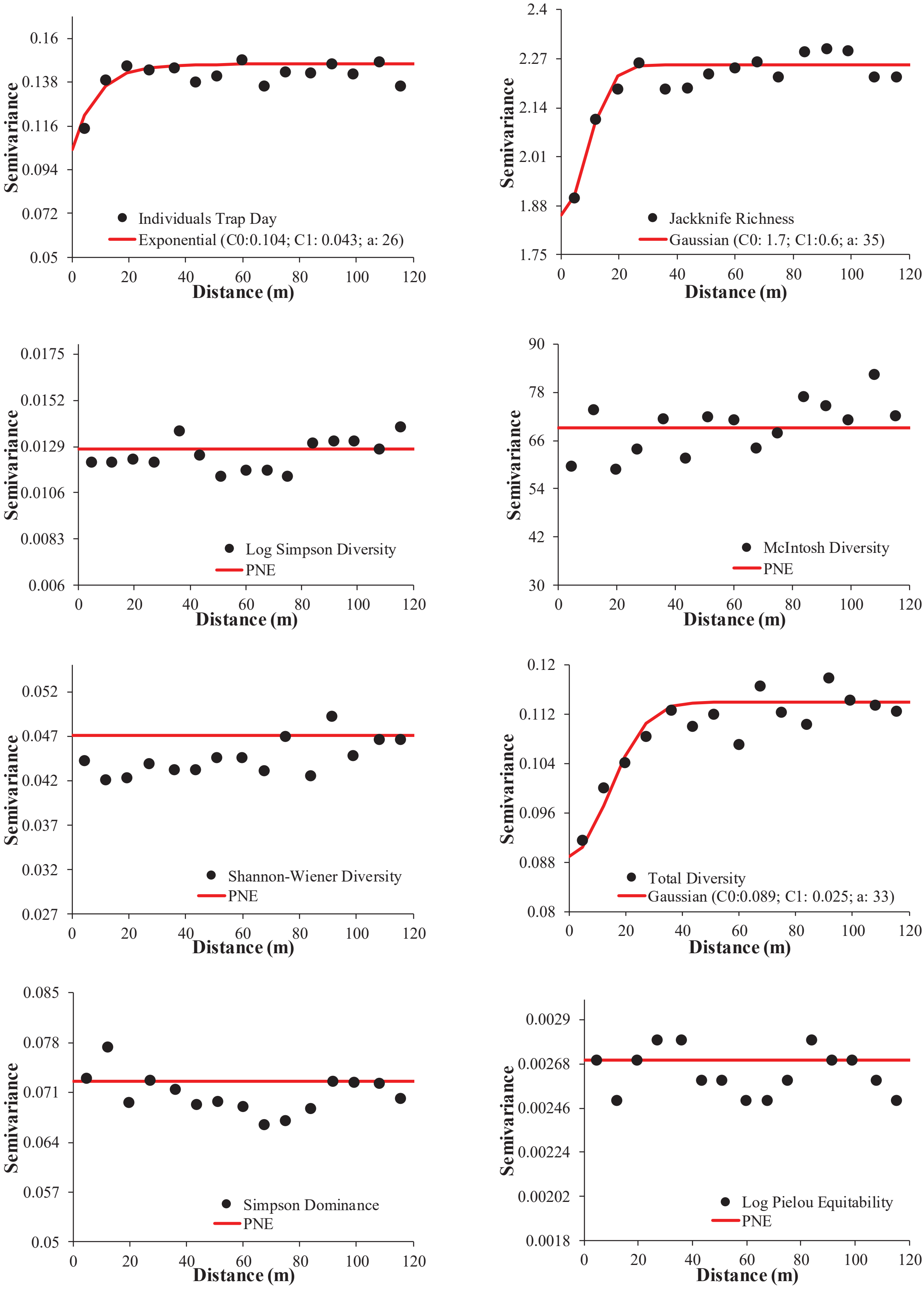

Figure 2S: Semivariograms for biodiversity indexes in the maize area.

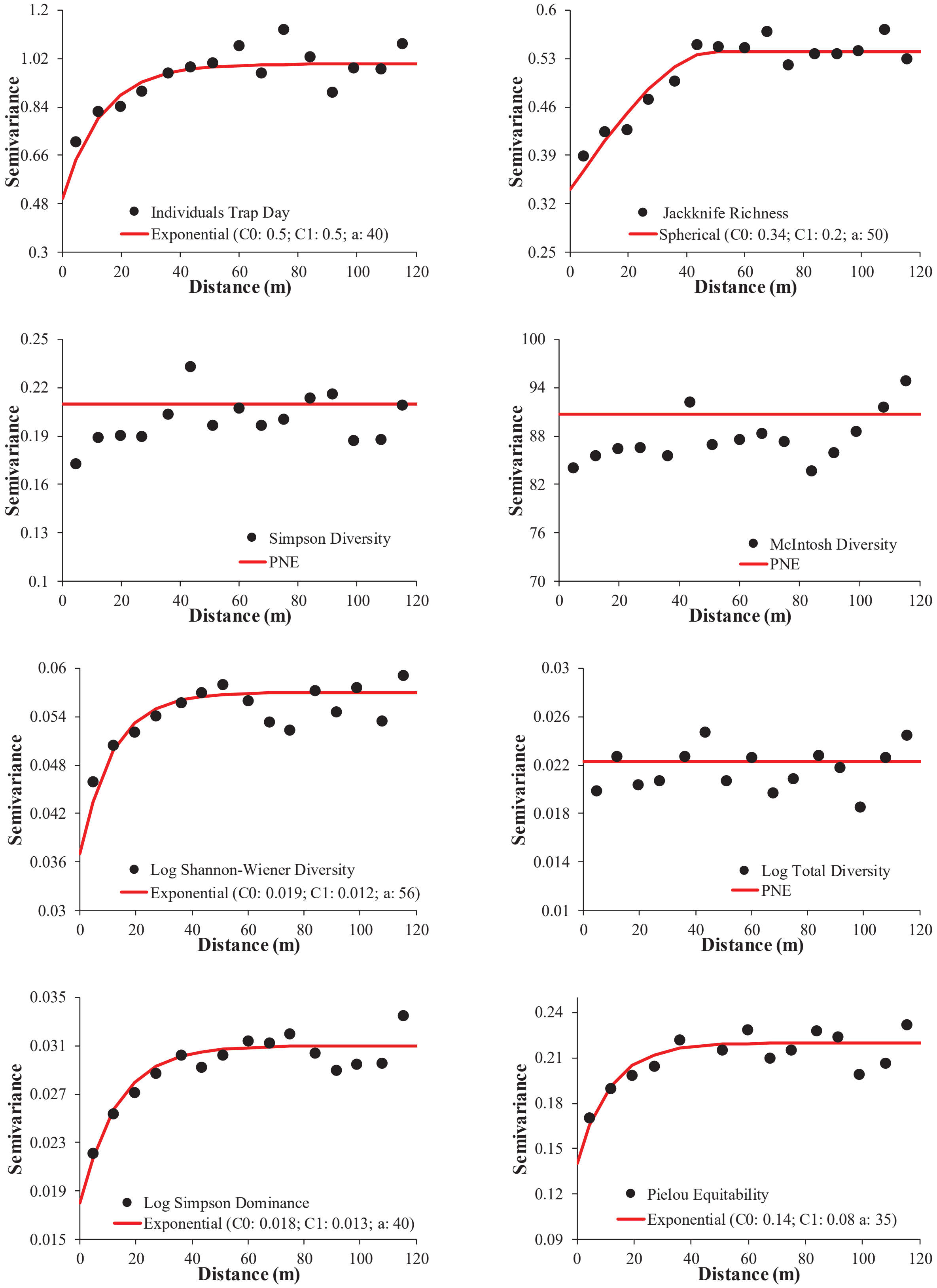

Figure 3S: Semivariograms for biodiversity indexes in the soybean area.

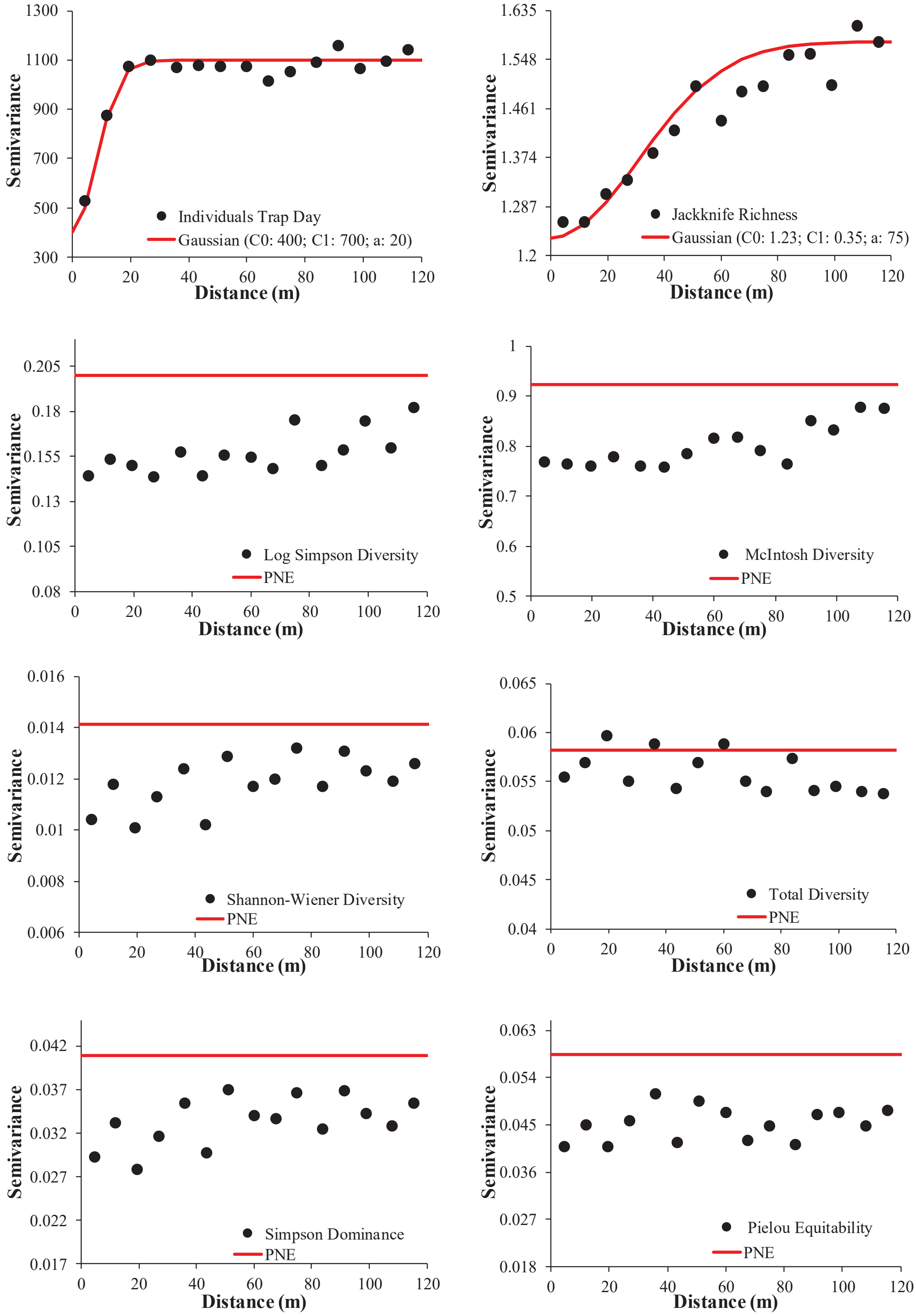

Figure 4S: Semivariograms for biodiversity indexes in the eucalyptus area.

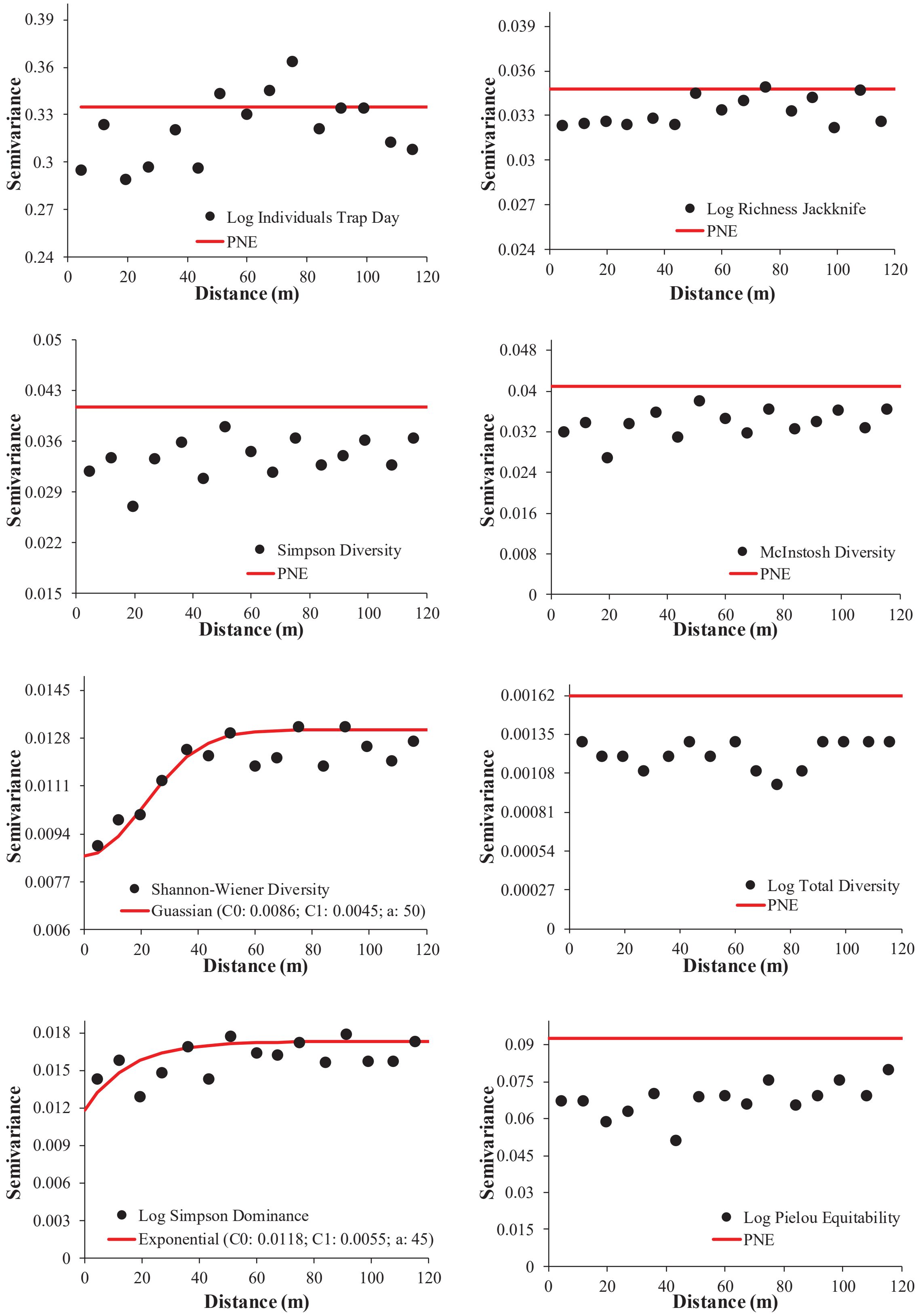

Figure 5S: Semivariograms for biodiversity indexes in the Preserved Cerrado area.

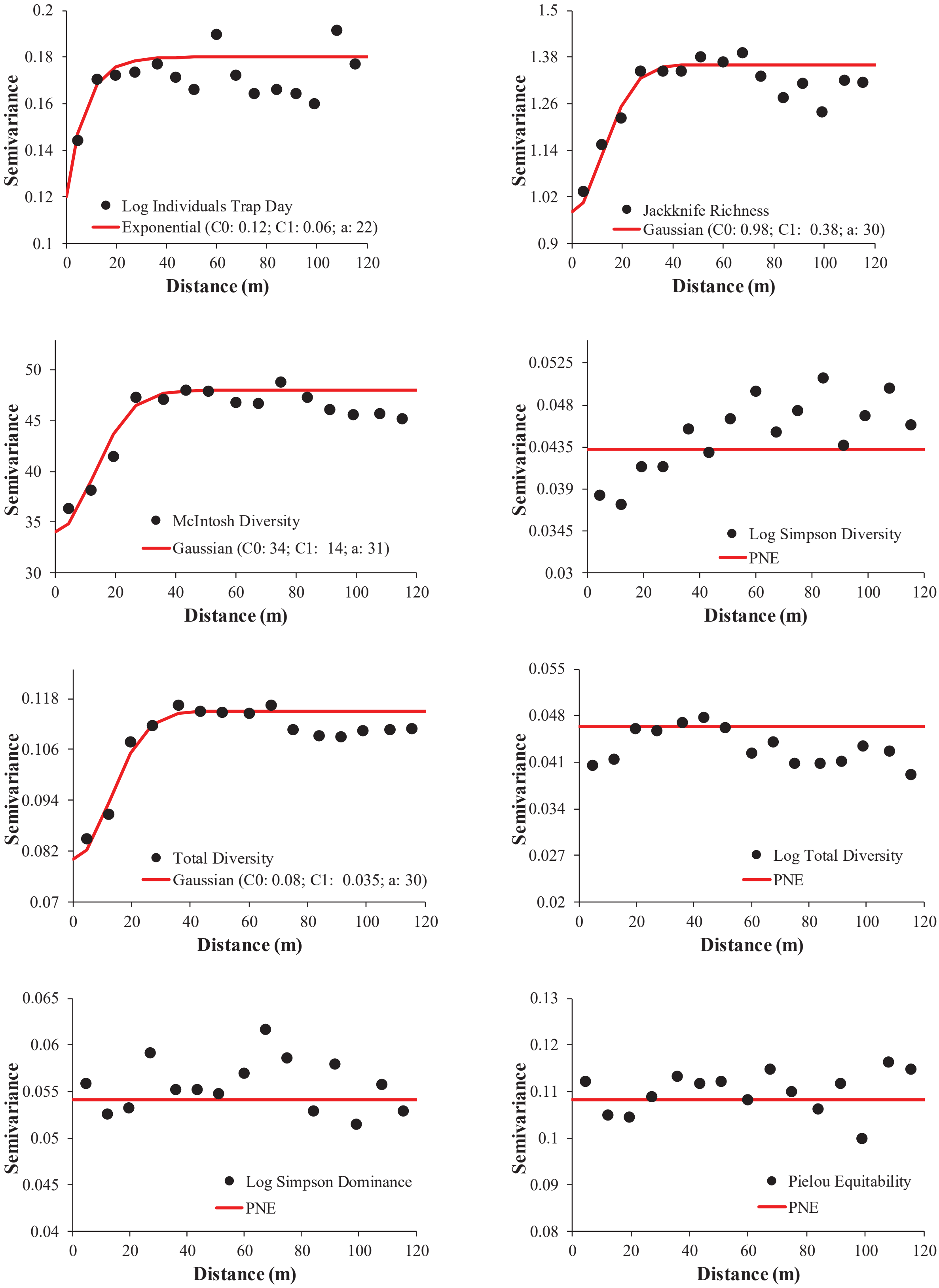

Figure 6S: Semivariograms for biodiversity indexes in the anthropic cerrado area.

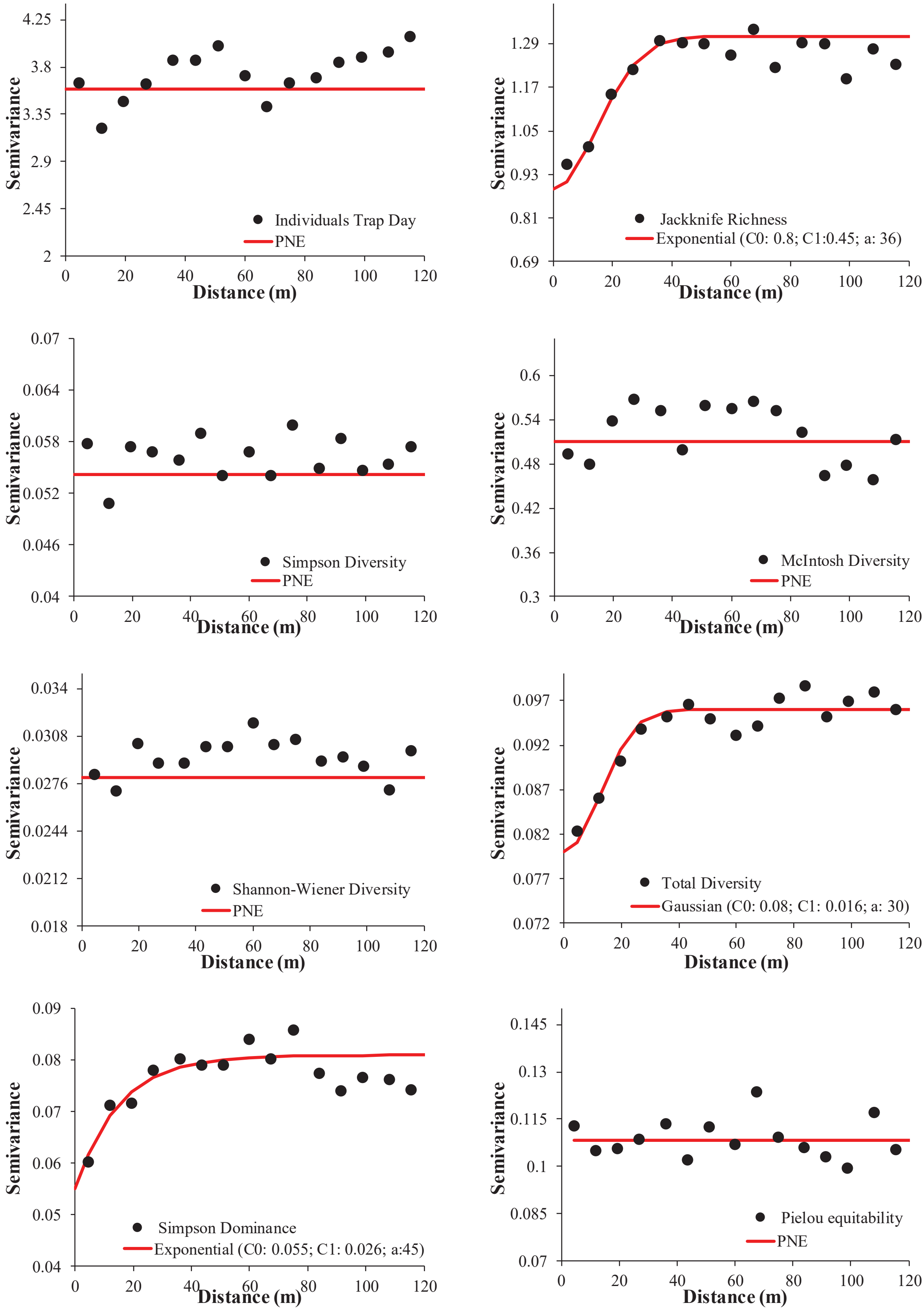

Figure 7S: Semivariograms for biodiversity indexes in the pasture area.

MULTIFRACTAL ANALYSIS OF SOIL FAUNA DIVERSITY INDEXES UNDER DIFFERENT USES AND MANAGEMENT

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ABSTRACT

Soil is a heterogeneous system, with intrinsic properties that are acquired by the interaction of the formation processes that provoke alteration in the spatial and temporal variability of the attributes. The soil management and use have a relevant influence on the variability of soil characteristics. This study aimed to evaluate the degree of multifractality of soil fauna diversity indexes under different land uses and management. The work was developed in the State of Maranhão, Brazil in the year 2015. Seven areas of different land use and management were sampled. The soil fauna was collected in pitfall trap, which remained in the field for a period of seven days. Right after this period the traps were removed, sorted and identified. Subsequently, were determined the diversity indexes, descriptive statistics and multifractality were estimated using the current method. Only millet and maize areas presented normality in the data set. All the coefficient of variation values for the seven areas were considered high. The multifractality analysis was performed for all the moments and partition functions were estimated for successive segments of different sizes ^{2k,} k=0 k=7 in interval q=+10 q=-10. The general size spectrum, $D_{0,}$ for all indexes in millet area was invariable, D_0=1.000 ± 0.000. In the maize area, the overall size spectrum in D_0 ranged from 0.956 ± 0.015 (jackknife richness, Simpson dominance, and Pielou equitability) to 1.000 (individuals traps day) and larger overall dimension values were for the McIntosh index on D_{10} and $D_{2,}$ and individuals traps day in D_1. The singularity spectra were curves in concave parables with higher or lower skewness for all sampled areas. The indexes remained asymmetric and shifted to the right, in some cases, as the Simpson diversity index, a broader right branch. What indicates the data heterogeneity and multifractality.

Keywords: Multifractality, generalized dimension, singularity spectrum

INTRODUCTION

The soil is a dynamic, heterogeneous system, with intrinsic properties that depends on the interaction of formation processes (climate, source material, formation time, topography and vegetation) that provokes spatial variability in the soil. Because it is a heterogeneous system, it cannot be studied in a homogeneous way. Besides to the soil characteristic processes, other factors may contribute to increase or reduce edaphic variabilities, such as soil tillage and fertilization, thus some attributes such as organic carbon content, nutrient availability, soil moisture, soil texture presents some variability (Caridad Cancela et al., 2011; Morales et al., 2012).

Lately, some methods have been proposed to evaluate the soil spatial variability. At the principle variability is often detected by geostatistical methods, however (Neves et al., 2010; Vieira et al., 2010; Aquino et al., 2015; Lima et al., 2015; Siqueira et al., 2016). However, geostatistics is only able to approach the second moment of a variable with scales and frequencies, in view that the soil variability cannot be described by a normal distribution, which may exhibit periodicity, non-stationary data, not linearity (Paz et al., 2000), among other typical characteristics of soils.

The fractal theory has been well diffused in the last years to characterize the soil properties in a wide measurement scales range (Vidal Vazquez et al., 2010; Vidal Vazquez et al., 2013; Siqueira et al., 2015; Wilson et al., 2016; Bertol et al., 2017). According to the fractal theory, a data set can be characterized by a single parameter, which is related to a power function called fractal dimension, D, which was perfectly applicable to soil characteristics (Vidal Vazquez et al 2008). However, it was realized that soil variability can occur at several intensities and scales, and only one exponent could not be enough to characterize this variability.

From these observations, the multifractal analysis enables the soil variability representation with multiple combinations of interlaced fractals scales. It allows to analyze the phenomena that present spatial and temporal variability in a quantitative way and is increasingly recognized the applicability of this method for soil data dependence analysis (Caniego et al., 2005; Vidal Vazquez et al., 2010; Bertol et al., 2017).

In this sense, the diversity, abundance, and richness of the soil fauna can be modified or altered by the soil management and use or it may still suffer influences by the system of soil preparation, culture and climatic factors (Bonnin et al., 2010; Pedroso et al., 2016). Thus, to characterize the distribution and variability of organisms in the most diverse environments becomes a necessity, given that the soil invertebrates provide relevant services to ecosystems. On the above, this study aimed to evaluate the degree of multifractality of the soil fauna diversity indexes under different uses and management of the soil.

MATERIAL AND METHODS

Study site

The study was carried out in the city of Mata Roma, in the state of Maranhão, Brazil, whose coordinates are 3º 70' 80.88" S and 43º 18' 71.27" W. The soil of the region according to the USDA classification (1999) is a yellow Latosol, with moist tropical climate, and annual average ranging from 27ºC to 30ºC, with two well-defined seasons, one dry and one rainy. The precipitation variation ranges from 1.400 mm to 1.600 mm and annual evapotranspiration of 1.114 mm^3.

The soil fauna was collected in the month of May of 2015, using pitfall traps in the transect. Were sampled five areas with different uses (preserved Cerrado and anthropic Cerrado) and managements (millet, maize, soybean, eucalyptus, and pasture) of the soil. In each area were installed 130 traps, in a spacing of 3 m from a trap to the other. In each trap contained 200 mL of 4% formalin for the conservation of invertebrates according to methodologies described by Aquino et al. (2001) and Siqueira et al., (2014). The pitfall traps remained in the field for a period of seven days and right after this period the traps were removed, taken to the laboratory, sorted and identified to the order and family level using the identification key proposed by Lawrence (1991).

Diversity indexes

The indexes were determined in the DivEs software (Rodrigues, 2015). Were determined the indexes of trap individuals day (Ind arm-1 day-1), Jackknife richness; the diversity indexes: Simpson, McIntosh, Shanon-Wiener, total diversity; Simpson's dominance index and Pielou equitability.

The descriptive statistics was determined using the R statistical software (R Development Core Team,2009), where the values of maximum, minimum, average, standard deviation, the coefficient of variation (CV), skewness, kurtosis, and normality were calculated by the Kolmogorov-Smirnov test at 0.001% probability.

Multifractal analysis

The multifractal analysis was carried out following the moment's method. Initially, a mesh with size δ was employed to overlap over all the support. In other words, the cross-sectional length was divided into smaller segments based on the reduction of the scales. The reduction was carried out through of successive divisions of the support, in k stages (k = 1, 2, 3 ...) that generate at each scale δ, a number of segments, N (δ) = 2^k in length, δ = L × k^{-2}, covering the entire length of the support, L, in this case, a cross-section (Evertsz & Mandelbrot, 1992; Caniego et al., 2005; Vázquez Vidal et al., 2013).

Then, the experimental data for each studied variable were converted into the mass distribution along the geometric support. Therefore, the probability of mass function pi (δ), for each segment was estimated as a proportion according to:

$$pi(\delta) = \frac{N_i\ (\delta)}{N_t} \quad (1)$$

Wherein N_i (δ) is the value of the measure in a given segment, i^{th}, and N_t is the sum of the measure in all transect.

The multifractal analysis involves several scaling functions: exponential mass, t_q, spectrum singularity, f(α), local scale index, α_q, and generalized or Rényi dimension, D_q. In practice, the function of scales with the size of the segment follows:

$$X(q, \delta) = \sum_{i=l}^{n(\delta)} pi_i^q\ (\delta) \quad (2)$$

Wherein n (δ) is the number of segments with size δ and statistical moments that are defined for -∞ <q <∞.

A log-log plot of the *X* quantity (q, δ) versus δ for different yield values: *X* (q, δ)∝ $\delta^{-\tau(q)}$, wherein t_q is the order function of the mass scale q. It's noted that the moment's method is justified if the parcels of *X* (q, δ) versus δ are straight lines (Halsey et al., 1986).

The mass function exponent t_q was estimated from the partition function as:

$$t\ (q) = \lim_{\delta \to 0} \frac{\log X\ (q,\delta)}{\log(1/\delta)} \quad (3)$$

The function t_q controls how the measurement moment μi balances with $_q$. In general, the multifractal measurements produce a non-linear function of t_q, while the monofractal corresponds to linear t_q.

For each segment, the probability of distribution is: $p_i(\delta) = \delta^{\alpha i}$, wherein α_i is the singularity or the Hölder's exponent of density characterization in the nth box (Halsey et al., 1986). The Hölder exponent, given by $\alpha^i = \log \mu_i(\delta)/\log \delta$, Can be interpreted as an agglomeration index for the concentration degree of the measure, μ. It is, in fact, the logarithm of the density of the nth box of the partition of the characteristic size δ.

For the distributed multifractal measurements, the number of $N_\delta(\alpha)$ of cells of the size δ having a singularity or the Hölder exponent equal to α increases to the decrease of δ and obeys a power law: $N(\alpha) \propto \delta\text{-}^{f(\alpha)}$, Where the exponent f(α) is a continuous function of α. The graph of f(α) versus α, called of the multifractal spectrum, typically, has, a down concave parabolic shape, with an interval of α values increasing with the measure heterogeneity increase. The minimum scale exponent $f(\alpha_{q-})$ corresponds to the most concentrated region of the measure, and the maximum exponent $f(\alpha_{q+})$ corresponds to the rarefied regions of the measure. The linkage between the scale exponents τ_q and f(α) can be done through a Legendre transformation. However, in this work, the functions t_q and f (α) were obtained by following Chhabra and Jensen (1989) with the equations:

$$\alpha(q) \propto \frac{\sum_{i=1}^{n(\delta)} \mu_{i(q,\delta)} \log[\mu_{i\,(\delta)}]}{\log(\delta)} \tag{4a}$$

$$f(\alpha(q) \propto \frac{\sum_{i=1}^{n(\delta)} \mu_{i(q,\delta)} \log[\mu_{i\,(q,\delta)}]}{\log(\delta)} \tag{4b}$$

The scale function, t_q, also is related to generalized fractal dimension (Hentschel & Procaccia, 1983), which can be defined by equations 5a. In fact, the generalized dimension concept, D_q, corresponds to the scaling exponent for the q^{th} measurement moment. Besides, the generalized dimension may also be defined by the Equation 5b. It is observed, however, that using equations 5a or 5b D1 becomes indeterminate because the denominator value is zero. Therefore, for the particular case where q = 1, the equation 5c is used.

$$D_1 = t(q)/(q-1) \tag{5a}$$

$$D_1 = \lim_{\delta \to 0} \frac{1}{q-1} \frac{\log[x(q,\delta)]}{\log \delta} \tag{5b}$$

$$D_1 = \lim_{\delta \to 0} \frac{\sum_{i=1}^{n(\delta)} Xi\,(1,\delta) \log[X_{1\,(1,\delta)}]}{\log \delta} \quad (5c)$$

For a monofractal, D_q is a constant function of q, so no additional information is obtained through the raised moments analyses. However, for multifractal measurements, the relationship between D_q and q is not constant. In this case, the generalized dimensions most frequently used are D_0 for q = 0, D1 for q = 1 and D_2 for q = 2, which are referred to as capacity, information (Shannon's entropy) and correlation dimension, respectively.

The capacity or dimension, D_0, and the scaling exponent of the non-empty segments number. Thus, is independent of the mass quantity in each box, but takes into account the fact that the segments are occupied or not. The information dimension, D_1, gives the probability of occupation of the nth segment of the size δ, without taking into account the way as the measure is distributed within each of these segments. Thus, D_1 provides a physical characterization, indicating how the heterogeneity and altered in a given scales interval, being also related to the Shannon entropy. The correlation dimension, D_2, describes the uniformity of the measurement values between the intervals. The generalized dimension, D_q, is widely used for broad multifractal studies. Differences between D_q allow the comparison of complexity between the studied set. The greater the heterogeneity of the structure, the closer the D_q values are; therefore in a monofractal D_q is constant.

RESULTS AND DISCUSSION

Table 1, are sampled the main statistical moments for the soil fauna in the studied areas. According to the Kolmogorov-Smirnov normality test, only millet and maize areas presented normal data for soil fauna. The values of the skewness coefficients varied from 1.163 for the millet area to 4.255 for the preserved Cerrado area. The kurtosis coefficient was high for preserved cerrado area (kurtosis = 26.574). The coefficients of a skewness and kurtosis are indicative for classifying the data as normal or not (Webster, 2001). Verifying the distribution of data normality allows us to check if there are any extreme values in the data set (Siqueira et al., 2009). According to the classification of Warrick and Nielson (1980), the coefficients of variation for all areas are considered high, values above 60%. The areas of Eucalyptus, preserved Cerrado and anthropic Cerrado obtained CV values above 100%. CV values above 100% are common for soil variables and may reach 1000% (Warrick e Nielson, 1980).

The multifractal analysis was performed for all indexes studied. The partition functions X (q, δ) were constructed for successive segments of different sizes, 2^k, k=0 to k= 7 (Table 2). For moments of q orders, in the interval range q = +10 to q = -10, as can be seen in figure 1 and figure 2 (Figure 1S as Supplementary Digital Content and figure 2S Supplementary Digital Content).

Table 1: Summary statistics of the studied soil fauna measured.

	Millet	Maize	Soybean	Eucalyptus	Preserved Cerrado	Anthropic Cerrado	Pasture
Number of values	130.000	130.000	130.000	130.000	130.000	130.000	130.000
Sum	9974.000	824.000	222.000	3841.000	2384.000	1777.000	1933.000
Minimum	3.000	0.000	0.000	0.000	0.000	1.000	0.000
Maximum	251.000	35.000	6.000	181.000	234.000	96.000	87.000
Mean	76.723	6.338	1.708	29.546	18.338	13.669	14.869
Variance	2587.023	34.458	1.139	1098.079	800.520	238.006	175.929
Standard deviation	50.863	5.870	1.067	33.137	28.293	15.427	13.264
CV (%)	66.294	92.611	62.488	112.154	154.285	112.863	89.203
Skew	1.163	2.048	1.659	2.325	4.255	2.800	2.809
Kurtosis	1.447	6.613	2.999	6.202	26.574	9.463	10.149
D*	0.114 n	0.14 n	0.308 Ln	0.225 Ln	0.258 Ln	0.266 Ln	0.208 Ln

CV (%): coefficient of variation; D*: Kolmogorov-Smirnov 0.001%.

The generalized dimension spectrum, D_0, for all indexes in the millet area was invariant, D_0 = 1.000 ± 0.000. However, for other dimensions, such as D_1, these values range from 0.869 ± 0.002 for the Shanon-Wiener diversity index to 0.996 ± 0.000 for the Jackknife richness index (Table 2). Similarly, in D_2, the Shanon-Wiener and Jackknife richness indexes obtained the lowest and highest dimension value, 0.823 ± 0.025 and 0.992 ± 0.001, respectively.

In the maize area, the generalized dimension spectrum in the D_0 ranged from 0.956 ± 0.015 (jackknife richness, Simpson dominance, and Pielou equitability) to 1.000 (individuals traps day). For the dimensions, D_{10}, D_1 and D_2, the Simpson diversity index obtained the lower dimension values. While, the highest values were for the McIntosh index in the D_{10} and D_2, and for individual trap day in D_1.

Table 2: Multifractality indices and parameters obtained from the generalized dimension.

Generalized dimension						
Millet						
	D_{-10}- D_{10}	D_{-10}	D_{10}	D_0	D_1	D_2
Individuals trap day	0.611	1.438±0.112	0.826±0.027	1.000±0.000	0.963±0.008	0.934±0.014
Jaccknife richness	0.125	1.060±0.020	0.935±0.016	1.000±0.000	0.996±0.000	0.992±0.001
Simpson Diversity	0.144	1.045±0.006	0.900±0.016	1.000±0.000	0.992±0.001	0.984±0.002
McIntosh Diversity	0.283	1.252±0.074	0.968±0.004	1.000±0.000	0.993±0.001	0.988±0.002
Shanon Diversity	1.196	1.926±0.140	0.729±0.030	1.000±0.000	0.869±0.002	0.823±0.025
Total Diversity	0.194	1.056±0.010	0.862±0.032	1.000±0.000	0.992±0.001	0.982±0.003
Simpson Dominance	0.222	1.187±0.068	0.965±0.007	1.000±0.000	0.994±0.001	0.989±0.002
Pielou Equitability	0.285	1.256±0.083	0.971±0.003	1.000±0.000	0.993±0.001	0.989±0.002
Maize						
	D_{-10}- D_{10}	D_{-10}	D_{10}	D_0	D_1	D_2
Individuals trap day	0.611	1.438±0.112	0.826±0.028	1.000±0.000	0.963±0.009	0.934±0.014
Jaccknife richness	0.363	1.258±0.128	0.895±0.009	0.956±0.015	0.940±0.012	0.930±0.010
Simpson Diversity	0.476	1.258±0.535	0.782±0.035	0.960±0.016	0.923±0.019	0.890±0.024
McIntosh Diversity	0.153	1.084±0.092	0.931±0.003	0.960±0.016	0.952±0.012	0.947±0.009
Shanon Diversity	0.906	1.573±0.098	0.667±0.029	0.971±0.010	0.868±0.019	0.801±0.014
Total Diversity	0.404	1.286±0.128	0.882±0.011	0.978±0.009	0.955±0.008	0.939±0.009
Simpson Dominance	0.281	1.165±0.171	0.884±0.007	0.956±0.015	0.939±0.011	0.927±0.010
Pielou Equitability	0.241	1.153±0.171	0.911±0.008	0.956±0.015	0.946±0.011	0.939±0.010
Soybean						
	D_{-10}- D_{10}	D_{-10}	D_{10}	D_0	D_1	D_2
Individuals trap day	0.273	1.121±0.031	0.848±0.016	0.998±0.001	0.971±0.004	0.945±0.008
Jaccknife richness	0.087	0.855±0.116	0.769±0.012	0.813±0.043	0.808±0.030	0.803±0.022
Simpson Diversity	0.245	0.798±0.089	0.553±0.037	0.631±0.047	0.610±0.045	0.592±0.044
McIntosh Diversity	0.038	0.822±0.121	0.784±0.014	0.811±0.044	0.805±0.033	0.800±0.024
Shanon Diversity	0.472	1.194±0.091	0.722±0.023	0.843±0.36	0.819±0.030	0.800±0.026
Total Diversity	0.237	1.107±0.033	0.870±0.015	0.997±0.002	0.977±-.004	0.957±0.006
Simpson Dominance	0.081	0.836±0.130	0.755±0.013	0.813±0.043	0.807±0.029	0.800±0.020
Pielou Equitability	0.080	0.859±0.111	0.779±0.013	0.813±0.043	0.806±-.031	0.800±0.023
Eucalyptus						
	D_{-10}-D_{10}	D_{-10}	D_{10}	D_0	D_1	D_2
Individuals trap day	0.879	1.527±0.081	0.648±0.027	0.999±0.001	0.902±0.007	0.823±0.012
Jaccknife richness	1.707	1.712±0.44	0.004±0.002	0.744±0.083	0.019±0.007	0.007±0.003
Simpson Diversity	0.232	1.144±0.034	0.912±0.019	1.000±0.000	0.991±0.001	0.984±0.003
McIntosh Diversity	0.572	1.444±0.041	0.871±0.008	0.990±0.005	0.952±0.008	0.932±0.009
Shanon Diversity	1.070	1.719±0.182	0.649±0.020	1.000±0.000	0.890±0.011	0.818±0.013
Total Diversity	0.237	1.177±0.044	0.939±0.007	1.000±0.000	0.988±0.003	0.979±0.004
Simpson Dominance	0.537	1.406±0.023	0.868±0.014	0.991±0.004	0.957±0.007	0.938±0.009
Pielou Equitability	0.644	1.501±0.035	0.857±0.007	0.991±0.004	0.949±0.008	0.926±0.009
Preserved Cerrado						
	D_{-10}-D_{10}	D_{-10}	D_{10}	D_0	D_1	D_2
Individuals trap day	1.040	1.568±0.06	0.528±0.067	0.991±0.004	0.860±0.025	0.758±0.042
Jaccknife richness	0.113	1.057±0.021	0.945±0.014	0.991±0.004	0.988±0.003	0.986±0.003
Simpson Diversity	0.232	1.144±0.034	0.912±0.019	1.000±0.000	0.991±0.001	0.984±0.003
McIntosh Diversity	0.572	1.444±0.042	0.872±0.008	0.991±0.004	0.953±0.008	0.932±0.009
Shanon Diversity	1.206	1.733±0.180	0.527±0.056	1.000±0.000	0.868±0.019	0.759±0.035

Total Diversity	0.237	1.177±0.044	0.939±0.007	1.000±0.000	0.988±0.003	0.979±0.004
Simpson Dominance	0.536	1.404±0.020	0.868±0.014	0.991±0.004	0.957±0.007	0.937±0.009
Pielou Equitability	0.233	1.144±0.035	0.911±0.020	1.000±0.000	0.992±0.001	0.984±0.003
Anthropic Cerrado						
	D_{-10}-D_{10}	D_{-10}	D_{10}	D_0	D_1	D_2
Individuals trap day	0.735	1.427±0.059	0.692±0.038	1.000±0.000	0.916±0.014	0.845±0.026
Jaccknife richness	0.393	1.309±0.050	0.916±0.005	0.981±0.011	0.960±0.010	0.947±0.009
Simpson Diversity	0.355	1.217±0.056	0.862±0.017	0.989±0.006	0.960±0.008	0.937±0.011
McIntosh Diversity	0.281	1.205±0.044	0.923±0.009	0.981±0.011	0.968±0.010	0.959±0.010
Shanon Diversity	1.249	1.924±0.205	0.675±0.029	0.993±0.004	0.879±0.017	0.812±0.021
Total Diversity	0.210	1.135±0.033	0.925±0.015	1.000±0.000	0.986±0.004	0.975±0.006
Simpson Dominance	0.308	1.214±0.037	0.906±0.010	0.981±0.011	0.964±0.011	0.952±0.010
Pielou Equitability	0.361	1.262±0.057	0.901±0.011	0.981±0.011	0.964±0.011	0.951±0.011
Pasture						
	D_{-10}-D_{10}	D_{-10}	D_{10}	D_0	D_1	D_2
Individuals trap day	0.638	1.370±0.080	0.732±0.051	0.999±0.001	0.948±0.012	0.897±0.024
Jaccknife richness	0.411	1.331±0.073	0.920±0.010	0.993±0.004	0.975±0.006	0.964±0.006
Simpson Diversity	0.356	1.222±0.056	0.866±0.017	0.989±0.006	0.961±0.008	0.938±0.011
McIntosh Diversity	0.245	1.163±0.029	0.918±0.012	0.980±0.012	0.969±0.011	0.961±0.010
Shanon Diversity	0.895	1.582±0.133	0.686±0.032	0.995±0.003	0.915±0.015	0.848±0.022
Total Diversity	0.223	1.143±0.024	0.920±0.011	1.000±0.000	0.985±0.003	0.972±0.006
Simpson Dominance	0.297	1.197±0.033	0.900±0.021	0.993±0.004	0.978±0.006	0.966±0.008
Pielou Equitability	0.300	1.219±0.055	0.919±0.020	0.993±0.004	0.980±0.006	0.970±0.008

D_0; D_1; D_2; D_{-10}-D_{10}; D_{-10}: are generalized dimension for *q*= 0, 1, 2, -10, 10.

The properties of scales that are observed through the partition function can be typified, to determine if the scale in question can be characterized as a simple scale, which characterizes a monofractal or multiple scales, which determines a multifractal (Vidal Vázquez et al., 2013).

The difference values of D_{-10}-D_{10}, in other words, D_{max}-D_{min} were above 1 for Shanon diversity index (1.196/millet), (1.070/eucalyptus), (1.206/preserved Cerrado) and (1.249/ anthropic Cerrado). According to Paz-Ferreiro et al. (2010), these difference values have been used as multifractality perception.

The determination coefficients R^2 were higher for the generalized dimension q = 0 (R^2 = 1.00). For q = 1 only Shanon diversity index obtained R^2 lower than 1000. From q = 2 there was a decrease in the values of R^2 for q = 10 and q = -10 for all indexes in the millet area (Table 3). A similar pattern was recorded by Paz Ferrero and Vidal Vázquez (2010) in the analysis of the distribution of soil pore size, where was obtained high values of R^2 for q = 0 and q = 1 and decrease with the increase of q.

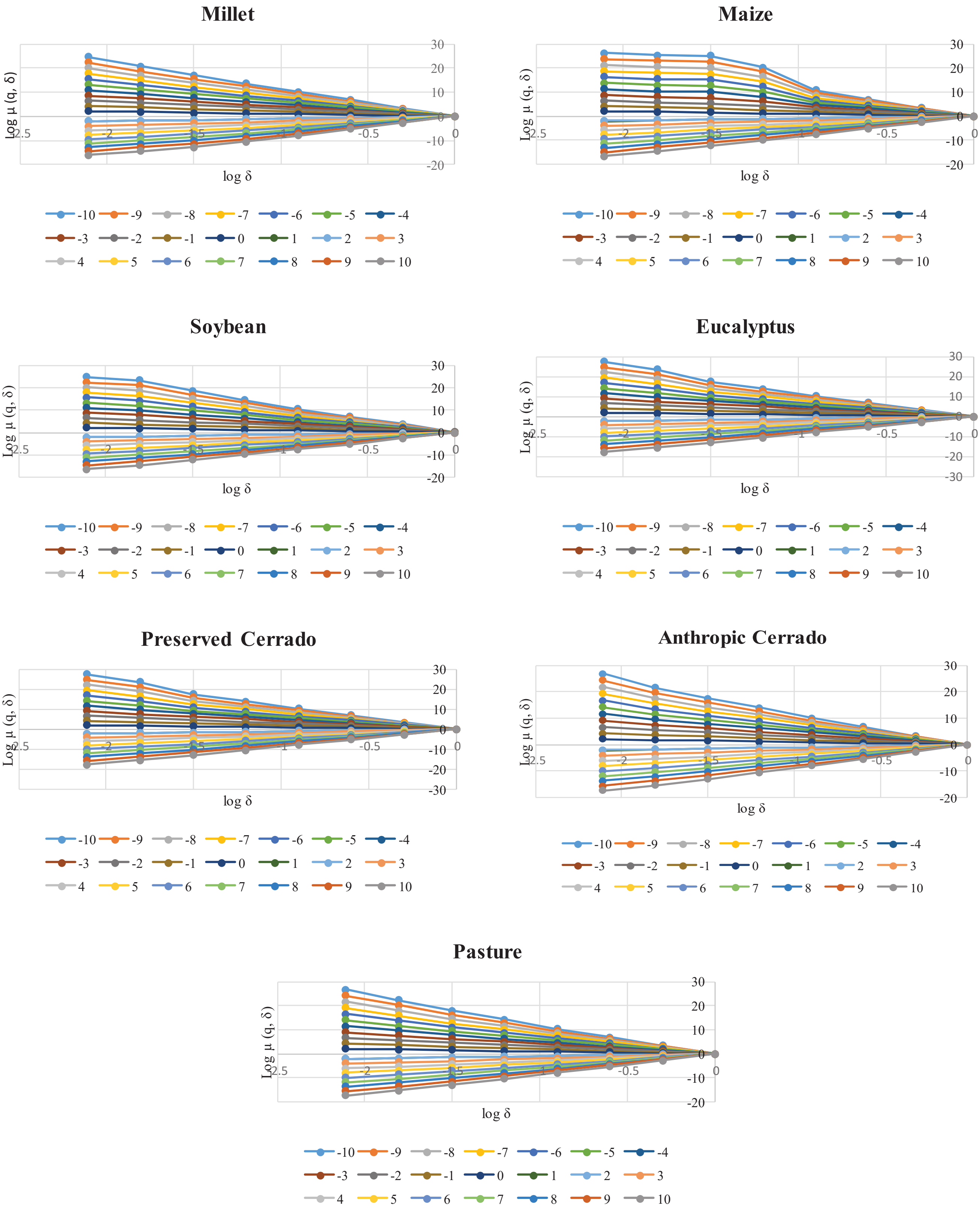
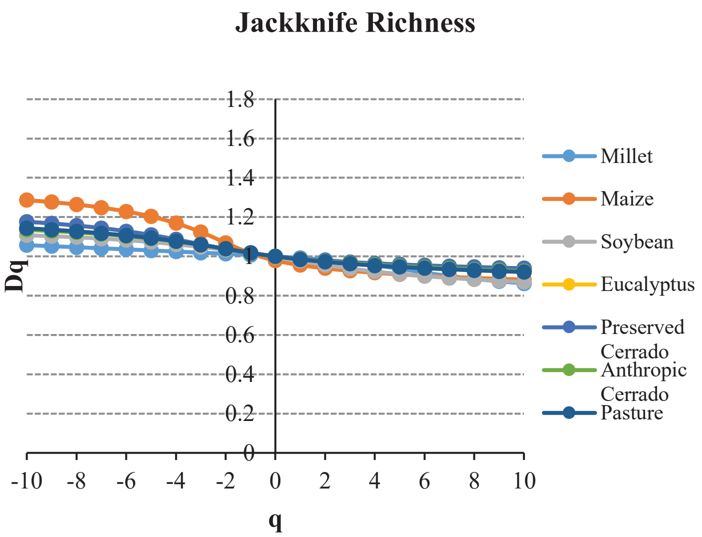


Figure 1: Partition function *X*(q, δ) against scale for a range of moment orders, *q* [-10, 10] Jackknife richness.



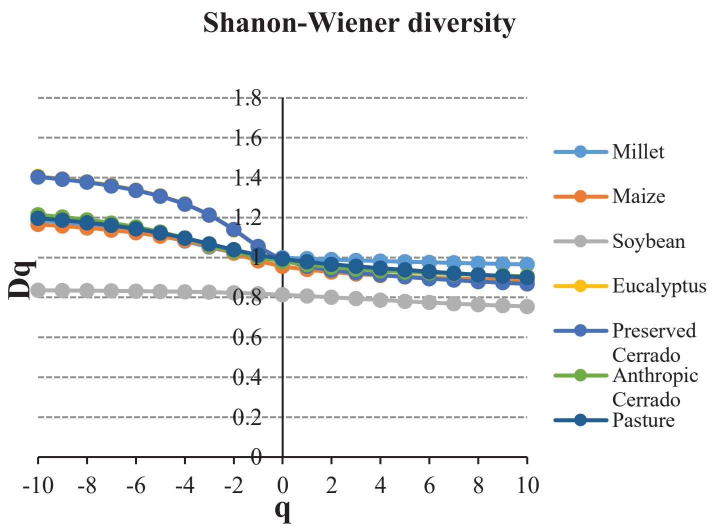


Figure 2: Generalized dimension, Dq, spectra (-10 < q <10).

For the maize area only the indexes of individuals traps day and total diversity obtained values of R^2 = 1.000 for q = 0 and q = 1. For q = 2 only the total diversity index obtained R^2 = 1.000. For q = 10 only McIntosh's diversity indexes and Simpson's dominance obtained values R^2 = 1.000. For q = -10, all indexes obtained values of R^2 below 0.999.

For the soybean area there was an increase of R^2 for all inexces as q increased, so q = 10 < q = 0 < q = 1 < q = 2 < q = -10. In the eucalyptus area, the jacckknife's richness index obtained the lowest R^2 values for all moments (q), being 0.464, 0.465, 0.546, 0.714 and 0.931, corresponding to q = -10, q = 2, q = 1 q = 10 and q = 0 respectively. The values of R^2 for q = 0 in anthropic cerrado were equal to 1.000 for all indexes at that time. While, in the pasture when q = 0, R^2 value was 0.999 for McIntosh's diversity index, however for the other indexes in the same time, R^2 was 1.000 (Table 3).

Table 3: Determination Coefficient of diversity indices.

	Millet				
	R^2 D_{-10}	R^2 D_{10}	R^2 D_0	R^2 D_1	R^2 D_2
Individuals trap day	0.965	0.827	1.000	1.000	0.999
Jackknife richness	0.998	0.935	1.000	1.000	1.000
Simpson Diversity	1.000	0.901	1.000	1.000	1.000

McIntosh Diversity	0.979	0.969	1.000	1.000	1.000
Shanon Diversity	0.969	0.729	1.000	0.996	0.994
Total Diversity	0.999	0.863	1.000	1.000	1.000
Simpson Dominance	0.980	0.965	1.000	1.000	1.000
Pielou Equitability	0.974	0.971	1.000	1.000	1.000
Maize					
	R^2 D_{-10}	**R^2 D_{10}**	**R^2 D_0**	**R^2 D_1**	**R^2 D_2**
Individuals trap day	0.965	0.993	1.000	1.000	0.999
Jackknife richness	0.942	0.999	0.998	0.999	0.999
Simpson Diversity	0.989	0.988	0.998	0.997	0.996
McIntosh Diversity	0.958	1.000	0.998	0.999	0.999
Shanon Diversity	0.977	0.989	0.999	0.997	0.995
Total Diversity	0.944	0.999	1.000	1.000	1.000
Simpson Dominance	0.886	1.000	0.998	0.999	0.999
Pielou Equitability	0.884	0.999	0.998	0.999	0.999
Soybean					
	R^2 D_{-10}	**R^2 D_{10}**	**R^2 D_0**	**R^2 D_1**	**R^2 D_2**
Individuals trap day	0.998	0.995	1.000	1.000	1.000
Jackknife richness	0.998	0.900	0.984	0.992	0.996
Simpson Diversity	0.974	0.931	0.967	0.969	0.969
McIntosh Diversity	0.998	0.885	0.983	0.990	0.994
Shanon Diversity	0.994	0.966	0.989	0.992	0.993
Total Diversity	0.998	0.995	1.000	1.000	1.000
Simpson Dominance	0.998	0.874	0.984	0.993	0.996
Pielou Equitability	0.998	0.910	0.984	0.991	0.995
Eucalyptus					
	R^2 D_{-10}	**R^2 D_{10}**	**R^2 D_0**	**R^2 D_1**	**R^2 D_2**
Individuals trap day	0.990	0.983	1.000	1.000	0.999
Jackknife richness	0.464	0.714	0.931	0.546	0.465
Simpson Diversity	0.997	0.995	1.000	1.000	1.000
McIntosh Diversity	1.000	0.995	1.000	1.000	0.999
Shanon Diversity	0.994	0.937	1.000	0.999	0.999
Total Diversity	1.000	0.992	1.000	1.000	1.000
Simpson Dominance	0.999	0.998	1.000	1.000	0.999
Pielou Equitability	1.000	0.997	1.000	1.000	0.999
Preserved Cerrado					
	R^2 D_{-10}	**R^2 D_{10}**	**R^2 D_0**	**R^2 D_1**	**R^2 D_2**
Individuals trap day	0.990	0.982	1.000	0.999	0.994
Jackknife richness	0.991	1.000	0.999	0.999	0.999
Simpson Diversity	0.987	0.998	1.000	1.000	0.999
McIntosh Diversity	0.992	0.999	0.999	0.999	0.999
Shanon Diversity	0.936	0.989	1.000	0.998	0.996
Total Diversity	0.995	0.998	1.000	1.000	1.000

Simpson Dominance	0.994	0.999	0.999	0.999	0.999
Pielou Equitability	0.988	0.999	0.999	0.999	0.999
Anthropic Cerrado					
	R^2 D_{-10}	**R^2 D_{10}**	**R^2 D_0**	**R^2 D_1**	**R^2 D_2**
Individuals trap day	0.989	0.913	1.000	0.995	0.982
Jackknife richness	0.998	0.999	1.000	1.000	1.000
Simpson Diversity	0.995	0.997	1.000	1.000	1.000
McIntosh Diversity	0.995	1.000	1.000	1.000	0.999
Shanon Diversity	0.939	0.936	1.000	0.997	0.988
Total Diversity	0.992	1.000	1.000	1.000	1.000
Simpson Dominance	0.999	0.999	1.000	1.000	0.999
Pielou Equitability	0.995	0.997	1.000	1.000	1.000
Pasture					
	R^2 D_{-10}	**R^2 D_{10}**	**R^2 D_0**	**R^2 D_1**	**R^2 D_2**
Individuals trap day	0.980	0.972	1.000	0.999	0.996
Jacckknife richness	0.983	0.999	1.000	1.000	1.000
Simpson Diversity	0.987	0.998	1.000	1.000	0.999
McIntosh Diversity	0.996	0.999	0.999	0.999	0.999
Shanon Diversity	0.960	0.987	1.000	0.998	0.996
Total Diversity	0.997	0.999	1.000	1.000	1.000
Simpson Dominance	0.995	0.997	1.000	1.000	1.000
Pielou Equitability	0.988	0.997	1.000	1.000	1.000

R^2 D_0, D_1, D_2, D_{-10}, D_{10}: are for q= 0, 1, 2, -10, 10: Determination coefficient.

The values of α and *f(α)* of the singularity spectrum were calculated by the equation 4a and 4b, for the moments of q, where the logarithm of normalized measures vary linearly (R^2 > 0.90). Thus, the minimum values for which the right branch of the spectrum q- ranged from q -=-1 to q-=-10 for millet area. While for the maize area, the variation of the minimum values was of q_-=-1 to q_-= -2.

The maximum values for the left branch were from q += 4 to q+= 10 for millet; of q+= 5 to q+= 10 for maize; of q+= 6 to q+= 10 for soybeans; of q+= 3 to q+= 10 for eucalyptus; of q+= 2 to q+= 10 for the preserved cerrado; of q+= 3 to q+= 10 for the anthropic cerrado and of q+= 2 to q+= 10 for the pasture (Table 4).

In Figure 3 (3S Supllementary Digital Content), realize that all singularity spectrum indices were curved in concave parabolas with higher or lower degrees of skewness for all sampled areas. The indexes remained asymmetric and shifted to the right, in some cases, as the Simpson's diversity index, a broader right branch. The width or amplitude of the singularity spectrum α_{max} and α_{min} is an indicator of heterogeneity because it provides information on the diversity of scale exponents of a given measure (Vidal Vázquez et al., 2010; Wilson et al., 2010). In this case, the higher the spectrum $f(\alpha)$-α, the greater the heterogeneity of the scales indexes.

Table 4: singularity spectra of diversity indices (q-, q+, α_0, α_{max}, α_{min}).

	+q	-q	α_0	R^2	α_{max}	α_{min}
Millet						
Individuals trap day	6	-1	1.043±0.021	0.999	1.180±0.100	0.801±0.062
Jackknife richness	6	-5	1.004±0.002	0.999	1.068±0.044	0.930±0.032
Simpson Diversity	6	-10	1.007±0.002	0.999	1.078±0.018	0.882±0.042
McIntosh Diversity	10	-2	1.009±0.004	0.999	1.149±0.113	0.954±0.010
Shanon Diversity	5	-1	1.202±0.074	0.993	1.737±0.240	0.722±0.059
Total Diversity	4	-8	1.007±0.002	0.999	1.095±0.039	0.903±0.047
Simpson Dominance	10	-2	1.007±0.004	0.999	1.091±0.075	0.943±0.021
Pielou Equitability	10	-2	1.009±0.005	0.999	1.160±0.132	0.958±0.008
Maize						
	+q	**-q**	α_0	R^2	α_{max}	α_{min}
Individuals trap day	6	-1	1.043±0.021	0.999	1.180±0.100	0.801±0.062
Jackknife richness	10	-1	0.976±0.042	0.997	1.051±0.123	0.877±0.20
Simpson Diversity	5	-2	1.001±0.029	0.998	1.185±0.094	0.768±0.077
McIntosh Diversity	10	-2	0.971±0.043	0.996	1.046±0.156	0.924±0.010
Shanon Diversity	5	-1	1.094±0.017	0.999	1.389±0.126	0.646±0.060
Total Diversity	10	-1	1.007±0.026	0.998	1.109±0.121	0.849±0.024
Simpson Dominance	10	-1	0.977±0.048	0.996	1.054±0.210	0.860±0.017
Pielou Equitability	10	-1	0.970±0.046	0.996	1.033±0.208	0.892±0.017
Soybean						
	+q	**-q**	α_0	R^2	α_{max}	α_{min}
Individuals trap day	10	-4	1.024±0.004	0.999	1.136±0.062	0.803±0.032
Jackknife richness	7	-1	0.818±0.111	0.971	0.828±0.173	0.755±0.031
Simpson Diversity	5	-2	0.653±0.112	0.955	0.765±0.185	0.546±0.072
McIntosh Diversity	7	-2	0.816±0.110	0.972	0.825±0.216	0.779±0.036
Shanon Diversity	6	-2	0.872±0.086	0.985	1.140±0.203	0.703±0.049
Total Diversity	10	-4	1.017±0.004	0.999	1.123±0.069	0.821±0.032
Simpson Dominance	7	-1	0.819±0.115	0.969	0.829±0.187	0.736±0.032
Pielou Equitability	7	-2	0.820±0.107	0.973	0.842±0.203	0.773±0.035
Eucalyptus						
	+q	**-q**	α_0	R^2	α_{max}	α_{min}
Individuals trap day	3	-2	1.101±0.016	0.999	1.481±0.141	0.678±0.051
Jackknife richness	9	-9	1.033±0.001	0.999	1.000±0.000	0.99±0.000
Simpson Diversity	5	-3	1.009±0.003	0.999	1.111±0.058	0.921±0.032
McIntosh Diversity	10	-2	1.044±0.008	0.998	1.452±0.103	0.836±0.021
Shanon Diversity	4	-1	1.132±0.038	0.999	1.554±0.296	0.647±0.042
Total Diversity	10	-3	1.014±0.006	0.999	1.162±0.085	0.912±0.015
Simpson Dominance	9	-3	1.037±0.005	0.999	1.471±0.062	0.826±0.034
Pielou Equitability	8	-2	1.053±0.010	0.999	1.515±0.089	0.825±0.016
Preserved Cerrado						
	+q	**-q**	α_0	R^2	α_{max}	α_{min}
Individuals trap day	2	-2	1.136±0.041	0.999	1.578±0.140	0.668±0.110
Jackknife richness	6	-6	0.994±0.009	0.999	1.082±0.062	0.944±0.027
Simpson Diversity	5	-3	1.009±0.003	0.999	1.111±0.058	0.921±0.032
McIntosh Diversity	10	-2	1.044±0.008	0.999	1.441±0.091	0.837±0.020

	+q	-q	α_0	R^2	α_{max}	α_{min}
Shanon Diversity	2	-1	1.146±0.045	0.997	1.571±0.293	0.662±0.096
Total Diversity	10	-3	1.014±0.006	0.999	1.162±0.085	0.912±0.015
Simpson Dominance	9	-3	1.038±0.005	0.999	1.466±0.054	0.826±0.034
Pielou Equitability	5	-3	1.009±0.003	0.999	1.110±0.059	0.921±0.033
Anthropic Cerrado						
	+q	**-q**	α_0	R^2	α_{max}	α_{min}
Individuals trap day	3	-2	1.087±0.028	0.998	1.404±0.142	0.717±0.081
Jackknife richness	10	-2	1.008±0.028	0.998	1.241±0.099	0.902±0.010
Simpson Diversity	8	-3	1.021±0.016	0.999	1.224±0.125	0.833±0.038
McIntosh Diversity	10	-2	0.995±0.023	0.999	1.117±0.125	0.896±0.021
Shanon Diversity	4	-0	1.145±0.044	0.997	1.145±0.046	0.674±0.057
Total Diversity	9	-9	1.016±0.009	0.999	1.195±0.073	0.894±0.040
Simpson Dominance	10	-2	0.999±0.023	0.999	1.122±0.040	0.876±0.026
Pielou Equitability	10	-2	1.001±0.022	0.999	1.173±0.077	0.867±0.027
Pasture						
	+q	**-q**	α_0	R^2	α_{max}	α_{min}
Individuals trap day	2	-2	1.050±0.020	0.999	1.311±0.160	0.847±0.069
Jackknife richness	8	-1	1.018±0.006	0.999	1.123±0.057	0.895±0.028
Simpson Diversity	9	-3	1.021±0.015	0.999	1.232±0.127	0.832±0.038
McIntosh Diversity	9	-3	0.991±0.025	0.998	1.135±0.050	0.884±0.033
Shanon Diversity	3	-1	1.083±0.027	0.999	1.352±0.164	0.715±0.063
Total Diversity	10	-6	1.017±0.008	0.999	1.193±0.062	0.885±0.025
Simpson Dominance	9	-3	1.010±0.005	0.999	1.188±0.077	0.888±0.047
Pielou Equitability	6	-2	1.010±0.004	0.999	1.154±0.097	0.912±0.041

R^2: Determination coefficient;

Siqueira et al. (2013) evaluating 50 profiles of resistance to penetration of the soil concluded that the singularity spectra were asymmetric, with a right shift and most presented a longer branch. Similarly, Wilson et al. (2015) evaluated the soil penetration resistance profiles and detected that the right side remained wider than the left side, which makes it clear that the spectra were compatible with the greater heterogeneity of the penetration resistance low values.

The jackknife richness, Pielou equitability, and total diversity indexes presented the singularity spectra reduced when compared to the other indexes, indicating that these indexes have a greater multifractality, which shows the heterogeneity among the diversity indexes. Or still, the multifractality may be determined by the number of individuals collected that gave rise to the diversity indexes presented.

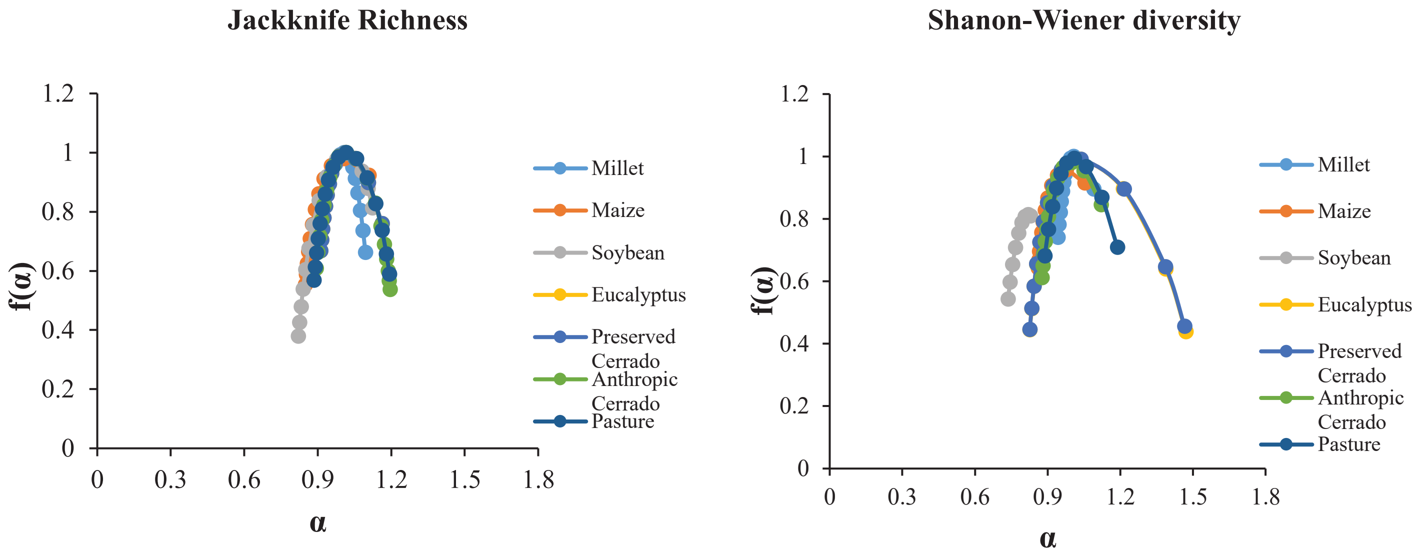


Figure 3: Multifractal spectra of the soil fauna studied.

The zero-order Holder exponent (α_0), in other words, the scale exponent corresponding to the maximum of *f*(x) ranged from 1.004 ± 0.002 (Jackknife's richness) to 1.202 ± 0.074 (Shanon diversity) for millet; while for maize area the variation in *f(x)* values was 0.071±0.043 (McIntosh diversity) at 1.043±0.021 (Individuals' trap day); for soybean was 0.653±0.112 (Simpson diversity) at 1.024±0.004 (individuals' trap day); for the eucalyptus, the variation was 1.009±0.033 (Simpson diversity) at 1.113±0.038 (Shanon diversity); for the other areas, preserved cerrado, anthropic cerrado, and pasture, the variation of *f*(x) was for the same indexes, McIntosh diversity and Shanon diversity, varying from 0.999±0.009 to 1.145±0.045; 0.995±0.023 to 1.145±0.044; 0.991±0.025 to 1.083±0.027 respectively (Table 4).

CONCLUSION

The data presented showed multifractal behavior, at different degrees of multifractality along the transect. The singularity spectra presented in some reduced indexes, indicating multifractality and higher values in the index heterogeneity. Statistical aspects showed that the data set presents high variation, once that not always all the points show a great abundance of invertebrates collected from the soil. The multifractal analysis showed to be a viable alternative to characterize the variability of the edaphic fauna sample in the transect.

Interest conflicts

The authors declare to have no interest conflicts.

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Supplementary Material

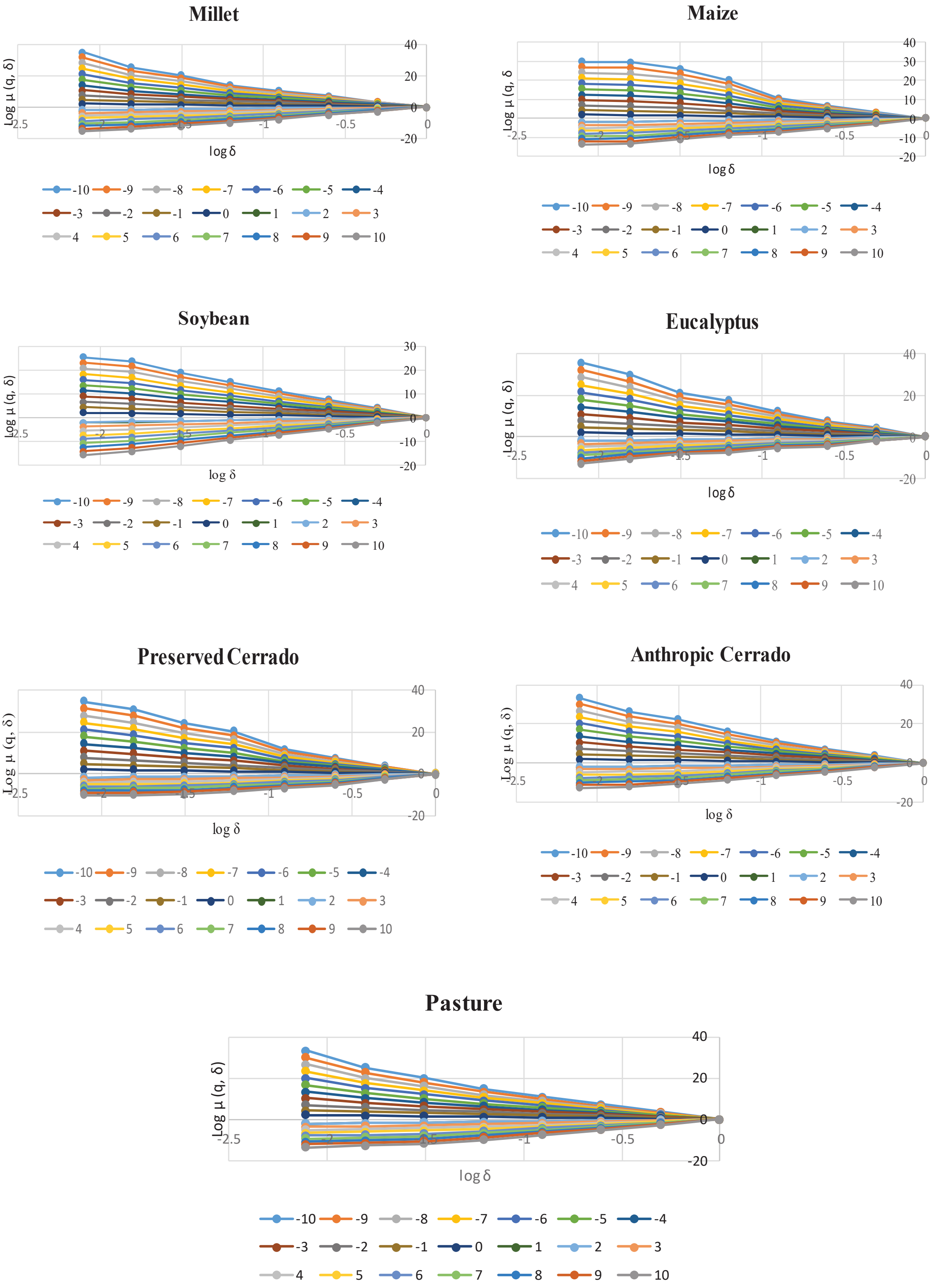

Figure 1S: Partition function *X*(q, δ) against scale for a range of moment orders, *q* [-10, 10], individual trap day.

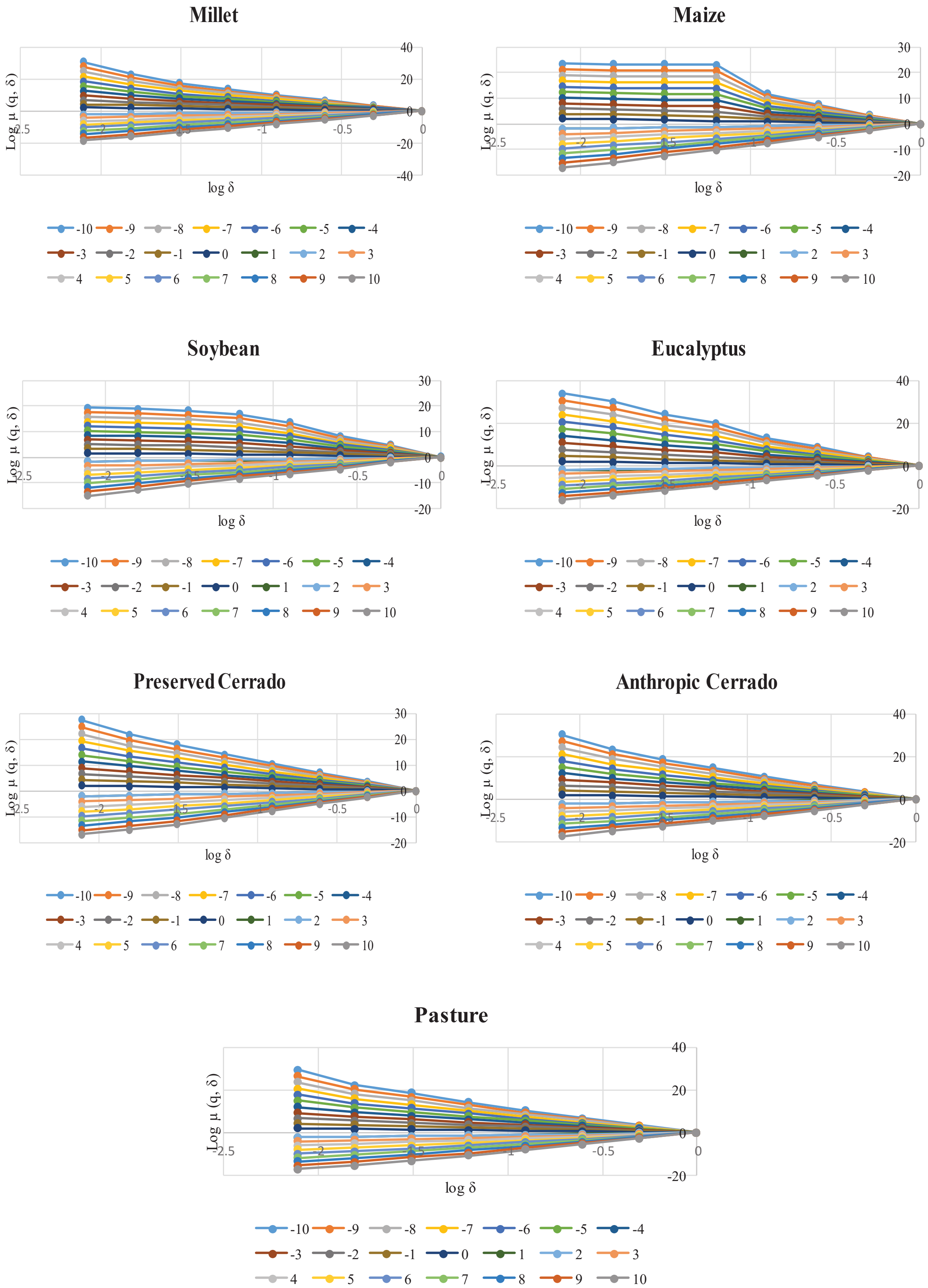

Figure 1S: Partition function *X*(q, δ) against scale for a range of moment orders, *q* [-10, 10], Simpson diversity.

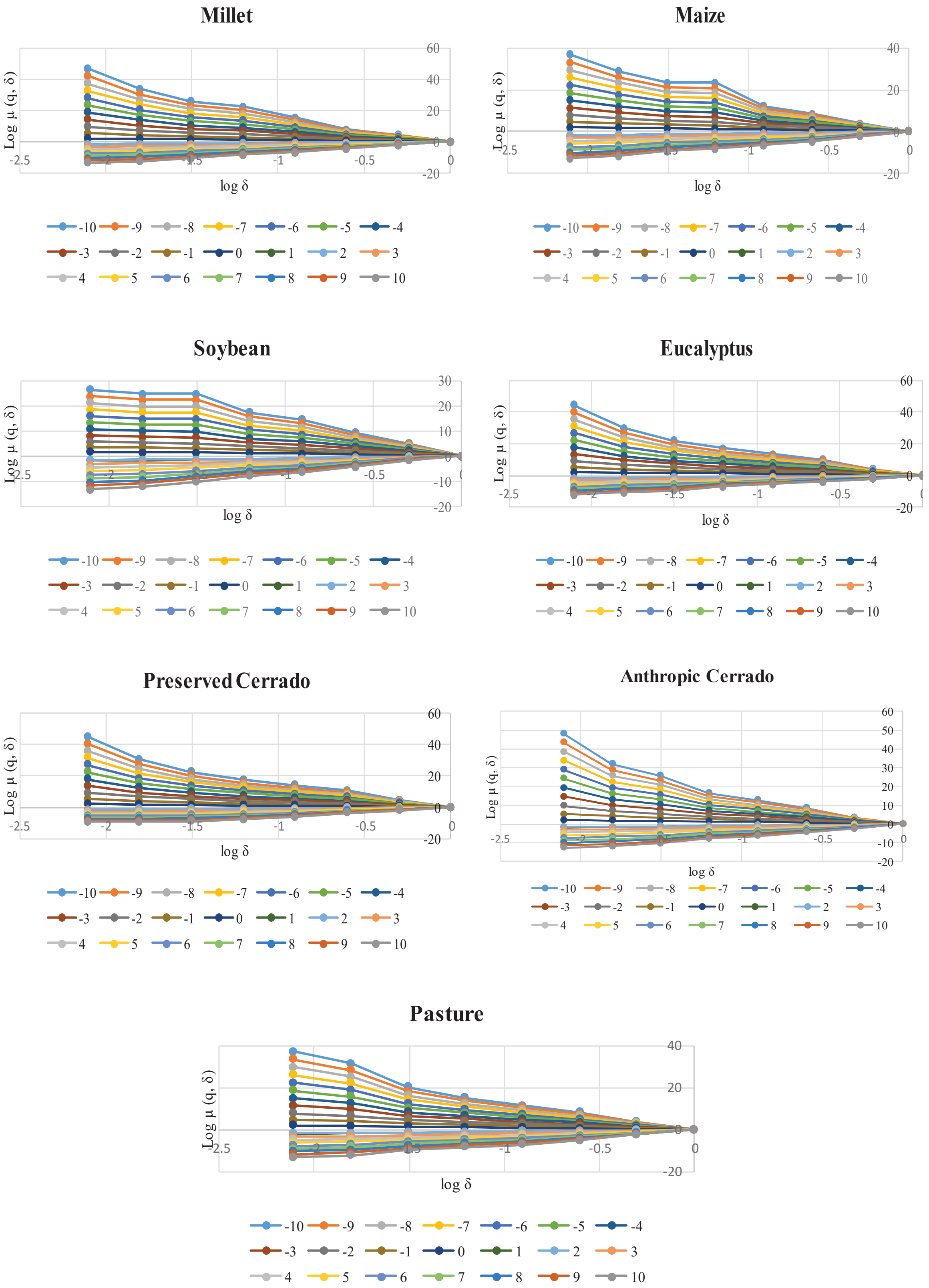

Figure 1S: Partition function *X*(q, δ) against scale for a range of moment orders, *q* [-10, 10], McIntosh diversity.

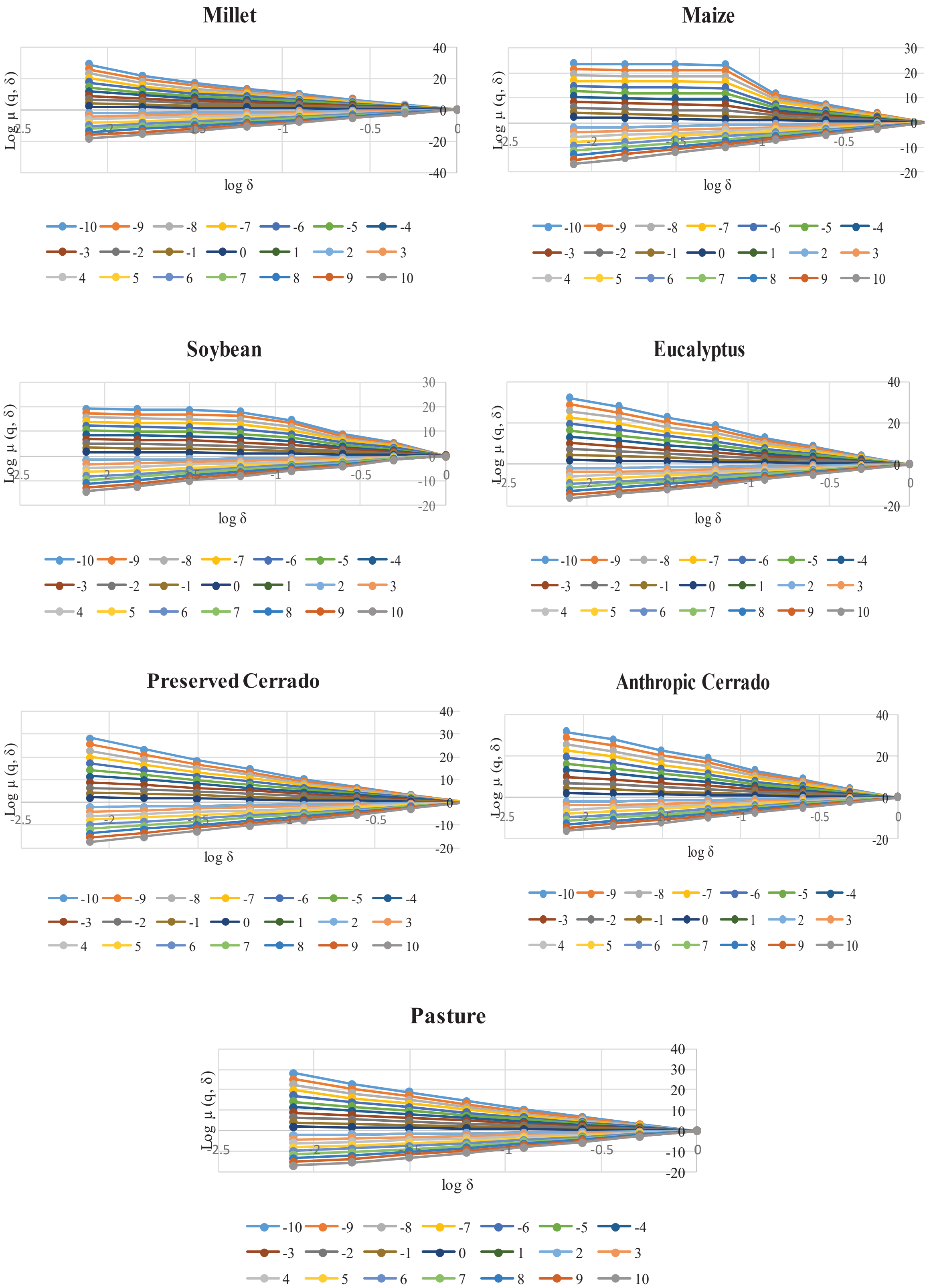

Figure 1S: Partition function X(q, δ) against scale for a range of moment orders, q [-10, 10], Shanon-Wiener diversity.

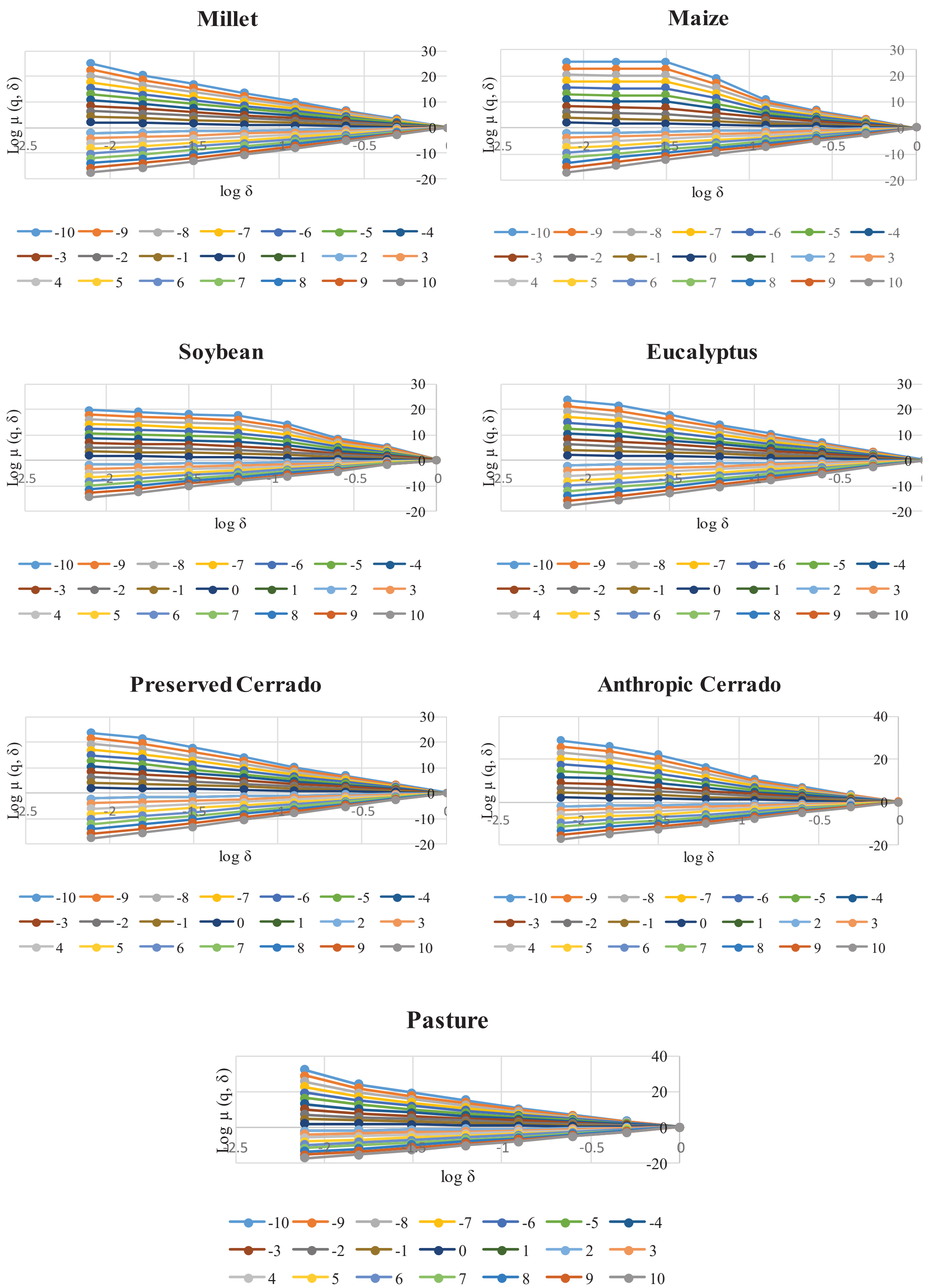

Figure 1S: Partition function *X*(q, δ) against scale for a range of moment orders, *q* [-10, 10], Total diversity.

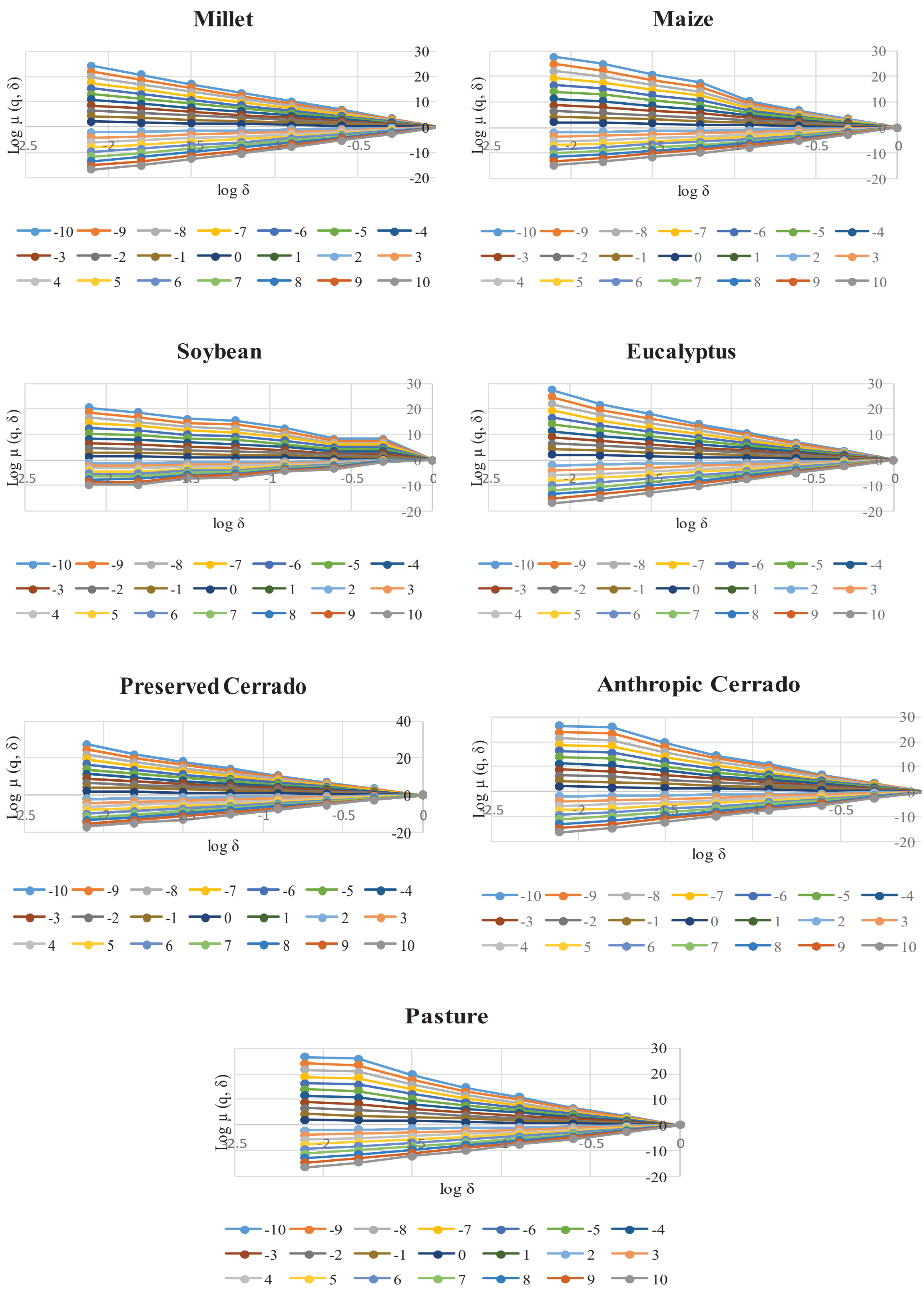

Figure 1S: Partition function *X*(q, δ) against scale for a range of moment orders, *q* [-10, 10], Simpson dominance.

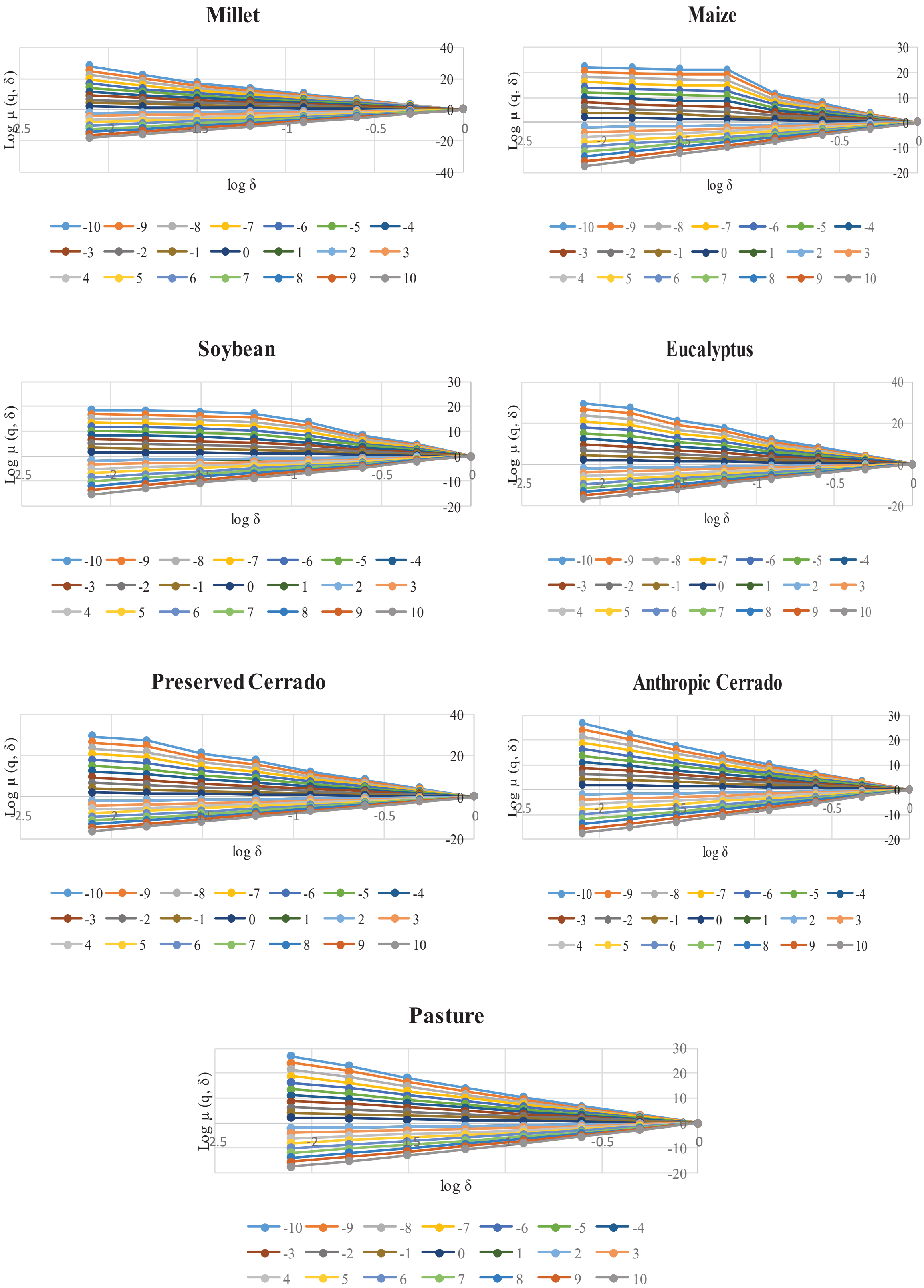

Figure 1S: Partition function X**(q, δ) against scale for a range of moment orders,** q **[-10, 10], Pielou equitability.**

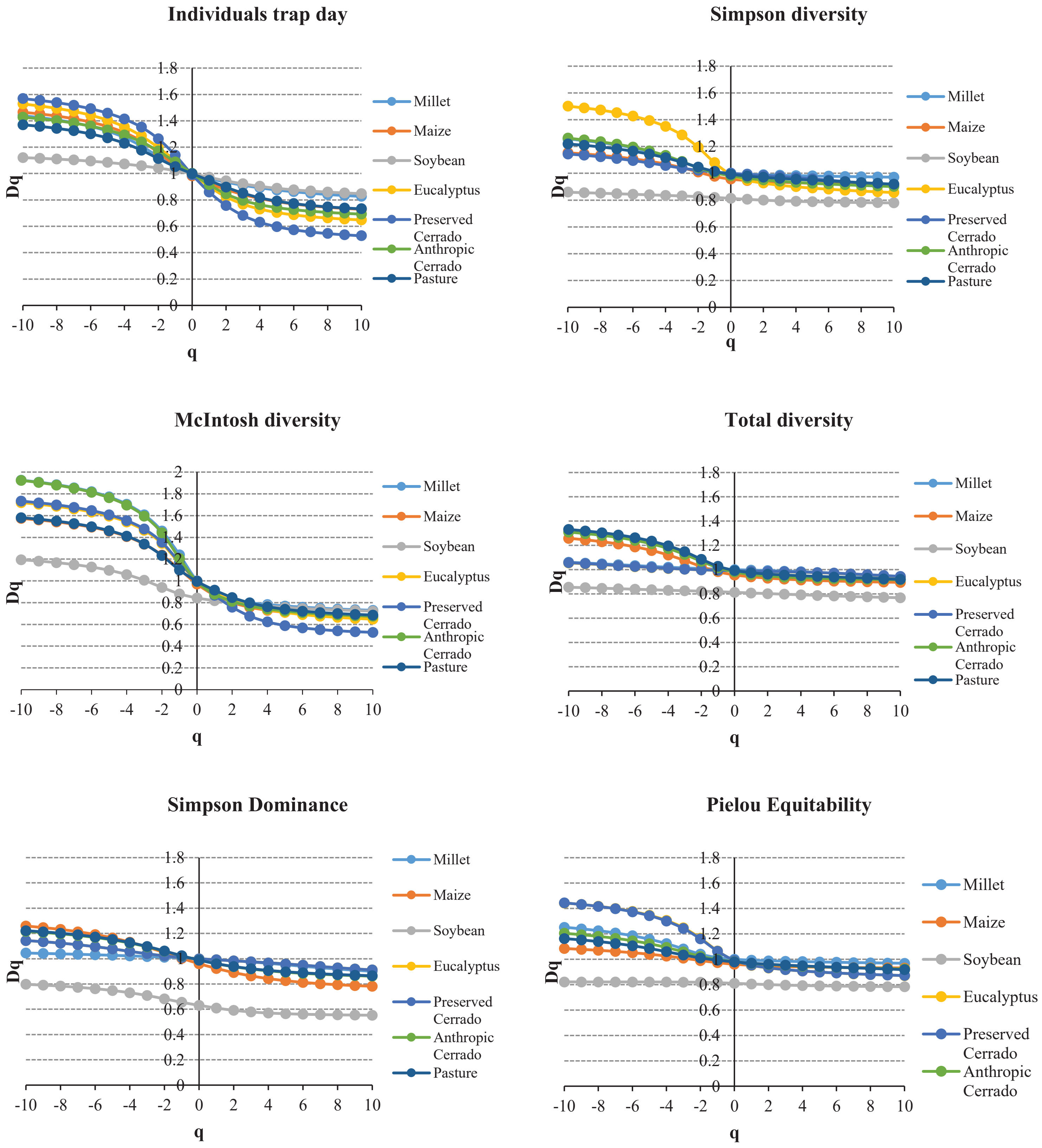

Figure 2S: Generalized dimension, Dq, spectra (-10 < q <10).

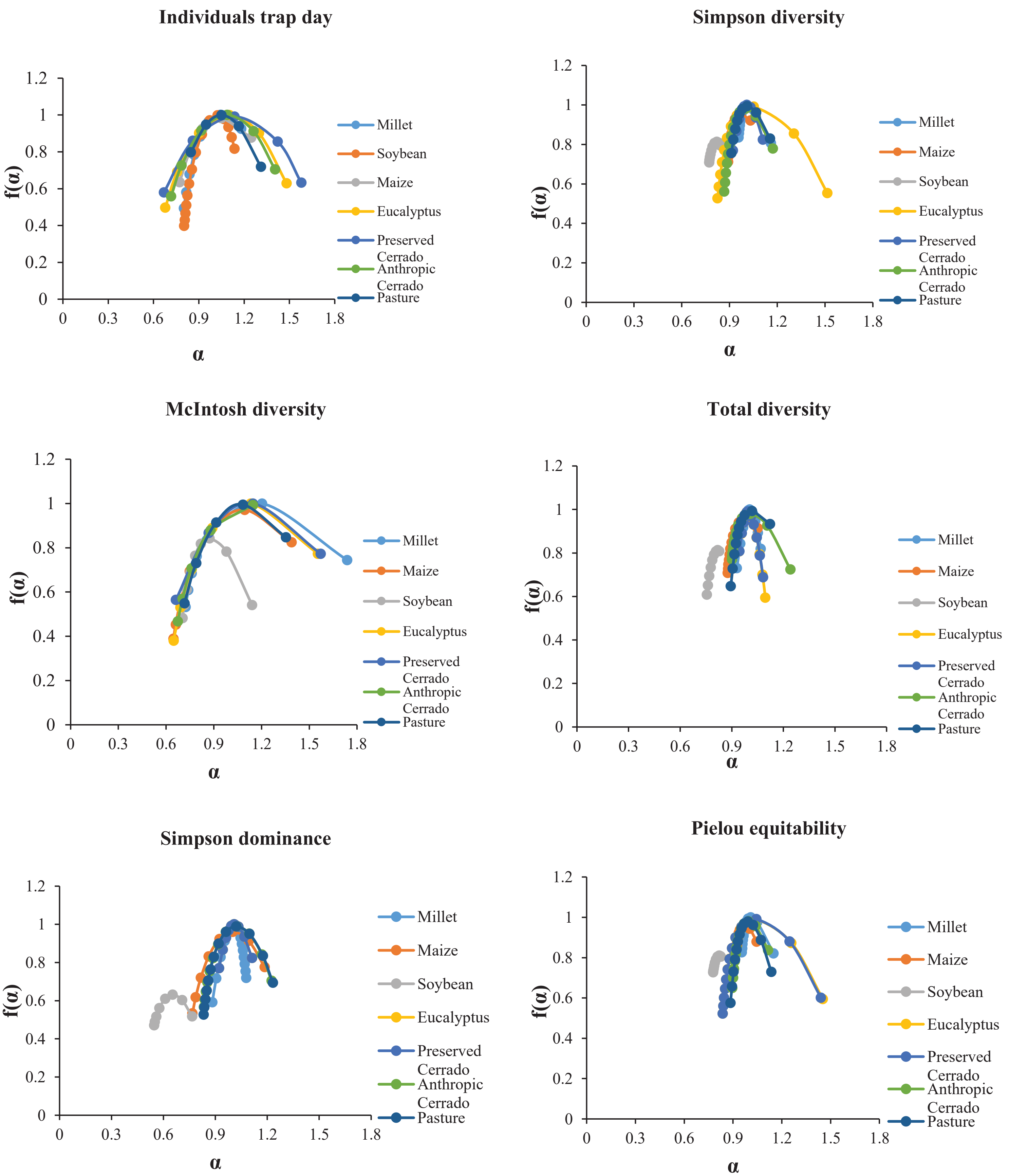

Figure 3S: Multifractal spectra of the soil fauna studied.

FINAL CONSIDERATIONS

The edaphic organisms are responsible for innumerable services ecosystemic to the environment, either by the physical, chemical or biological modification to a natural or managed system. Depending on the practices adopted, edaphic diversity tends to reduce or favor abundance of a specifically adapted group. This can be clearly seen in areas that have coverage or absence of this, or even in systems with constant use of agrochemical.

The State of Maranhão is a highly diverse and rich region in terms of biological diversity. The high number sampled in the present study (20,955 individuals and 20 orders) shows that differently managed agricultural systems and systems with different uses present varying diversity, richness and abundance. The high diversity of soybeans is due to the use of chemicals, which throughout the sample selected the most resistant individuals and reduced large populations. The predominance of specific groups occurs in the majority of the favorable conditions of the agricultural system in which these groups were inserted, in which case the reproduction rate, food supply and favorable habitats were determinant for high abundance of Acari, Dermaptera and Araneae.

The diversity, equitability, and wealth indexes used were sufficient to describe how the individuals are distributed in the seven environments studied. Through these indexes it is possible to measure the stability of the communities of the fauna of the soil, taking into account the environmental conditions of the areas under the communities.

The evaluation of the spatial variability of the soil fauna indexes allowed to know the geostatistical models in which these data were adjusted. Some indices require less spacing to detect spatial variability. The other indices that conformed to some geostatistical model obtained different values of C_0 (nugget effect), C_1 (structural variance) and a (reach). The lower C_0 values express the accuracy and precision of the adjustment of the index to the model. In addition to C_0 expressing the precision, all indexes expressed values of r^2 above 0.99, which corroborates with the C_0 values in the accuracy of the adjustment.

Although the studied areas have different management, when analyzed the behavior of the pooled indexes, the pasture and the soybean described similar behaviors. In this case, the semivariance values of the indices for these two areas range from 0.75 to 1.20.

When the indexes were evaluated by fractal geometry, the indices expressed different degrees of multifractality and heterogeneity. What was detected by the opening and amplitude of the branch of the singularity spectrum. The variation of the data was high, with values that extrapolate 100% of variation. What is common in soil data, due to the high heterogeneity of edaphic profiles.

In general, both the descriptive analysis of the data by multivariate pattern, as well as by spatial variability or analysis in different fractal scales, describe that the fauna of the soil presents different behaviors that in its majority is caused by the practices of management and use of the soil in seven environments.