Journal of Agricultural Science; Vol. 10, No. 9; 2018
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Associations Between Different Soil Management Practices, Soil Fauna and Maize Yield

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Received: May 20, 2018 Accepted: June 23, 2018 Online Published: August 15, 2018

doi:10.5539/jas.v10n9p333 URL: https://doi.org/10.5539/jas.v10n9p333

The research is financed by Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão (FAPEMA).

Abstract

Soil fauna play an important role in ecosystems, and in this context, it is important to better understand how the abiotic and biotic drivers of these organisms interact. We hypothesize that soil fauna are affected by different soil management practices, which has an influence on maize grain yields. The aim of this study was to evaluate the structure of soil fauna under different soil management practices and their associations with maize grain yield. The experiment was conducted in Maranhão, Brazil, in an area divided into 24 plots of 4 × 10 m in a randomized block design with six treatments with four replicates (R). Pitfall traps were placed in the area. The treatments were *Leucaena leucocephala*-Leucaena (L), nitrogen (N), humic acid + nitrogen (HA + N), nitrogen + Leucaena (N + L), humic acid + Leucaena (HA + L) and humic acid + nitrogen + Leucaena (HA + N + L). The soil fauna dominance, abundance, richness, Shannon-Wiener diversity index, Pielou evenness index and maize grain yield were determined. Formicidae was clearly affected by management with Leucaena, while Coleoptera was affected by management with nitrogen. Despite this, Isopoda and Diplura were the only groups associated with the maize yield. Although fauna abundance did not differ among treatments, it was related to the yield. This study confirms that the abundance and some taxa of soil fauna can influence yield and that these organisms can be used to increase agricultural sustainability.

Keywords: abundance, diversity indexes, principal component analysis, soil quality, sustainability

1. Introduction

Ecosystem functions such as decomposition, nutrient cycling and maintenance of physical and chemical properties are greatly influenced by the contribution of edaphic organisms (Davidson & Grieve, 2006). These organisms play an important role in the formation and stabilization of soil structure (El Titi, 2003). They regulate the rates of movement of nutrients, water and gases, and they lead to the development of macropores, which increase water absorption and reduce run-off, erosion and waterlogging. They also alter the competitive balance between plants with different rooting depths by changing the distribution of water in the soil profile (Sanginga et al., 1992).

The role of soil fauna in litter decomposition has been intensively studied over the past 40 years (Zhang et al., 2015). El Titi (2003) reported that these organisms have an important role in the production and decomposition of organic matter and population stability of other organisms that inhabit the soil. Bedano et al. (2016) highlighted the importance of soil fauna in soil organic matter cycling, mainly mesofauna and macrofauna.

Nevertheless, little has been done to link indicator taxa with their ecosystem functions and services (Rousseau et al., 2013), and it is necessary to take an integrative approach to address these gaps in knowledge (Tsiafouli et al., 2015). Birkhofer et al. (2011) affirmed that it is important to better understand how the abiotic and biotic drivers of soil fauna activity interact at spatial and temporal scales to possibly counteract negative consequences of ecosystem functioning. According to Siqueira et al. (2014), there is not enough knowledge about how arthropods, for example, are affected by extensive and/or intensive agricultural systems. According to Ying-Hua et al. (2013), there are few studies on the effect of different fertilizers on soil fertility and soil fauna.

Many mechanical and chemical changes occur within agricultural environments, and this modifies the responses of the native species populations in the area (Hernández-Ruiz & Castaño-Meneses, 2006). Brussaard et al. (2007) observed that organic matter, for example, is one of the limiting factors of soil organism functions. According Violet (2015), organic inputs modify soil macrofauna, increasing the biomass, abundance and diversity. Reeve et al. (2010) report that soil fauna structure is also affected by fertilizers, because these components alter plant residues and soil properties, interfering in the composition of the community. In this context, Franco et al. (2016) found that Formicidae population increased when content of nitrogen increased in a sugarcane crop.

According to Korboulewsky et al. (2016), biotic and abiotic agents affect these organisms, but Yang et al. (2007) emphasized that in the humid tropics, the soil fauna also affect the environment because they increase the decomposition rate of the soil. Carrillo et al. (2011) suggested that soil fauna alter the effect that litter quality exerts on decomposition and this process is important for fertility. Zhang et al. (2015) showed that when soil fauna were absent, decomposition rate of plant litter decreased. In this context, Huguenin et al. (2006) concluded that soil fauna increases agricultural production. Shukla et al. (2016) showed that soil engineers modify the soil structure and this enhances the yield in cereals. These organisms build tunnels to forage and nest, increasing water infiltration and aeration into the soil, influencing availability of several nutrients. When water infiltration is deeper, evaporation from the soil surface decrease and absorption of water by plants improves (Evans et al., 2011). This effect can be relevant to agricultural yield. The type of soil fauna feeding also may influence grain yield, such as maize, through providing different contents of nutrients to the soil (Jiang et al., 2015).

Thus, it is necessary to understand how soil fauna populations are changed when the environment is modified and how these organisms may modify surroundings. Therefore, we hypothesize that soil fauna are affected by different management practices, and this influences maize grain yields. The aim of this study was to evaluate the structure of soil fauna under different soil management practices and their relation to increases in maize grain yield.

2. Materials and Methods

2.1 Study Area

The experiment was performed at Brejo City (3°38′S latitude and 42°58′W longitude), Maranhão, in the northeast of Brazil. The climate there is humid tropical with 1200-1400 mm of average annual precipitation and an average annual temperature above 27 °C. The soil is an Arenic Hapludult (Soil Survey Staff, 2010), presenting a flat topography (slope < 1%) with the following characteristics: pH 4.4 (0.01 M $CaCl_2$); organic C 15.5 g kg^{-1}; potential acidity 4.7, and CEC 7.9 mmol$_{(c)}$ dm^{-3}; Ca 2.6, Mg 0.5, and K 0.1 mmol$_{(c)}$ dm^{-3}; P 3.7 g dm^{-3} (resin); base saturation 40.2%; and a sandy textural class.

The experimental area was established in 2012 and consists of an alley cultivation system with Leucaena (*Leucaena leucocephala*) planted with an inter-row spacing of 4 m and an inter-plant spacing of 0.5 m.

In 2015, the area between the rows of the Leucaena was divided into 24 plots of 4 × 10 m with six treatments and four replicates (R) in a randomized block design. The treatments were: 133 kg ha^{-1} of urea, as a source of Nitrogen (N); 15 t ha^{-1} of *Leucaena leucocephala*-Leucaena (L); 133 kg ha^{-1} of urea + 15 t ha^{-1} of Leucaena (N + L); 500 L ha^{-1} of humic acid + 15 t ha^{-1} of Leucaena (HA + L); 500 l ha^{-1} of humic acid + 133 kg ha^{-1} of urea (HA + N) and 500 l ha^{-1} of humic acid + 133 kg ha^{-1} of urea + 15 t ha^{-1} of Leucaena (HA + N + L). All treatments received 120 kg ha^{-1} of P_2O_5, 60 kg ha^{-1} of K_2O and 25 kg ha^{-1} of $ZnSO_4$. These doses were defined according to the result of the soil analysis.

2.2 Soil Fauna

Soil fauna was sampled using the pitfall trap method in each plot, which allows the capture of different groups of this fauna. The traps were made of plastic, allocated to the ground level, and were approximately 9 cm high and 8 cm in diameter. The collection occurred during a seven-day period in July 2015, and samples were preserved in glasses with 200 mL of formaldehyde solution (4%). The contents of the glasses were transferred to pots with 70% alcohol and properly identified.

In the laboratory, each sample was processed, separated and identified at the order or family level using a binocular microscope and taxonomic keys. Formicidae was separated from Hymenoptera due to the ecological importance it has in the community.

Abundance, dominance and ecological indexes—richness, Shannon-Weaner diversity index (*H'*) and Pielou equitability index (*J'*)—were used for evaluation of the soil fauna structure.

The fauna abundance is calculated as the number of individuals per pitfall per day. The dominance is the number of individuals in each taxon per trap per day. The richness is the number of groups that occurred in each sample. The Shannon-Weaner index is calculated by the following formula:

$$H' = -\sum_{i=1}^{s} pi \cdot \log_2(pi) \quad (1)$$

where, *pi* = probability of meeting a taxon *i* in a trap per day and *s* = total number of taxa encountered in a trap per day. The Pielou evenness index indicates how individuals are distributed among the different taxa present in the sample. It is calculated as:

$$J' = \frac{H'}{\log_2(s)} \quad (2)$$

where, *H*' is Shannon index and *s* is number of groups present in a trap per day.

2.3 Maize Grain Yield

Each plot was cropped with maize (*Zea mays* L.), variety QPM BR 473, in March 2015 in a total area of 1,280 m^2. At physiological maturity, ten cobs were collected from each plot, and their grains were extracted. The grain yield was estimated in Mg ha^{-1} from the total grain mass in each plot and the number of plants per hectare.

2.4 Statistical Analyses

For the statistical analysis, a one-way ANOVA was conducted to determine the significance of the difference in the means of the soil fauna dominance, abundance, richness, Shannon-Wiener index, Pielou index and maize yield. Diversity and evenness data were transformed to meet the assumptions of normal distribution and homogeneity of variance. The Duncan test was used to determine which differences were significant ($p < 0.05$). For cluster analysis with Ward's method, the Euclidean distance between the mean abundances of soil fauna groups was used as the measure of similarity. The relation between the maize grain yield and the major groups of soil fauna was analysed. The relations between the maize grain yield and the ecological indexes and abundance were also analysed. For this investigation, principal component analysis (PCA) was used after standardization of the data. Statistica version 7 (Statsoft Inc., 2004) was used for all analyses.

3. Results

3.1 Soil Fauna

A total of 1 993 soil fauna individuals belonging to 27 taxa were collected. The maximum number of taxa occurred at HA + N (20), and the minimum occurred at N + L (13). The largest soil fauna community was found at HA + N + L (369), and the smallest was found at L (289) (Table 1). The taxa with the greatest numbers of individuals were Formicidae, Coleoptera, Diplura and Isopoda, accounting for 77.5% of the collected organisms.

Table 1. Total number of individuals collected by pitfall traps in one week per taxonomic group studied

Taxon	HA + N	HA + N + L	L	HA + L	N	N + L
Araneae	39	27	17	31	16	11
Araneae (Cocoon)	3			1		
Auchenorrhyncha	2			1	2	2
Blattodea		1				
Chilopoda					1	
Coleoptera	45	54	48	68	94	41
Coleoptera (Larva)	1	1	1	3	3	
Dermaptera	1		2	2		
Diplopoda	1		1	7		
Diplura	51	74	35	39	59	78
Diptera	1		1		4	2
Diptera (Larva)					1	2
Entomobryomorpha	3	2	7	11	11	1
Formicidae	103	149	110	121	85	107
Heteroptera	1	1	3	2	5	2
Hymenoptera	11	6	11	5	2	3
Isopoda	36	36	18	15	41	37
Isoptera	3	1				
Lepidoptera	1					
Lepidoptera (Larva)		1	3	2	1	
Neuroptera (Larva)		1	1			
Opillionida	1	1	3	7	5	5
Orthoptera	14	13	27	26	28	25
Phasmatodea	1					
Pseudoscorpionida		1			1	
Sternorrhyncha	1					
Thysanura			1			
Total	319	369	289	341	359	316

Note. HA + N = humic acid + nitrogen; HA + N + L = humic acid + nitrogen + Leucaena; L = Leucaena; HA + L = humic acid + Leucaena; N = nitrogen; N + L = nitrogen + Leucaena.

Formicidae was the group with the largest mean number of individuals (37.25±31.36 at HA + N + L). Significant differences were detected between the mean number of individuals in this group and the other taxa at the HA + N and L treatments, which had 25.25±9.74 and 27.5±11.27 Formicidae individuals, respectively ($p < 0.05$) (Figure 1).

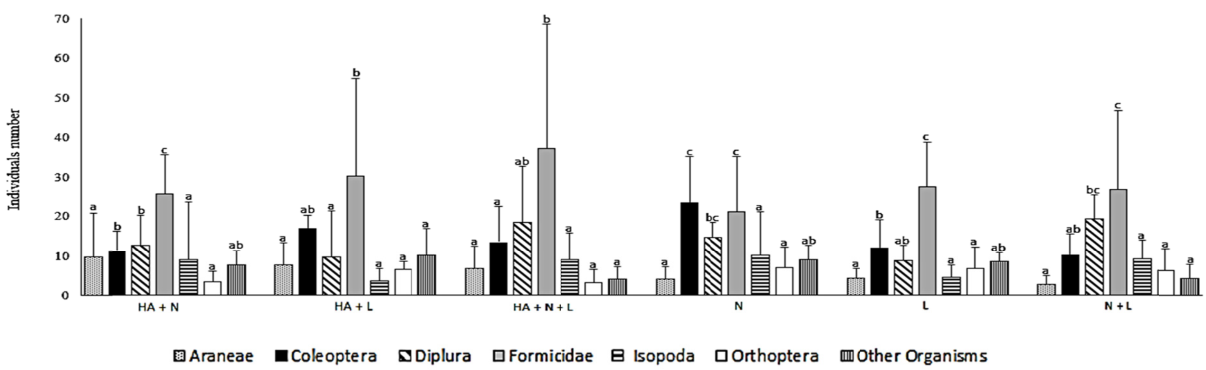

Figure 1. Dominance of taxonomic groups of soil fauna (mean±standard deviation) per treatment

Note. Taxa with distinct letters within the same treatment are significantly different (ANOVA with Duncan test, $p < 0.05$). HA + N = humic acid + nitrogen; HA + N + L = humic acid + nitrogen + Leucaena; L = Leucaena; HA + L = humic acid + Leucaena; N = nitrogen; N + L = nitrogen + Leucaena.

The Shannon index, Pielou index, richness and abundance values showed no significant differences ($p > 0.05$) (Table 2).

Table 2. Shannon index, Pielou index, total richness and abundance values of soil fauna communities at different treatments (mean±standard deviation)

Treatment	*H'* ± std. dev.	*J'* ± std. dev.	S ± std. dev.	A ± std. dev.
HA + N	1.681±0.228a	1.676±0.141a	10.5±3.3a	11.39±1.08a
HA + N + L	1.401±0.499a	1.656±0.222a	7.7±4.1.0a	13.18±8.81a
L	1.877±0.076a	1.789±0.094a	11.2±1.0a	10.32±3.96a
HA + L	1.798±0.3a	1.761±0.194a	10.5±1.7a	12.18±4.22a
N	1.788±0.24a	1.819±0.089a	10.0±2.7a	12.82±5.64a
N + L	1.634±0.234a	1.793±0.037a	8.5±2.4a	11.29±6.03a

Note. Same letters within the same column indicate not significantly differences (ANOVA with Duncan test, p > 0.05). HA + N = humic acid + nitrogen; HA + N + L = humic acid + nitrogen + Leucaena; L = Leucaena; HA + L = humic acid + Leucaena; N = nitrogen; N + L = nitrogen + Leucaena; *H'* = Shannon index; *J'* = Pielou index; S = total richness; A = abundance; std. dev. = standard deviation.

The treatments with a Euclidean distance between 70 and 80 were classified into three groups, i.e., (1) N, (2) HA + L, L and (3) HA + N + L, N + L, HA + N. Group 1 predominantly contains Coleoptera, group 2 includes treatments at which Formicidae was predominant, and group 3 comprises the treatments at which three taxa were predominant (Formicidae, Diplura and Coleoptera) (Figure 2).

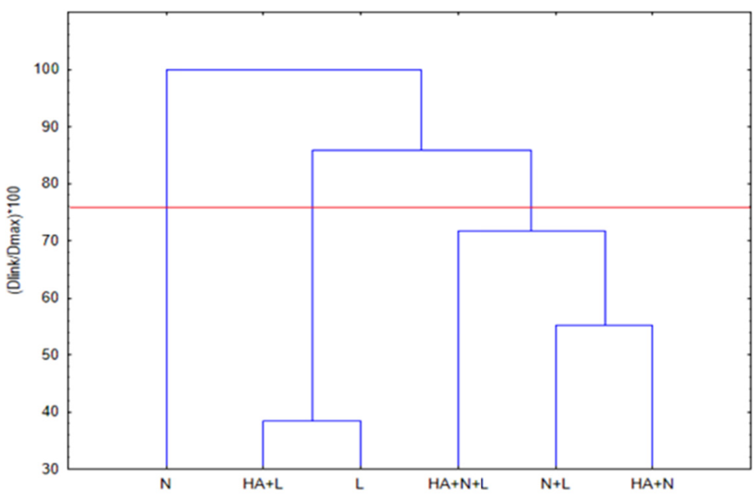

Figure 2. Dendrogram resulting from hierarchical cluster analysis, with the formation of groups based on the Euclidian distance of the taxonomic groups of soil fauna

Note. N = nitrogen; HA + L = humic acid + Leucaena; L = Leucaena; HA + N + L = humic acid + nitrogen + Leucaena; N + L = nitrogen + Leucaena; HA + N = humic acid + nitrogen.

3.2 Maize Grain Yield

The maize grains yield at N + L was significantly higher than that in the other treatments ($p < 0.05$). In the other treatments that also received nitrogen, the yield was significantly higher than that in the treatments that did not receive it ($p < 0.05$) (Table 3).

Table 3. Maize grain yield at different treatments

Treatment	Grains Yield (Mg ha^{-1})
HA + N	4.02 b
HA + N + L	4.62 b
L	1.47 c
HA + L	1.60 c
N	3.93 b
N + L	5.38 a

Note. Distinct letters indicate significant differences (ANOVA with Duncan test, $p < 0.05$).

HA + N = humic acid + nitrogen; HA + N + L = humic acid + nitrogen + Leucaena; L = Leucaena; HA + L = humic acid + Leucaena; N = nitrogen; N + L = nitrogen + Leucaena.

3.3 Relations Between Soil Fauna and Maize Grain Yield

In the PCA that associated yield with taxonomic groups, 65.22% of the variation was explained by its two main components. Axis 1 was mainly associated with Isopoda, Diplura, Coleoptera and Formicidae, while axis 2 was associated with Orthoptera. Yield showed a strong positive correlation with Isopoda and Diplura (Figure 3a).

In the PCA that associated yield with ecological indexes and abundance, its two main components explained 89.13% of the variation. Axis 1 was mainly associated with the Shannon index and richness, while axis 2 was associated with abundance and the Pielou index. The only positive correlation found was between yield and abundance (Figure 3b).

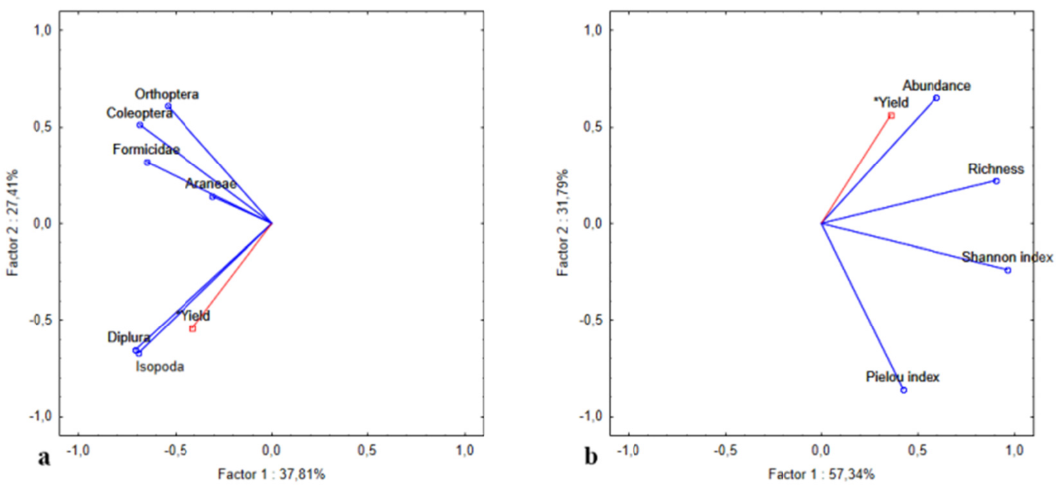

Figure 3. Principal component analysis (PCA) of the yield and major groups of the soil fauna (a); yield and the ecological indexes and abundance (b)

4. Discussion

4.1 Soil Fauna

We found that the total number of individuals and the number of taxa of soil fauna varied between treatments. Soil changes modify soil characteristics such as temperature, water content and nutrients, affecting the environment of soil organisms (Erouissi et al., 2011), and this causes differences in the fauna communities between sites. Ayuke et al. (2009) emphasizes that some management practices, such as the application of organic residues, are among the causes of variations found in soil fauna. In this study, we did not identify specific variations in the total number of individuals or taxa in treatments with organic residues.

Formicidae, Coleoptera, Diplura and Isopoda had the predominant number of individuals at the study site. Ants are engineers and strongly affect the fluxes of gases and water in soil. They incorporate plant litter and crop residues into the soil, providing resources to other individuals, modifying the microhabitats for them and transporting materials for the formation of nests (Paul et al., 2015; Segat et al., 2017; Siqueira et al., 2014; Wolters, 2000). This may explain the coexistence of a high number of Formicidae with other taxa.

In the present study, Formicidae dominated the other groups, especially in two of the treatments. This finding corroborates those of Siqueira et al. (2014), who affirmed that differences in these invertebrate communities can be influenced by how land is used, even at the taxa level. According to Sileshi and Mafongoya (2006a), when the abundance of functional groups such as soil engineers increases, some soil ecosystem functions will be enhanced.

One of the treatments at which Formicidae numbers were particularly high was composed only of Leucaena. In this sense, Moura et al. (2015) emphasized that the presence of some functional groups of soil fauna can be influenced by applying biomass on the soil surface. Blanchart et al. (2006) showed that the presence of a legume stimulated the development of organisms that can promote soil structure and nutrient availability. This result was observed in the present research, where ants dominated the Leucaena biomass treatment. Franco et al. (2016) observed that ant number was related to the nitrogen content in the soil, which occurred in our results when nitrogen was associated with humic acid.

Pellens and Garay (1999) reported that some species of Leguminosae could even be used for natural recolonization of edaphic communities. Blanchart et al. (2006) found that the presence of legumes modified the composition and diversity of soil biota in a maize cropping system. This result was not verified in the present study, where the average diversity and richness between treatments did not show significant differences ($p > 0.05$).

The abundance of soil fauna can be significantly affected by the soil use. For example, the water retention capacity of soil can be increased by the accumulation of organic matter and then influence the soil fauna (Sileshi & Mafongoya, 2006b). For Cluzeau et al. (2012), fertilization intensity also affect the abundance of soil fauna. As Paul et al. (2015) noted, there are studies that have found relationships between the management and abundance of soil fauna. In our results, however, we did not detect significant differences in abundance between treatments ($p > 0.05$).

Cluster analysis verified the formation of three groups based on the shortest Euclidian distance. This distance represents the degree of association between treatments, and according to Lee et al. (2006), the shorter this distance, more intimate the association is; therefore, treatments in the same group represent the nearest relationship. Vasconcellos et al. (2013) verified that Coleoptera was one of the most important taxa for discriminating between sites and that it showed good potential as a bioindicator of soil quality. This result was also found in this research, where the groups had different associations with this taxon. The two groups in which Coleoptera was a major taxon were composed of treatments with nitrogen. Hunt et al. (1992) noted that nitrogen in crops causes faster development of some beetle species. This finding may explain the results found here. As a whole, the treatments grouping according to cluster analysis was consistent with the predominance of some taxa.

4.2 Maize Grain Yield

Maize grain yield was significantly higher in treatments that received nitrogen than in those that did not receive it ($p < 0.05$). This increase may be related to some groups of soil organisms, because fertilization is one of the factors that can influence these organisms (Ying-Hua et al., 2013), for example, when nitrogen content changes (X. Zhu & B. Zhu, 2015). According to Lavelle et al. (1995), nitrogen fertilization alters pH and this changes the composition of soil fauna communities. Ying-Hua et al. (2013) affirm that soil fauna populations that parasite plants decrease when nitrogen is applied. This decrease in parasites populations may increase yield.

4.3 Relations Between Soil Fauna and Maize Grain Yield

Soil ecosystem services associated with sustainable agricultural production are driven in part by edaphic organisms (Creamer et al., 2016). Lavelle et al. (1995) and Ouédraogo et al. (2006) highlighted positive effects of soil fauna on soil fertility via the conservation of organic matter and nutrients, which benefits plant growth. Shukla et al. (2016) found that the ecosystem engineering activities of a species of ant enhanced the yield of cereals. However, in our study with maize, we did not detect an association between ants and crop yield. The only association we found by PCA between yield and soil fauna occurred with Isopoda and Diplura. This result is unlike those of Paul et al. (2015), who found that higher maize grain yields in Kenya were related to the exclusion of groups of soil fauna. Isopods are general detritivores, and they can feed on the foliage of seedlings (Coleman et al., 2004). This ecological function increases the cycling of nutrients in the soil (Culliney, 2013) and may influence yield. Diplura are predators, and according to Rivers et al. (2016), predators may consume insect pests, lowering the overall plant damage. This activity also may increase the crop yield.

The biodiversity of edaphic biota is a key component of soil quality (Creamer et al., 2016), and it leads to production sustainability (Altieri, 1999; van der Putten et al., 2004). According Thakur et al. (2014), disturbances may alter local environmental conditions, and it is very important to understand how local species diversity could be influenced by these disturbances. For Cluzeau et al. (2012), the impact of management systems on soil biodiversity strongly depends on the nature and intensity of the agricultural practices employed. In our results, we did not find an association between the yield and diversity indexes. Nevertheless, we observed a correlation between yield and fauna abundance. The increased yield associated with increased abundance may be related to the presence of invertebrates with different ecological functions in the soil, even without an increase in biological diversity. For Kilowasid et al. (2012), this functional diversity improves ecosystem services such as yield. In this sense, Blanchart et al. (2006) affirmed that biota resources may increase the functional properties of ecosystems and allow better agricultural productivity and sustainability. Sanginga et al. (1992) noted that the management of biological processes could be one way to restore and sustain fertility because biological factors influence the soil nutrient and physical characteristics.

5. Conclusion

The main results of this research indicate that Leucaena treatments may have caused increases in the dominance of ants. Nitrogen also demonstrated an influence over the community of Coleoptera. Despite this, although another studies have associated Formicidae with ecosystems services, we could not observe a relation between this group and maize grain yield. Isopoda and Diplura were the only groups associated with the yield, which may be related to their ecological functions in the environment. We did not observe differences in the ecological indexes between different soil management practices, and we did not find a relation between these indexes and the yield. Although fauna abundance also did not vary among management treatments, it was related to the yield. This finding may be due to the importance of the diversity of ecological functions performed by fauna rather than biological diversity. This study does not confirm the hypothesis that different soil management practices affect soil fauna, thus influencing the yield. However, we do confirm that the abundance and some taxa of soil fauna can influence yield. These taxa could be used to increase agricultural sustainability.

Acknowledgements

We would like to thank Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão (FAPEMA).

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