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Soil fauna diversity in integrated production systems in the Brazilian Cerrado

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ABSTRACT: Soil fauna is an important indicator of soil quality. This study aimed to evaluate soil fauna collected using pitfall traps and soil chemical and microbiological properties under different land uses in the Cerrado. The systems evaluated were soybean under 14-year no-till; soybean under 3-year no-till; eucalyptus rows; soybean grown between eucalyptus rows, and native Cerrado. Collected individuals were identified as classes, subclasses, order, or family classes. We evaluated the number of individuals trap^{-1} day^{-1}, total richness, average richness, Shannon Diversity Index, Pielou Evenness Index, total soil organic carbon (TOC), soil microbial activity, and soil chemical indicators. Data were submitted to one-way ANOVA, and means were compared by the Tukey Test ($p<0.05$). Principal component analysis and grouping analysis were performed among the groups and number of individuals. We identified 16 groups with a greater occurrence for Collembola, Acari, Formicidae, and Coleoptera. Systems containing threes provided a greater abundance of individuals. The largest populations occurred in the systems with the highest TOC levels. Components of the same silviagricultural system (soybean + eucalyptus) shared the same soil fauna groups, indicating a flow of individuals between these systems. The soybean adoption time under no-till systems does not change the population and diversity of soil fauna groups.

Keywords: integrated systems, pitfall, soil invertebrates, agroecological balance.

INTRODUCTION

Inadequate agricultural practices increase soil degradation and decrease crop productivity due to the excessive use of inputs, the lack of crop rotation or integrated crops, and the low diversity of input from organic sources. Consequently, these factors contribute to decreased soil biodiversity (Rodrigues et al., 2013; Plaas et al., 2019).

On the other hand, more sustainable and economically suitable agricultural practices, such as the crop-livestock-forest integration system (CLFI), have been consolidated as technological alternatives that are more efficient in nutrient cycling, and that enable the improvement of physical, chemical, and biological soil properties (Salton et al., 2014; Pinheiro et al., 2021). Integrated systems include a set of agronomical principles such as crop rotation, intercrops and provision of permanent soil cover through a great production and deposition of crop and livestock residues biomass on the soil surface, whose decomposition makes organic matter available (Sá et al., 2017).

Soil is a complex structure and dynamic mix of chemical, physical, and biological components, representing one of the most important reservoirs of biodiversity, where the biotic and the abiotic (moisture, temperature) components interact together for organic matter decomposition, nutrient cycling, and physical changes (Snyder et al., 2013; Wang et al., 2019). Decomposing organisms are a key point in these processes (Sanghaw et al., 2017).

Edaphic fauna is the invertebrate organisms that live permanently or undergo a few phases of development in the soil or plant litter (Lavelle and Spain, 2001). For greater ease in studying the groups of soil fauna, we classify them according to size, with macrofauna individuals ranging from 2 to 20 mm. They can also be classified according to their functional groups: geophagus/bioturbator; scavenger/decomposer; phytophagus/pest; and predator/parasite (Lavelle et al., 2006). Edaphic fauna community plays a prominent role in litter decomposition dynamics and, consequently, in the availability of nutrients in the soil to plants (Silva et al., 2013). Soil organisms are important indicators of soil quality since they are highly sensitive to small changes in the ecosystem and perform important functions to maintain the ecosystem services (García-Segura et al., 2018; Velasquez and Lavelle, 2019). Edaphic fauna is influenced by soil use and management, modifying its abundance and diversity, especially through changes in the quantity and quality of organic matter, fertilization, liming, soil compaction, nutrient and mineral availability, and humidity, temperature, and irradiation (George et al., 2017). Changes in management practices can lead to the reduction or extinction of some organisms and thus result in losses of soil physical quality and fertility and may increase the groups of pest organisms (Silva et al., 2019). For example, Santos et al. (2020) found that no-tillage systems performed in the Cerrado of south Piauí (Brazil) provided higher density and richness of soil fauna families compared to conventional systems. They also observed that using mono-crop grass species as cover crops increased soil fauna density.

Other studies have shown that land conversion to agricultural systems negatively affects soil fauna compared to native forest areas. In the Piauí State (Brazil), Cunha et al. (2021) found that converting native Cerrado vegetation into no-till grain production areas led to a drastic reduction in the number and diversity of soil macrofauna individuals. However, adopting more environmentally friendly soil management systems such as well-managed pasture and forest-livestock integrated systems mitigated the impact on soil fauna communities. Similarly, Rousseau et al. (2022) observed for the east Amazon in the Brazilian state of Maranhão, that the adoption of conservation management practices such as slash-and-mulch enhanced the presence of soil fauna individuals from specific functional groups (ecosystems engineers and predators) compared to native forest fragments. The authors point out that land conversion to more sustainable management systems is the best way to conciliate food production and soil macrofauna conservation. Structurally complex habitats such as native forest areas or complex agricultural designs that include intercrops of annual grain crops and forage species and the tree component (crop-livestock-forest integration- CLFI) support greater soil fauna species diversity because they provide more ecological niches, including available resources (Tews et al., 2004). Similarly, Bartz et al. (2014) and Santos et al. (2018) pointed out that the maintenance of forest fragments and the adoption of integrated systems contribute to maintaining soil fauna diversity and soil quality. Moreover, these complex environments allow individuals to move between different habitats (Santos et al., 2018), which can impact soil quality and ecological stability. Therefore, conservationist soil management systems can reduce the negative impacts on edaphic biodiversity by providing soil cover with diverse plant residues that offer food and shelter. These systems are usually associated with crop rotation and multiple species associations that can raise total organic carbon and nutrients in the soil, favoring biological activity (George et al., 2017).

Despite the positive effects of conservationist land-use systems on the population and diversity of the soil fauna, few research results show the effects of different forms of management on these groups of organisms, especially in areas involving CLFI systems. In particular, there is a scarcity of data comparing the effects of soybeans as mono-crops and systems that include soybean cultivation intercropped with tree components such as Eucalyptus in CLFI. Here, we hypothesized that land uses that promote a permanent soil cover, such as those containing the tree component, will lead to the highest soil organic carbon content and the largest populations of soil fauna individuals. We also hypothesized that the time of adoption of sustainable agricultural systems modulates the number and diversity of soil fauna individuals. This study aimed to evaluate the diversity of the soil fauna and the chemical and microbiological properties of the soil under different management systems in the Cerrado of Eastern Maranhão.

MATERIALS AND METHODS

Area characterization

The study was carried out at Barbosa Farm, in the municipality of Brejo, Maranhão (03° 42′ 44″ S; 42° 55′ 44′ W; 55 m altitude). According to the Köppen-Geiger classification system, the climate in the area is Aw, tropical with a well-defined rainy (January-June) and dry season (July-November). Average rainfall in 2019 was 1,426 mm, according to data collected at Barbosa Farm. Average maximum and minimum temperatures in 2019 were 32 and 23 °C, respectively (Inmet, 2021) (Figure 1).

The soil of the experimental area is an Acrisol (IUSS Working Group WRB, 2015), with a loamy-sandy texture. Soils of this region are acidic, formed by minerals with low-activity clay, originating from the Barreiras Formation (Dantas et al., 2014) and exhibiting a cohesion character, which hampers agricultural activity due to limited water drainage and a naturally poor supply of nutrients to the crops (Corrêa et al., 2008). The prevailing vegetation in the region is associated to the Cerrado-type biome (Brito et al., 2023), with a diverse floristic composition that can range from more sparse vegetation (*campo Cerrado* or *Cerrado ralo*) to more dense forms of vegetation (*Cerrado típico* or *Cerrado denso*) (Dantas et al., 2014).

Five uniform management areas were divided into silviagricultural systems (rows of eucalyptus and soybean intercalated) and soybean mono-crop systems (consolidated cultivation under no-till for 14 years and recent cultivation under no-till for three years), in addition to a native Cerrado area as control. The area under silviagricultural systems and the area of recent soybean cultivation were installed in 2017. Both the areas under silviagricultural and no-till monoculture soybeans were deforested in 2004 and 2005, respectively, and upland rice was cultivated. Soybean under no-till was adopted from 2006 to 2010.

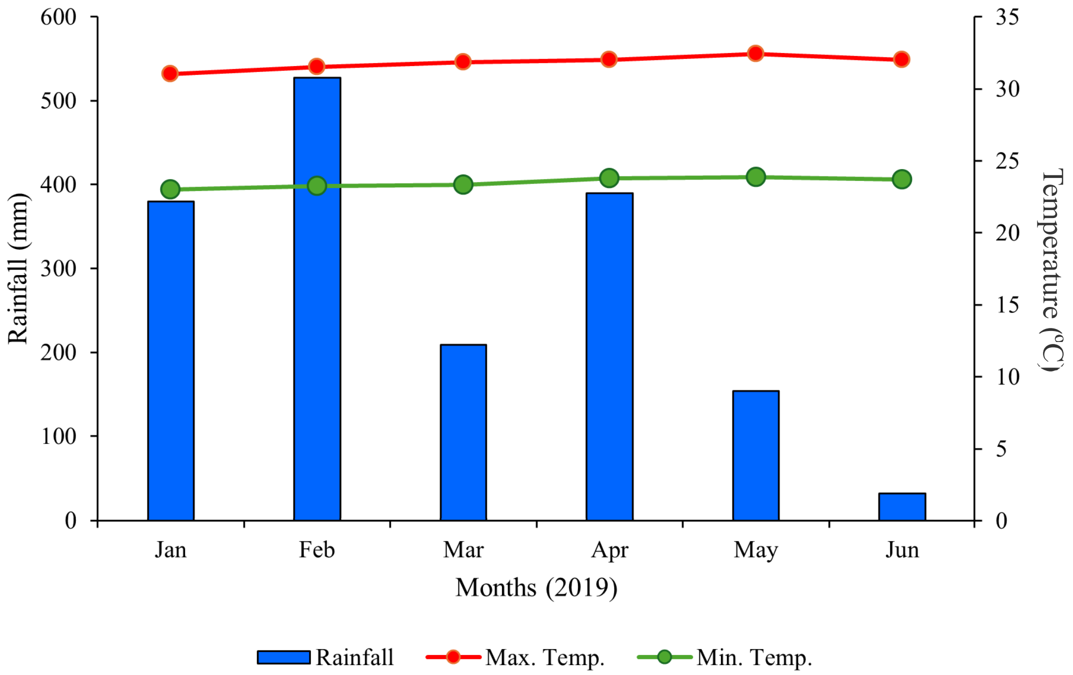

Figure 1. Rainfall (data from Barbosa Farm - Brejo, Maranhão) and maximum and minimum temperatures in the first half of 2019 (Inmet, 2021).

Urochloa brizantha cv. Marandu was oversown in soybeans, and cattle were allowed to enter the pasture after harvesting the soybeans and undergoing adequate forage development. Approximately 30 days before planting soybean in the next crop, the forage was desiccated and maintained as mulch. The history of land use in each management system is presented in table 1.

The management of the areas before soybean planting began with the desiccation of the plants with glyphosate and 2.4 D amine in SOYEUC, SOYREC and SOYNT. Fertilization was carried out with 280 kg ha^{-1} using the formulation NPK 09-46-00 at planting and 280 kg ha^{-1} of the formulation NPK 09-00-36 as topdressing 30 days later. Micronutrients were supplied in two applications via foliar fertilization (30 g ha^{-1} of Mo, 20 g ha^{-1} of Co, 100 g ha^{-1} of Zn, and 200 g ha^{-1} of Mn). Weed control was performed throughout the plant development cycle using the herbicide Clethodim. Fungicides based on Propiconazole, Difenoconazole, and Mancozeb were used for disease control. Pest control was carried out using the insecticide Teflubenzuron.

Soil fauna and soil sampling

Soil fauna was collected during the rainy period in April 2019, when the accumulated precipitation was 295.5 mm (Figure 1). Individuals were captured using pitfall traps, according to Moldenke (1994). Traps were made of 0.10 m high and 0.10 m in diameter plastic pots buried in the ground, with the edge at surface level. Each trap contained plastic containers with a diameter of 0.20 m fixed at a height of approximately 0.10 m using wooden sticks attached to the soil and pots. These containers were positioned to reduce or prevent plant debris and/or water from rain from entering the pots. In each management system, seven traps were randomly installed at a minimum distance of 10 m from each other, avoiding the border areas. In each trap, 300 mL of a 4 % formalin solution was added to prevent the deterioration of the organisms.

After seven days in the field, the traps were removed from the soil, and washed with tap water using a 0.10 mm filter to remove soil and/or plant debris present in the pots. Subsequently, the organisms were transferred to a 50 mL plastic container and preserved in 70 % alcohol for future identification. Collected individuals were identified using an optical magnifying glass and classified according to subclass, class, order, or family, according to Dindal (1990).

Soil sampling was carried out at 0.00-0.10 m layer in the same areas where the soil fauna was collected. Samples were refrigerated prior to carbon (MBC) and nitrogen (MBN) microbial biomass analysis and basal soil respiration (BSR). The MBC and MBN were determined by the irradiation-extraction method, according to Zagal (1989) and Ferreira et al. (1999). Basal soil respiration was determined, as described by Alef (1995), by quantifying the CO_2 released for seven days. The first determination was performed after 48 h of incubation under aerobic conditions.

The metabolic quotient (qCO_2), obtained by the ratio of basal soil respiration (mg CO_2 kg^{-1} h^{-1}) and microbial biomass C (mg C g^{-1} h^{-1}) were also calculated (Anderson and Domsch, 1993). Microbial quotient (*q*MIC), or Cmic/TOC ratio, was calculated according to Sparling (1992). For chemical analysis (pH, P, K, Ca, Mg, Al and TOC), an aliquot of the soil samples was air-dried and passed through a 2-mm sieve, according to Teixeira et al. (2017). Total organic carbon (TOC) levels were determined according to Yeomans and Bremmer (1988).

Data analysis

Soil fauna abundance was calculated using the number of individuals $trap^{-1}$ day^{-1}. Ecological indices of total richness (S); average richness (RM); Shannon-Weaner index (H); and Pielou evenness (e) were also calculated.

The Shannon-Weaner Index (H) quantifies the diversity of an area by the number of species and relative abundance, expressed through equation 1.

$$H = -\sum pi \times lnpi \qquad \text{Eq. 1}$$

in which: pi = ni/N; ni is the abundance of each group; and N is the total abundance.

Pielou Evenness Index (e) represents the uniformity of species in planting systems and is determined by equation 2:

$$e = \frac{H}{log\,S} \qquad \text{Eq. 2}$$

in which: H is the Shannon Index and S is the Total Richness (Bandeira et al., 2013). Values close to 0 indicate that a group is more dominant in the system, while values close to 1 denote an equilibrium between the groups.

Data were submitted to a one-way ANOVA according to a completely randomized experimental design. Means of each management system were compared by the Tukey Test at 5 % when significant effect of the treatments were detected. Multivariate principal components analysis (PCA) and grouping analysis were also carried out using the Euclidean distance between the data of the soil fauna (average number of individuals) and the management systems studied.

RESULTS

FOREST and EUCROW showed the greatest abundance of invertebrate soil fauna. Individuals from the orders Araneae, Blattodea, Coleoptera, Dermaptera, Diptera, Hemiptera, Hymenoptera, Isoptera, Larvae, Orthoptera, Pseudoscorpiones, Scolopendromorpha, Thysanoptera, from subclasses Acari, Collembola, and Oligochaete, and class Diplopoda were collected. Those from the Formicidae family were collected among the individuals of the order Hymenoptera (Table 2). Total richness, average richness, Shannon Diversity Index, and Pielou Evenness Index were close, with no difference between management systems. Collembola, Acari, Formicidae, Coleoptera, Oligochaete, Diptera, and Araneae were found in all soil management systems. Collembola order presented greater relative distribution in all management systems.

The Acari formed the second taxonomic group with the greatest relative distribution in the FOREST and SOYNT areas, and the third with the greatest expression in SOYREC and SOYEUC. Mites had a smaller distribution in EUCROW than in other management systems (Table 3). The orders Araneae, Coleoptera, and Diptera, and the family Formicidae presented considerable proportions in the studied systems. However, relatively low frequencies were observed for the Blattodea, Hymenoptera, Oligochaete, Isoptera, Pseudoscorpiones, and Thysanoptera groups (Table 3).

The PCA showed that the two selected components explained 62.29 % of the total variance of the data, and principal component (PC) 1 explained 34.12 % of the variation, while PC2 explained 28.14 % (Table 4). Grouping analysis showed the dissimilarity among the soil management systems based on the joint analysis of the number of individuals from different taxonomic groups (Figure 2). The dendrogram showed the formation of three distinct groups, one consisting of the FOREST, another composed of the SOYREC and SOYNT, and a third group formed by EUCROW and SOYEUC. Thus, differences in the soil fauna in the soybean cropping systems were evident in monoculture and when cultivated between eucalyptus rows.

The PCA distinguished the managements, where FOREST was linked to the groups that presented negative values for PC1 (Acari, Blattodea, Coleoptera, Collembola, Formicidae, Isoptera, Hymenoptera, Larvae, Orthoptera, and Thysanoptera) (Table 4 and Figure 3).

Table 1. Systems management history at Barbosa Farm, in Brejo, Maranhão, Brazil

Land use system	Description of the management history
Eucalyptus rows (EUCROW)	- 2017: *Eucalyptus globulus* was planted in the east-west direction, in rows with three lines 4 m spaced (3 m between plants in lines). Rows were spaced every 26 m and were 160 m long. Plowing and harrowing were performed in the installation. Soil was limed and fertilized according to soil analysis.
Soybeans grown between eucalyptus rows (SOYEUC)	- 2017: the area between eucalyptus rows was plowed and harrowed, and corn was intercropped with *Urochloa brizantha* cv. Marandu. - 2018 and 2019: soybean cultivated between rows of eucalyptus, under no-till, on millet straw used as a cover plant.
Soybeans in a consolidated no-till system (SOYNT)	- 2006: soybean under no-till folowing corn+Marandu intercropping cultivated every 4-5 years. Soil was limed and fertilized according to soil analysis. - 2016: soybean under no-till, on millet straw used as a cover plant. - 2017: corn+Marandu intercropping (soil scarification before corn cultivation). - 2018 and 2019: soybean under no-till, on millet straw used as a cover plant.
Soybean in a recent no-till system (SOYREC)	- 2017: area cultivated with sorghum. After harvesting, plant straw was maintained as soil cover. - 2018: area cultivated with corn+Marandu intercropping. - 2019: soybean cultivation on the straw of corn+Marandu.
Native Forest (FOREST)	- Native Cerrado area. The area had a fire in the second semester of 2017.

Table 2. Values of individuals trap^{-1} day^{-1}, total richness, average richness, Shannon Diversity Index, and Pielou Evenness Index of edaphic fauna in different management systems in Brejo, Maranhão, 2019

Management system	ind. trap^{-1} day^{-1} ± standard error	Total Richness	Average Richness	Shannon Diversity Index	Pielou Evenness Index
FOREST	62.00 ± 14.57 a[(1)]	15	8.1	1.13	0.29
EUCROW	35.76 ± 11.18 ab	12	7.7	1.40	0.39
SOYREC	10.73 ± 2.21 b	15	6.1	2.49	0.64
SOYEUC	8.29 ± 3.11 b	11	7.2	2.27	0.65
SOYNT	9.93 b ± 2.48 b	12	7.2	2.20	0.61

[(1)] Means followed by the same letters in the column do not differ by the Tukey Test ($p \leq 0.05$).

Table 3. Relative distribution (%) of edaphic fauna taxonomic groups in different management systems in Brejo, Maranhão, 2019

Groups	SOYNT	SOYREC	SOYEUC	EUCROW	FOREST
			%		
Acari	15.59	11.60	6.90	1.71	8.03
Araneae	1.68	9.32	5.17	6.74	0.33
Blattodea	-	-	-	2.40	0.10
Coleoptera	12.71	20.72	6.03	2.68	5.30
Collembola	51.08	43.35	50.57	77.28	81.40
Dermaptera	-	0.38	-	-	-
Diplopoda	-	0.19	-	-	0.10
Diptera	11.75	3.42	20.69	2.63	0.46
Formicidae	1.68	4.75	4.02	4.97	1.61
Hemiptera	0.48	-	2.59	0.91	0.10
Hymenoptera	-	0.57	-	0.06	0.03
Isoptera	1.20	2.66	0.57	-	1.38
Larvae	0.24	-	2.30	0.46	0.23
Oligochaete	0.72	1.52	0.86	0.06	0.07
Orthoptera	-	0.76	-	-	0.53
Pseudoscorpiones	0.48	0.19	0.29	-	-
Scolopendromorpha	-	0.19	-	-	-
Thysanoptera	2.40	0.38	-	0.11	0.33

Table 4. Coefficients of weights (auto vectors), eigenvalues, and variance explained by PC1 and PC2 of the edaphic fauna taxonomic groups in different management systems in Brejo, Maranhão, 2019

Groups	PC1	PC2
Acari	-0.38	-0.06
Araneae	0.08	0.19
Blattodea	-0.38	0.12
Chilopoda	0.08	-0.34
Coleoptera	-0.34	-0.20
Collembola	-0.36	0.16
Dermaptera	0.08	-0.34
Diplopoda	0.19	0.17
Diptera	0.03	-0.02
Formicidae	-0.13	0.25
Hemiptera	0.06	0.32
Hymenoptera	-0.02	-0.15
Isopoda	0.20	0.18
Isoptera	-0.36	-0.11
Larvae	-0.04	0.40
Oligochaete	0.14	-0.37
Orthoptera	-0.37	-0.06
Pseudoscorpiones	0.10	-0.28
Thysanoptera	-0.24	-0.12
Eigenvalues	6.48	5.34
Total variance (%)	34.12	28.14
Cumulative variance (%)	34.12	62.29

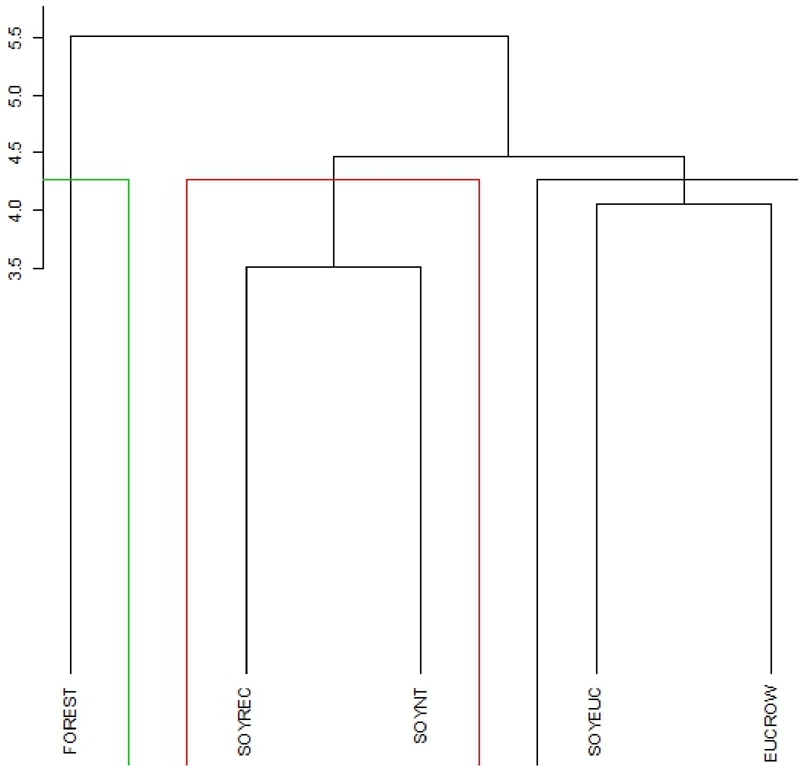

Figure 2. Dissimilarity dendrogram between the average number of individuals in taxonomic groups and different management systems in Brejo, Maranhão, 2019.

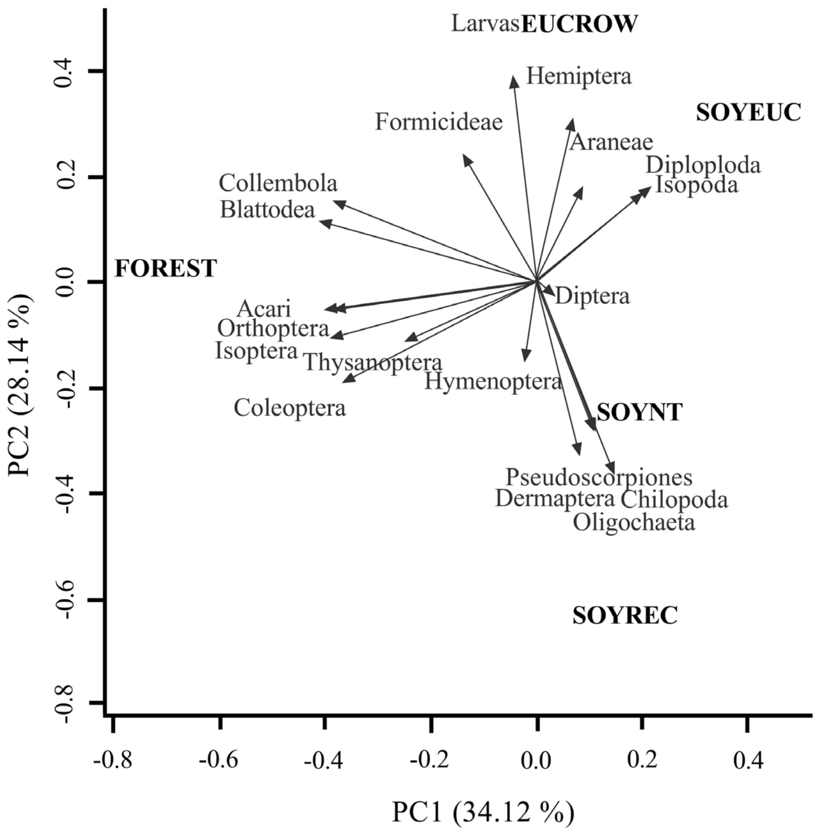

Figure 3. Biplot of the relationship between the average number of individuals in taxonomic groups and the different management systems in Brejo, Maranhão, 2019.

Silviagricultural systems (SOYEUC and EUCROW) were linked to the groups that presented positive values for PC1 and PC2 (Aranae, Diplopoda, Hemiptera, and Isopoda). SOYREC and SOYNT differed by being close to the groups with positive scores for PC1 and negative for PC2 (Chilopoda, Dermaptera, Diptera, Hymenoptera, Isoptera, Oligochaete, and Pseudoscorpiones) (Table 4 and Figure 3).

FOREST presented the lowest values for pH, P, Ca^{2+}, and Mg^{2+} but without differing from EUCROW for pH and Mg. FOREST also presented a higher value of Al compared to the other management systems that received the application of fertilizers and lime during its establishment (Table 5). Soil under EUCROW presented higher TOC values than under SOYEUC. However, these values did not differ from the SOYREC, SOYNT, and FOREST. The highest values of basal respiration were observed in the SOYREC and SOYEUC systems (Table 6).

DISCUSSION

Forest area accounted for 49 % of the individuals caught in the traps. This is due to the greater diversity and regularity in the supply of plant material from both the trees and plants from the herbaceous stratum, associated with the absence of soil disturbance. Since Cerrado vegetation is composed of trees, shrubs, and grass species (Dantas et al., 2014), it is possible that the influence of this plant diversity allowed the availability of food resources and organic compounds with different stages of decomposition, which served as refuge and shelter for the soil fauna, providing better conditions for their reproduction. Additionally, the shading provided by the plant canopy reduced soil temperature and humidity variations, favoring greater variability of niches for colonization, and less competition between groups (Nunes et al., 2019; Silva et al., 2019; Zagatto et al., 2019).

Table 5. Average values of chemical properties of soil under different management systems in Brejo, Maranhão, 2019

Systems	pH($CaCl_2$)	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}
		mg dm^{-3}		cmol$_c$ dm^{-3}		
FOREST	4.8 c[(1)]	2c	0.09	2.0 d	1.1 b	0.091 a
EUCROW	4.8 c	28b	0.09	3.0 c	0.9 b	0.039 b
SOYREC	5.2 b	30b	0.10	2.7 c	1.3 a	0.005 c
SOYEUC	5.2 b	52 a	0.10	3.6 b	1.3 a	0.007 c
SOYNT	5.7 a	32 b	0.09	4.1 a	1.3 a	0.002 c

[(1)] Means followed by the same letters in the column do not differ by the Tukey Test ($p \leq 0.05$).

Table 6. Average values regarding chemical and biological properties of soil submitted to different management systems in Brejo, Maranhão, 2019

Systems	TOC	MBC	MBN	BSR	qCO_2	qMic
	g kg^{-1}	µ g^{-1}		mg CO_2 g^{-1} day^{-1}	mg g^{-1} day^{-1}	%
FOREST	12 ab[(1)]	81	1.1	30 b	0.40	0.7
EUCROW	13 a	105	1.1	25 b	0.29	0.9
SOYREC	9 ab	111	0.8	46 a	0.47	1.4
SOYEUC	8 b	67	0.3	45 a	0.82	0.9
SOYNT	11 ab	82	0.8	31 b	0.42	0.7

[(1)] Means followed by the same letters in the column do not differ by the Tukey Test ($p \leq 0.05$).

Eucalyptus trees (EUCROW) also provided favorable conditions for soil fauna, which were similar to those in FOREST, as also observed by Gualberto et al. (2021) and Nunes et al. (2021). Although eucalyptus was cultivated as a monoculture, other plant species eventually grew under the canopy of plants, which guaranteed food and shelter for the edaphic organisms, enabling this system to sustain a greater abundance of individuals than soybean cropping systems. Other studies demonstrated that the areas under cultivation of eucalyptus were among those with the highest number of soil fauna individuals, mainly due to the large amount of vegetation cover in these areas (Silva et al., 2019).

Systems with the highest soil TOC levels showed the largest populations of soil fauna. Both characteristics were favored by the presence of the arboreal component (FOREST and EUCROW), confirming our first hypothesis. Variations in soil chemical characteristics and soil organic matter (SOM) associated with soil macrofauna have been useful to explain or predict changes in soil quality (Velasquez and Lavelle, 2019). Cerrado areas converted to agricultural management systems led to rapid changes in the soil macroinvertebrate community, followed by slower changes in soil chemical parameters, including SOM content. This was confirmed by Franco et al. (2020), who demonstrated that the reduction of SOM content is linked to the decrease in the abundance of organisms considered soil engineers, leading to destabilization and consequent reduction of the C allocated within soil aggregates.

This statement corroborates the data observed in this study in intensively managed systems with soybean. The SOYNT, SOYREC, and SOYEUC systems showed the lowest individual abundance. The areas under these systems produced plant material with more uniform characteristics, providing conditions that contrast with those observed in FOREST, causing negative effects on the soil fauna (Menta, 2012; Beugnon et al., 2019). Eliminating plant biodiversity in the systems and consequently reducing the amount of plant residues significantly reduced the population of soil fauna individuals, which was accompanied by a reduction in the TOC levels. This condition also meant the highest microbial activity, with the highest CO_2 emissions in systems with more recent adoption (SOYREC and SOYEUC). Soybean cultivated over a 14-year no-till system (SOYNT) mitigated the intensity of basal soil respiration, although it did not increase the population of soil fauna individuals.

Despite the largest soil fauna population, FOREST presented a low diversity of individuals and the greatest dominance of specific groups, such as Collembola. These data are indicative of an imbalance caused by recent disturbances, since the Collembola shows a fast response to changes in the balance of the ecosystem, with a sharp decline in the population under unfavorable conditions and explosive growth under ideal conditions (Hopkin, 1997; Baretta et al., 2007; Menta, 2012; Coleman et al., 2017). It is possible that a natural fire event that occurred in 2017 (Table 1) affected the ecosystem balance in FOREST, resulting in losses of group diversity. Also, vegetation regeneration likely allowed this environment to rapidly re-establish specific groups of individuals to the detriment of others. In particular, the Collembola is a group sensitive to anthropogenic interventions, qualifying them as bioindicators of disorders and changes in soil quality (Cutz-Pool et al., 2007). Thus, the regeneration of FOREST restored its capacity to produce and supply plant residues, favoring the predominance of Collembola, which helps to decompose these residues, catalyzing microbial activities, nutrient cycling, and soil structuring (Coleman et al., 2017).

Multivariate analysis distinguished the edaphic macrofauna in three distinct groups of land use (1-FOREST; 2-SOYEUC and EUCROW; and 3-SOYREC and SOYNT) (Figure 3). The formation of a group composed of components from the same silviagricultural system (SOYEUC and EUCROW) indicates that eucalyptus rows possibly influenced the presence of individuals in SOYEUC, as these systems shared the same soil fauna groups (Figure 2), of which Araneae and Hemiptera are noteworthy. The first is a group of predators often found in areas with recent planting (Pekár, 2003) and the second includes insect pests important for soybean crops (Edde, 2021). Thus, it is possible that the eucalyptus rows served as a refuge for the soil fauna, which explains the lowest values of individuals in SOYEUC. Araneae and Hemiptera groups have great mobility to colonize new food sites in plants, either for predation in soil (Araneae) or moving through the air (Hemiptera). As demonstrated by the cluster analysis, the association of the same groups of soil fauna to SOYEUC and EUCROW reinforces the evidence of the flow of these individuals between the systems.

Cultivation of strips intended for the maintenance of perennial plants species is reported as a way to reduce the impacts of agricultural activity on biological diversity, providing areas for conservation and multiplication of soil invertebrate species, contributing to sustainable agriculture in temperate climate regions (Smith et al., 2008; Crittenden et al., 2015). Data from the present study demonstrate unpublished evidence of the importance of cultivating strips with eucalyptus in tropical grain-producing areas to contribute to the shelter, protection, and flow of species between areas and the ecological balance of the systems.

Soil under SOYNT and SOYREC shared the same soil fauna groups, notably those that act in improving the soil physical quality, such as Hymenoptera, Chilopoda, and Oligochaeta (Lavelle et al., 2006). Therefore, our data could not support the hypothesis that the time of adopting an agricultural system modulates the diversity of soil fauna groups. SOYNT and SOYREC systems differed from the other systems regarding high pH and soil fertility characteristics, especially when compared to FOREST and EUCROW, due to the application of lime and fertilizers. In these systems, the rotation of soybeans with forage grasses ensured the combination of the large volume of straw produced by the corn+Brachiaria intercropping and the high-quality soybean residue. The conversion of Cerrado areas to these systems induced similar soil changes, allowing soil colonization by similar groups of organisms capable of adapting to this condition (Marchão et al., 2009).

Overall, the systems that improve soil quality indicators, such as TOC content, also increase the population of soil fauna individuals but not the diversity of groups. Similarly, soybean production under different times of adoption of the no-tillage system did not affect the population or the structure of the soil fauna groups. The lack of significant effects of the systems on the diversity of soil fauna groups could have been overcome if a higher number of pitfall traps had been used in our study. Furthermore, the data in this study are based on samples originating from a single farm and a single cropping season, which hampers a broader representativity of the systems considered in this study. Despite that, our results indicate the main factors influencing soil fauna dynamics in integrated cropping systems on the Cerrado of Northeast Brazil. Such results point towards the need for future detailed studies to comprehend better the effects of land use systems on soil fauna dynamics under such conditions. Moreover, such studies should include the impact of different management systems on specific soil functionalities of biological groups that could be explored to optimize ecosystem services (Sechi et al., 2017).

CONCLUSIONS

The presence of the tree component either in natural ecosystems (native cerrado vegetation) or in silviagricultural systems provides a greater abundance of soil fauna individuals. The largest populations of individuals occurred in systems with the highest soil organic carbon concentrations. Soil under different components of the same silviagricultural system (soybeans grown between eucalyptus rows and eucalyptus rows) share the same soil fauna groups, indicating a flow of soil fauna individuals between these components. Time of adoption of the no-till system in soybean rotated with forage grasses does not modulate the population and diversity of edaphic fauna groups.

DATA AVAILABILITY

The data will be provided upon request.

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