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Soil macrofauna as bioindicator of soil quality in different management systems

Macrofauna edáfica como bioindicadora da qualidade do solo em diferentes sistemas de manejo

La macrofauna del suelo como bioindicador de la calidad del suelo en diferentes sistemas de gestión

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Abstract

Soil management systems can alter the soil fauna compound by organisms of high sensibility to the agricultural practices, especially those practices that interfere with the soil structure. Thus, this study's objective was to evaluate the diversity of soil macrofauna at different soil depths and management systems. A 4×3 factorial scheme [four soil managements: 1- no-tillage system (NTS) implemented 6 years ago (NTS6), 2- NTS for 17 years (NTS17), 3- conventional planting system (tillage) for 20 years (CTS) and 4- native forest for 20 years (NF20); three soil depths: 0-0.1; 0.1-0.2 and 0.2-0.3 m] was set in a completely randomized design with five replications in an area of the Cerrado biome. The monolith method was used to sample the macrofauna from the litter and soil, where the number of individuals, total richness (TR), Shannon (SI) and Pielou (PI) indexes were quantified. TR values at a depth of 0-0.3 m were higher in the NTS6 and NTS17. The highest densities of individuals and TR occurred in the litter of NTS6. In the NTS17, at 0-0.1 m, the highest TR, SI and PI were recorded among the management systems. The TR, SI, PI values and the analysis of vertical distribution by Cluster, demonstrated that NTS areas are similar to the NF20 at all soil depths evaluated. The NTS areas presented the highest macrofauna indexes compared the CTS.
Keywords: Conservation; Conventional tillage; No-tillage; Soil fauna.

Resumo

Os sistemas de manejo podem alterar a comunidade da fauna edáfica, pois são organismos sensíveis as práticas agrícolas. O objetivo deste estudo foi avaliar a diversidade da macrofauna edáfica na serapilheira e em diferentes profundidades do solo sob sistemas com manejo em uma área de Cerrado. Foi utilizado o delineamento inteiramente casualizado, em esquema fatorial 4x3, com: 1-Sistema de plantio direto (SPD) implantado há 6 anos (SPD6), 2- SPD há 17 anos (SPD17), 3-Sistema de plantio convencional há 20 anos (SPC20) e 4-Mata Nativa há 20 anos (MN20), Para a amostragem da macrofauna foi utilizada a método de monólitos (TSBF), para a serapilheira e solo nas profundidades: 0-0,10; 0,10-0,20 e 0,20-0,30 m, com cinco repetições para cada área. Foram quantificados o número de indivíduos por metro quadrado, riqueza total (RT) e índices de Shannon (IS) e Pielou (IP). Os valores da RT na profundidade de 0-0,30m foram maiores no SPD6 e SPD17 respectivamente. A serapilheira do SPD6 se destacou pelos maiores densidade e RT. Na profundidade 0-010 no SPD17 foram registrados maior RT, IS e IP, entre as áreas

de cultivo. O manejo com SPD promoveu melhores condições para a comunidade da macrofauna. Os valores de RT, IS, IP e a análise da distribuição vertical por Cluster mostram que o SPD6 e SPD17 se assemelham a área de MN20 em todas das profundidades do solo
Palavras-chave: Conservação; Fauna do solo; Plantio convencional; Plantio direto.

Resumen
Los sistemas de manejo pueden alterar la comunidad de fauna edáfica, ya que son organismos sensibles a las prácticas agrícolas. El objetivo de este estudio fue evaluar la diversidad de la macrofauna edáfica en la hojarasca y a diferentes profundidades del suelo bajo sistemas de manejo en un área del Cerrado. Se utilizó un diseño completamente al azar, en un esquema factorial 4x3, con: 1-Sistema de labranza cero (SPD) implantado hace 6 años (SPD6), 2- SPD hace 17 años (SPD17), 3-Sistema de siembra convencional hace 20 años (SPC20) y 4-Mata Nativa hace 20 años (MN20) Para el muestreo de macrofauna se utilizó el método monolito (TSBF), para hojarasca y suelo a profundidades: 0-0,10; 0,10-0,20 y 0,20-0,30 m, con cinco repeticiones por cada zona. Se cuantificó el número de individuos por metro cuadrado, la riqueza total (RT) y los índices de Shannon (IS) y Pielou (IP). Los valores de RT a una profundidad de 0-0,30 m fueron más altos en SPD6 y SPD17 respectivamente. La arena SPD6 destacó por su mayor densidad y RT. A la profundidad 0-010 en SPD17, se registraron mayores RT, IS e IP, entre las áreas de cultivo. El manejo con SPD promovió mejores condiciones para la comunidad de macrofauna. Los valores de RT, IS, IP y el análisis de la distribución vertical por Cluster muestran que SPD6 y SPD17 se asemejan al área MN20 en todas las profundidades del suelo.
Palabras clave: Conservación; Fauna del suelo; Labranza cero; Labranza convencional.

1. Introduction

The no-tillage system (NTS) was consolidated as the most sustainable cropping system for the Brazilian Cerrado biome (Savanah-like biome) because it provides positive changes to the soil physical, chemical and biological attributes throughout its developing phases (Silva et al., 2020).

The initial NTS phase occurs in the first 5 years of its implementation, then comes the transition (5-10 years), consolidation (10-20 years), and maintenance (over 20 years) phases. At this last stage, soil attributes improvements are more accentuated and quantifiable (Sá et al., 2004). However, it is important to consider that the response time depends on the attribute evaluated, which may respond in a short time (Mazetto junior et al., 2019).

The application of organic residues to the soil surface, plus the remnants of the crop root systems in the subsurface, improve the soil's physical and chemical attributes through modifications in the soil organic matter (SOM) and its distribution in soil compartments (Araujo et al., 2018; Torres et al., 2019). This increment in SOM raises the soil fauna diversity (Ferreira et al., 2019), especially the invertebrate macrofauna and consequently improving soil quality (Lima et al., 2020).

The changes that occur to the soil environment are directly related to the crop management implemented. These changes can be qualified and quantified by soil quality indicators (Bianchi et al., 2017). In this context, soil fauna is considered an important indicator of soil quality. The soil organisms' community is sensitive to crop management practices, to the type of vegetation covering the area, and the season of the year (Santos et al., 2008; Lima et al., 2019).

The activity of these organisms and their specificities are fundamental for the sustainability of natural or manageable ecosystems; however, soil management practices can affect the fauna diversity, directly influencing the ecological and biological functions in the soil (Ferreira et al., 2019; Kitamura et al., 2020).

The interaction of these soil organisms with different soil management for cropping is an important parameter for evaluating soil quality. The decrease in these organisms' diversity affects soil quality and the functioning of the agroecosystems (Bianchi et al., 2017; Fagundes et al., 2021). The abundance, richness, and diversity of organisms depend not only on the management practices but also on soil use intensity, changes to microclimate, and cover-crop vegetation (Giácomo et al., 2017).

The use of the soil fauna as an indicator of soil quality is a very effective tool in the evaluation of crop management systems, considering that several studies show that these organisms are sensitive to changes in the environment and quickly respond to soil changes (Aquino et al., 2008; Almeida et al., 2017; Lima et al., 2020).

The study of the fauna present in different cropping systems was hypothesized considering the context of using soil fauna as a bioindicator and considering the lack of long-term studies with soil fauna in areas under a no-tillage system in the Cerrado biome. Thus, the objective of this study was to evaluate the diversity of soil macrofauna at different soil depths and management systems in a characteristic soil of the Cerrado biome.

2. Methodology

2.1. Characterization and design of the experimental area

The study implemented to attend this study's objective was developed in an experimental area in Uberaba, Brazil. The study area is between the coordinates 19º39'10,17" S and 47º58'15.65" W, with an altitude ranging between 790 and 819 m, between the months of November and December 2019.

The climate of the region is classified as Aw - warm tropical, according to the updated Koppen's classification (Beck et al., 2018), with the hot rainy season in the summer and the dry cold season in the winter. The annual averages of precipitation, temperature and relative humidity were 1600 mm, 22.6 ºC and 68 %, respectively. During the evaluation period, the accumulated precipitation was 416.1 mm.

The soil of the experimental areas was classified as Oxisol (Santos et al., 2018), medium sandy texture. The entire experimental area was cultivated in a conventional tillage system (CTS) until the implementation of the no-tillage system (NTS), which was introduced at different times. A completely randomized design was set in a 4×3 factorial scheme - being four different management systems and three soil depths (0-0.1; 0.1-0.2 and 0.2-0.3 m) - and five replications. The distinct areas were characterized in Table 1.

Table 1 - Description of the areas of each soil management system studied.

Soil system	Characteristics
NTS6	Total area: 0.21 ha; height: 797 m *asl*; location: 19º39'22.69" S, 47º57'25.86" E; area in the process of transition to a stabilized no-tillage system.
NTS17	Total area: 0.21 ha; height: 798 m *asl*; location: 19º39'21.81" S, 47º57'26.82" E; area in the process of consolidation of a stabilized no-tillage system.
CTS20	Total area: 6.75 ha; height: 819 m *asl*; location: 19º39'10.17" S, 47º58'15.65" E; irrigated area (irrigated) and conducted under conventional tillage system.
NF20	Total area: 10.20 ha; height: 790 m *asl*; location: 19º39'38.89" S, 47º57'45.06" E. Area of preservation, without anthropic interference.

NTS6: no-tillage system implemented 6 years ago; NTS17: no-tillage system implemented 17 years ago; CTS20: conventional planting system (tillage) for 20 years; NF20: native forest for 20 years. *asl*: above sea level. Source: Authors.

2.2. Evaluations performed

The sample collection was performed using the soil monolith methodology proposed by the Tropical Soil Biological and Fertility (TSBF) program, described by Anderson e Ingram (1993) and adapted by Aquino (2001). In each area, five replications were collected; the sampling area was delimited by a metallic jig of 0.25×0.25×0.30 m. Initially, litter was collected, then soil samples at depths of 0-0.1, 0.1-0.2 and 0.2-0.3 m, always between 8:00 and 9:00 a.m.

Litter and soil samples were packed in identified plastic bags and properly closed. Subsequently, the fauna was manually collected using tweezers and then packed in bottles with an alcohol solution (70 %). The individuals were identified at the level of class and order, according to Pereira et al. (2018) and quantified.

2.3. Data analysis

The density of the orders identified was expressed by individuals of each order per square meter (ind.m-2). For the total wealth, the total of orders identified in the repetitions was considered and the average wealth was calculated from the average of the total wealth. The Shannon diversity index (H) (Shannon and Weaver, 1949) was calculated and, for equitability, the Pielou index (J) (Pielou, 1969), according to the following equations:

The Shannon index (H) = $-\Sigma$ pi.log pi Equation (1)

Where pi = ni/N; ni = density of each group, N = Σ of the density of all groups.

Pielou index (J) = H/log R Equation (2)

where: R = total richness.

The Kruskal - Wallis nonparametric (Zar, 1996), test was used at 5% significance level (R Core Team, 2019) and Cluster similarity analysis was performed for the litter and depth data.

3. Results and Discussion

3.1. The total number of individuals.

The total number of individuals counted after identification was 20,307 ind m^{-2}, being 1,245 ind. m^{-2} collected in the CTS20, 11,030 ind. m^{-2} in the NTS6, 2,515 ind. m^{-2} in the NTS17 and 5,517 ind. m^{-2} in the NF20 areas, distributed in 26 taxonomic groups, especially the 12 taxonomic groups who presented higher density and the least numerous grouped in the "others" group (Table 2). Among these 12 groups, the ones that stood out the most in terms of density in the different management systems were Coleoptera, Diptera, Formicidae and Hemiptera.

The order Coleoptera presented higher density in the NTS6 compared to the other areas; the lowest density was observed in NTS17 area (Table 2). This order has the largest number of species cataloged (Korasaki et al., 2013). The Coleoptera are good environmental indicators because there is a high diversity, occupying different trophic levels, having their specificities within their ecological niches, and changes in soil management are sensitive (Kitamura et al., 2020). Besides, colepterans are predators and regulate insect populations (Santos et al., 2017).

The order Diptera also presented higher density in the NTS6 treatment, with a value 4.5 times higher than that observed in the NF20 area (Table 2). The high density of this group can be justified by the increase in organic matter levels in NTS when entering the NTS transition phase of the system.

These insects are phytophagous, decomposers, pollinators and predators, which play an important role in the decomposition of organic matter and in biological control, which are more sensitive to environmental impacts are more demanding regarding the presence of litter and moisture, which also makes them good biological indicators (Araujo et al., 2018).

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Table 2. Density of individuals (Ind. m^{-2}) of the soil macrofauna at 0 to 0.3 m depth, and ecological indexes at different management systems.

Groups	CTS20	NTS6	NTS17	NF20
	....Ind. m^{-2}...			
Araneae	16±7 a	22±115 a	9±12 a	74±24 a
Coleoptera	269±47 c	1667±230a	211±54 c	714±105 b
Diplopoda	0±0 b	3±3 a	10±6 a	38±31 a
Diptera	179±62 c	5776±919 a	246±8 c	1274±213 b
Formicidae	173±92 b	1146±216 a	1142±342 a	1040±253 a
Hemiptera	387±184 b	1162±282 a	352±171 b	179±32 b
Hymenoptera	6±4 c	253±53 a	10±6 c	38±8 b
Isoptera	10±6 c	54±19 b	109±31 a	1664±1019 a
Coleoptera	19±15 a	131±43 a	125±39 a	86±24 a
Oligochaeta	58±21 a	96±66 a	106±40 a	99±41 a
Psocoptera	3±3 d	413±128 a	38±11 b	16±5 c
Thysanoptera	16±9 c	125±28 a	16±10 c	26±6 b
*Others	109±109 c	182±90 b	122±60 c	269±123a
Total	1245±559 c	11030±2089 a	2515±861 b	5517±1885 b
Total richness	14	22	19	25
Shannon index	2.72	2.30	2.73	2.80
Pielou index	0.72	0.52	0.64	0.60

Averages followed by similar lowercase letters in line do not differ the soil management systems by Kruskal Wallis test ($p < 0.05$). CTS20: conventional planting system (tillage) for 20 years; NTS6: no-tillage system implemented 6 years ago; NTS17: no-tillage system implemented 17 years ago; NF20: native forest for 20 years. *Others: Blattodea, Chilopoda, Dermaptera, Gastropoda, Heteroptera, Hirudinae, Homoptera, Isopoda, Diptera Larva, Lepidoptera Larva, Lepidoptera, Neuroptera, Orthoptera, Thysanura and Scorpionida. Source: Authors.

In the NTS6, NTS17 and NF20 areas, the highest densities of the Formicidae group were verified, with values equal to or higher than those observed in the CTS20 (Table2). This high density may be related to the higher intake of plant residues on the soil surface when compared to CTS20. Ants stand out for their activities in the soil, in the construction of nests transport large amounts of particles to the surface, contributing to aesthetion and drainage, still fragmenting and mixing organic material, contributing to nutrient cycling (Oliveira et al., 2014; Souza et al., 2015). The Formicidae group is dominant in most terrestrial ecosystems, being considered a good indicator due to its sensitivity to changes in the environment (Korasaki et al., 2013).

The Isoptera group was the most abundant in NF20 (Table 2), possibly this result is related to more diverse litter materials, which favors the higher occurrence of termites in the area. These are social organisms, classified according to their feeding habits in phytophagous, rhizophagous or detritivores (Brown et al., 2015). In a similar study, Araujo et al. (2018) and Ferreira et al. (2019) also observed a high Isoptera density in their reference areas when compared to other areas.

The Formicidae, Isoptera and Oligochaeta groups are recognized as ecosystem engineers (Lavelle et al., 1997) because they have a functional role in the decomposition of plant residues and organic matter. Formicidae and Isoptera also contribute to the porosity and infiltration of water in the soil due to their construction of galleries and nests in the soil and

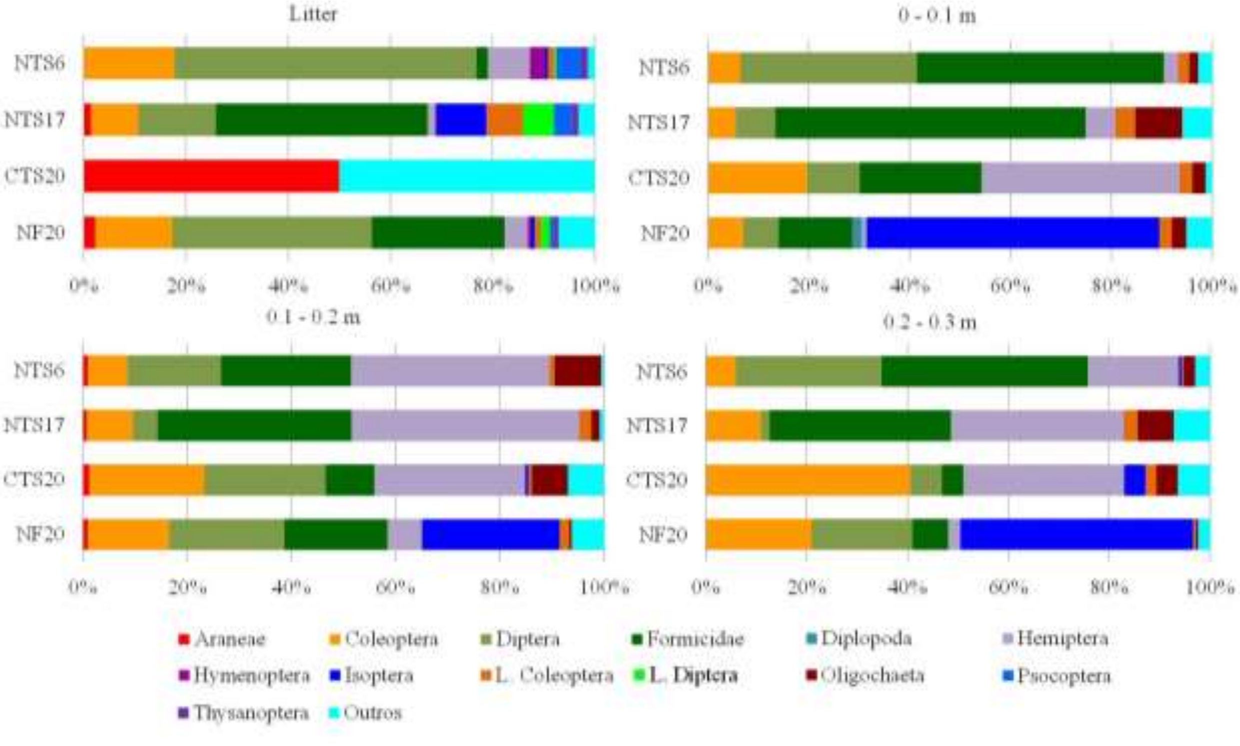
Oligochaeta, which was also present in all areas (Santos et al., 2017; Araujo et al., 2018). According to Brown et al. (2015), these groups contribute to ecosystem support and regulation services, as they have significant roles in the biome's ecology.

Regarding the total richness in the 0-0.3 m soil depth, the NTS6 and NTS17 presented the high values being only surpassed by the richness found in the NF20 area (Table 2). The Shannon diversity index was very close between CTS20, NTS17 and the reference area (NF20), with the lowest diversity observed in the NTS6. Pielou's values; however, these values did not follow the pattern of diversity; the value observed in CTS20 stood out with Pielou's best value (Table 2). The lower Pielou's value was observed in the NTS6 area and can be explained by the high density of the Diptera, Formicidae and Hemiptera groups.

3.2. The relative frequency of groups

The relative frequency of macrofauna groups in the litter of NTS6 and NTS17 presented a high occurrence of the Diptera (59.2 %) and Formicidae (41.5 %) in detriment of the other groups that occurred in lower percentages (Figure 1). The CTS20 treatment presented the dominance of the Araneae group (50 %) and equal percentage for “Others” group formed by fauna groups with low occurrence.

Figure 1. Relative frequency of large taxonomic groups of macrofauna and their ecological indices in litter and soil at different depths and management systems.



Source: Authors.

The relative frequency of macrofauna groups at the 0-0.1 m soil depth revealed that the Formicidae group was more frequent in the NTS17 (61.6 %) and NTS6 (49.1 %) areas. In the CTS20 area, the Hemiptera, Formicidae and Coleoptera groups were the most frequent. It is worth highlighting the predominance of the Isoptera group (58.1 %) in the reference area (NF20). Furthermore, the Coleoptera (adult and larva) and Oligochaeta groups were observed in all areas (Figure 1). These soil invertebrates have great evolutionary success, and the groups Formicidae, Coleoptera and Isoptera are among the most abundant of all terrestrial niches, as highlighted by Melo et al. (2009).

At a soil depth of 0.1-0.2 m, the Hemiptera group was the most frequent in treatments, being NTS17 (43.7 %), NTS6 (38.0 %) and CTS20 (28.9 %), while Isoptera predominated in NF20 (26.4 %). A high occurrence of the Formicidae group was observed in the cropping areas evaluated – 37 % in NTS17, 25 % in NTS6 and 9 % in CTS20. The presence of Oligochaeta in the cropping systems, and of Coleoptera and Araneae in all areas is also noteworthy. At the 0.2-0.3 m soil depth, a high frequency of the Isoptera group was observed in the native forest (46.2 %), Formicidae in the NTS6 (41.0 %) and NTS17 (36.0%), and Coleoptera in the soil tillage system (41.3 %). The groups remained at this soil depth, with emphasis on the increase of Coleoptera and the presence of Oligochaeta in agricultural areas.

The presence of ants and earthworms at all soil depths in agricultural areas, being in high frequencies in the NTS, indicating that the evaluated soils are under transformation, in a dynamic restructuring process. Ants and earthworms cause modifications to the soil physical attributes by transporting soil particles during the formation of nests and galleries, consequently increasing soil porosity and drainage (Souza et al., 2015). Additionally, ants and earthworms may have been favored by the management of the system, which maintains a more favorable edaphoclimatic condition, providing food and shelter for them.

In litter compartments, the NTS6 presented a high density of individuals (Ind. m^{-2}) and total richness, while in the CTS20 area, low density and richness were observed (Table 3). This fact resulted in the lowest Shannon index while the high Pielou's value occurred due to the low frequency of groups; in this case, only two groups in the CTS20 treatment. However, in the NTS17 area, improved values of Shannon and Pielou indexes were recorded, indicating that the litter, in this system, provided better conditions for the macrofauna development in terms of diversity and equitability. On the “Others” group, the lowest Pielou's value in NTS6 occurred due to the predominance of the Diptera.

At 0-0.1 m soil depth, the highest density was observed for the NTS areas, while in the NTS17 treatment, higher richness and ecological indexes were recorded (Table 3). The lowest Shannon and Pielou indexes were observed in the NTS6 treatment, indicating that in this system there was no uniform distribution of the groups. The lowest densities and richness values were recorded for the CTS20; these low values directly influence the indexes, which in turn were high, but with low diversity and equitability (Table 3).

The lower values of total density and total richness observed in CTS20 can be explained by the lower availability of food and edaphoclimatic conditions limiting the establishment of organisms, with colonization restricted to a few taxonomic groups (Lima et al., 2019). Aquino et al. (2008) highlighted that as the content of organic matter in the soil increases, diversity values increase, probably due to the greater availability of plant residues.

Among the cultivated areas, at the 0.1-0.2 m soil depth, the highest density of macrofauna was recorded in the NTS6 treatment, but the highest richness of groups was observed in the NTS17 area. The Shannon and Pielou's values also revealed that NTS areas generated good values of diversity and equitability, since these values are close to that observed in the reference area (NF20) (Table 2). According to Ferreira et al. (2019), when there is a high total richness in areas under NTS this is usually related to a greater supply of food resources, with different qualities and presence of microhabitats. These microhabitats are formed due to the plant residues on the soil surface, which increases the number of individuals and the total richness of groups.

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Table 3. Density of soil macrofauna (Ind. m^{-2}), richness and ecological indices in litter, at different soil depths for different soil management systems.

Soil system	Ind. m^{-2} Litter	Total richness	Shannon	Pielou
			……………….Index……………….	
CTS20	6 ± 6	2	1.00	1.00
NTS6	8605 ± 1915	19	2.04	0.48
NTS17	1117 ± 406	15	2.77	0.71
NF20	2179 ± 554	18	2.59	0.62
		0 to 0.1 m		
CTS20	582 ± 395	9	2.48	0.78
NTS6	708 ± 315	10	1.87	0.56
NTS17	649 ± 305	13	2.09	0.57
NF20	1994 ± 1488	18	2.22	0.53
		0.1 to 0.2 m		
CTS20	403 ± 242	8	1.90	0.63
NTS6	640 ± 298	8	2.24	0.75
NTS17	509 ± 240	13	2.65	0.72
NF20	678 ± 393	13	2.70	0.73
		0.2 to 0.3 m		
CTS20	147 ± 85	9	2.26	0.71
NTS6	1082 ± 588	14	2.14	0.56
NTS17	346 ± 213	9	2.21	0.70
NF20	669 ± 381	11	2.08	0.60

Source: Authors.

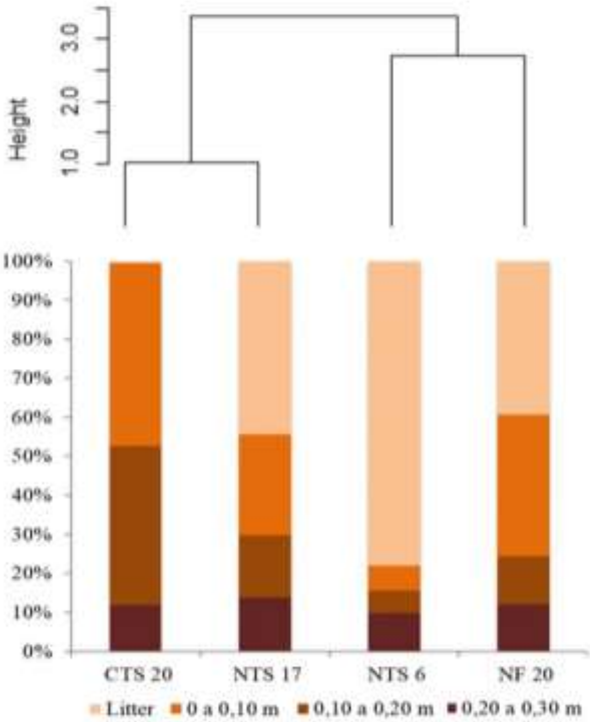
At 0.2-0.3 m soil depth, the NTS stand out with the highest density and richness in SDP6, while in the NTS17 treatment there was better rates of Shannon diversity and Pielou equitability indexes. Almeida et al. (2017) highlight that in management systems such as NTS, where there is a constant supply of residues on the surface, allow a greater abundance of organisms in the soil. The best ecological indices can be confirmed by the relative frequency of the groups (Figure 1).

This occurred due to the number of individuals in the soil depths, considering that the soil tillage system practically did not present organisms in the litter. The second cluster occurred between the NTS6 treatment and the reference area (NF20). This was possibly due to the percentages of groups in litter and especially at the 0.2-0.3 m soil depth. In the NTS17 area, the presence of macrofauna was verified in the litter, being extremely beneficial for this system in relation to the CTS20, as this directly influences the processes of fragmentation and decomposition of residues, indirectly increasing soil fertility.

3.3. The analysis of cluster similarity

The analysis of cluster similarity, combined with the vertical distribution of the number of ind. m^{-2} of the large taxonomic groups, showed the formation of two groups. The NTS17 presented greater similarity with the CTS20 (Figure 2).

Figure 2. Cluster analysis of grouping of similarity and percentage of vertical distribution of the number of individuals per m^2 of the large taxonomic groups of macrofauna found in litter and soil at different depths and management systems.



Source: Authors.

According to Ferreira et al. (2019), the time of implementation of the system exerts a strong influence on the macrofauna community, showing that the longer the time under NTS, the greater the diversity of organisms, a pattern also observed in this study. The authors explain that the absence of soil revolving and the addition of crop residues on the soil surface favors the presence of more saprophagous and predators, such as Oligochaeta, Isopoda and Araneae groups. In the Cerrado biome, Santos et al. (2008) observed the following decreasing order of relative density: Formicidae, Oligochaeta, Dermaptera, Coleoptera, Hemiptera, Isoptera, Araneae, Lepidoptera, Blattodea and Diptera larvae, with the highest densities observed in areas with crotalaria, brachiaria and co-cropped brachiaria with corn and sorghum, and concluded that the use of cover plants favors soil colonization by macrofauna.

4. Conclusions

1. The no-till management system improved soil conditions for the fauna community, and the area in a 6-year no-tillage system favored higher density individuals and the richness of fauna groups.

2. Soil fauna richness, ecological indexes and analysis of vertical distribution by Cluster demonstrated that no-tillage systems resemble the forest area at all of the soil sampling depths.

3. Areas under no-tillage system, compared to the conventional tillage system, presented higher fauna indexes in litter, directly favoring soil fertility.

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