Revista Brasileira de Ciência do Solo
ISSN: 0100-0683
revista@sbcs.org.br
Sociedade Brasileira de Ciência do Solo
Brasil

Vieira da Cunha Neto, Felipe; Fernandes Correia, Maria Elizabeth; Almeida Pereira, Guilherme Henrique; Pereira, Marcos Gervasio; dos Santos Leles, Paulo Sérgio
Soil fauna as an indicator of soil quality in forest stands, pasture and secondary forest
Revista Brasileira de Ciência do Solo, vol. 36, núm. 5, octubre-noviembre, 2012, pp. 1407-1417
Sociedade Brasileira de Ciência do Solo
Viçosa, Brasil

DIVISÃO 2 - PROCESSOS E PROPRIEDADES DO SOLO

Comissão 2.1 - Biologia do solo

SOIL FAUNA AS AN INDICATOR OF SOIL QUALITY IN FOREST STANDS, PASTURE AND SECONDARY FOREST[1]

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SUMMARY

The interactions between soil invertebrates and environmental variations are relatively unknown in the assessment of soil quality. The objective of this study was to evaluate soil quality in areas with different soil management systems, based on soil fauna as indicator, in Além Paraíba, Minas Gerais, Brazil. The soil invertebrate community was sampled using pitfall traps, in the dry and rainy seasons, from areas with five vegetation types (acacia, mimosa, eucalyptus, pasture, and secondary forest). The abundance of organisms and the total and average richness, Shannon's diversity index, the Pielou uniformity index, and change index V were determined. The fauna was most abundant in the areas of secondary forest and mimosa plantations in the dry season (111.3 and 31.7 individuals per trap per day, respectively). In the rainy season, the abundance of organisms in the three vegetation types did not differ. The highest values of average and total richness were recorded in the secondary forest in the dry season and in the mimosa stand in the rainy season. Shannon's index ranged from 1.57 in areas with acacia and eucalyptus in the rainy season to 3.19 in the eucalyptus area in the dry season. The uniformity index was highest in forest stands (eucalyptus, acacia and mimosa) in the dry season, but higher in the rainy season in the pasture and secondary forest than in the forest stands. The change index V indicated that the percentage of extremely inhibited groups was lowest in the area with mimosa, both in the dry and rainy season (36 and 23 %, respectively). Of all forest stands, the mimosa area had the most abundant soil fauna.

Index terms: edaphic community, soil management, biological indicators.

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(1) Part of the Master's degree dissertation of the first author, Graduate Course of Environmental and Forest Sciences (PPGCAF) of Universidade Federal Rural do Rio de Janeiro - UFRRJ. Received for publication in February 2, 2011 and approved in October 6, 2012

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RESUMO: *FAUNA EDÁFICA COMO INDICADOR DA QUALIDADE DO SOLO EM POVOAMENTOS FLORESTAIS, PASTAGEM E FLORESTA SECUNDÁRIA*

As interações entre os invertebrados edáficos e as variações ambientais, para avaliação da qualidade do solo, são pouco conhecidas. Nesse sentido, o objetivo deste estudo foi avaliar a qualidade do solo em áreas com diferentes manejos, utilizando a fauna edáfica como indicador. O trabalho foi realizado em Além Paraíba, MG, em cinco áreas com diferentes coberturas vegetais (acácia, mimosa, eucalipt, pastagem e floresta secundária). Para a amostragem da comunidade de invertebrados do solo, foram utilizadas armadilhas "pit fall", nas estações seca e chuvosa. Foram determinados a abundância da fauna, as riquezas média e total, o índice de diversidade de Shannon, o índice de uniformidade de Pielou e o índice de mudança V. As áreas de floresta secundária e plantio de mimosa apresentaram a maior abundância da fauna no período seco (111,3 e 31,7 indivíduos por armadilha por dia, respectivamente). No período chuvoso, as áreas de floresta secundária, de mimosa e de acácia não diferiram. Os maiores valores de riqueza média e total foram quantificados na área de floresta secundária no período seco e na área de mimosa no período chuvoso. O índice de Shannon variou de 1,57 nas áreas de acácia e eucalipto, no período chuvoso, a 3,19 na área de eucalipto, no período seco. O índice de uniformidade de Pielou foi maior para os povoamentos florestais (eucalipto, acácia e mimosa), na estação seca. Já na estação chuvosa, as áreas de pastagem e floresta secundária superaram os povoamentos florestais. Pela aplicação do índice de mudança V, a área de mimosa foi a que apresentou a menor percentagem de grupos extremamente inibidos, tanto no período seco quanto no chuvoso (36 e 23 %, respectivamente). Entre os povoamentos florestais, a área de mimosa foi a que proporcionou a maior abundância de fauna edáfica.

Termos de indexação: comunidade edáfica, manejo do solo, indicadores biológicos.

INTRODUCTION

The soil-litter system is the natural habitat of various organisms, including soil fauna invertebrates. These organisms vary in size and metabolism, and they play numerous functional roles in the environment (Lavelle et al., 1994). Due to their functional diversity, the soil fauna is an important element in the process of ecosystem reestablishment (Majer et al., 2007).

One of these ecosystem processes is the recycling of nutrients by the soil fauna through the decomposition of organic matter (Mason, 1980; Haag et al., 1985; Lavelle et al., 1992). The role of the fauna in this process involves the fragmentation and redistribution of vegetation debris (Correia & Oliveira, 2000) or the indirect stimulation of microbial activity and regulation of the decomposing fungal populations (Moço et al., 2005). In addition to contributing to the decomposition of organic matter and, thus, to soil fertility, the invertebrates that inhabit the soil-litter system consume roots and make galleries and in this way influence soil aggregation as well (Correia & Oliveira, 2000).

Several of the functions of the soil fauna are associated with the variety of resources and microinhabitats of the soil-litter system (Lavelle et al., 1992; Menezes et al., 2009). Compared to mixed forest stands, monoculture areas, pastures and eucalyptus stands tend to be less rich and the predatory activity reduced (Moço et al., 2005; Silva et al., 2009). Forests with diverse vegetation or in more advanced successional stages tend to have a richer soil fauna and to be more abundant in saprophagous species and predators than forest stands in the initial stages of recovery (Menezes et al., 2009). Thus, alterations in the properties of the invertebrate community of the soil fauna reflect the development of ecosystems.

Modifications in the invertebrate community of the soil are related to variations in the environment (Correia, 2002). Variations in the vegetation composition and in soil management, litter quality, food availability, and degree of degradation or recovery of the ecosystem have a great influence on the soil invertebrate community (Moço et al., 2005; Baretta et al., 2006; Silva et al., 2006; Dias et al., 2007; Azevedo et al., 2008; Ribas et al., 2011). In general, the removal of the vegetation results in a simpler habitat, which immediately reduces food supply and diversity, and shelter and reproduction sites (Guerra et al., 1982; Souto et al., 2008; Silva et al., 2009). Additionally, the protection of the vegetation against microclimate variations is reduced, which results in high insolation, extreme soil temperatures and low moisture, making the environment less favorable for survival and reproduction (Guerra et al., 1982). The soil fauna sensitivity to environmental variations can therefore be a potential indicator of soil quality.

Biological indicators are species or groups of species that reflect the impact of habitat changes due to their sensitivity to the environmental conditions (McGeoch, 1998). The quality of the soil environment is related to its capacity to sustain biological production and to maintain or improve the environmental quality within the limits of a natural or managed system (Doran & Parkin, 1994). However, the interactions between soil invertebrate and environmental conditions are little known in the assessment of soil quality. The objective of this study was to evaluate the soil quality in stands in Além Paraíba, Minas Gerais, in areas under different soil management systems, based on soil fauna as indicator.

MATERIAL AND METHODS

This study was conducted on the Fazenda Cachoeirão, in the municipality of Além Paraíba, Minas Gerais (21º 56' 53.52" S and 42º 53' 40.42" W). The annual rainfall in the region is 1,290 mm, with a dry season from June to September. The average annual temperature is 22.3 °C (annual average maximum 28.3 °C and average annual minimum 16.3 °C). The region has a very rugged and mountainous relief and a mean altitude of 390 m asl. The vegetation cover was classified as Seasonal Semideciduous Forest (Veloso et al., 1991).

The soil quality was assessed based on soil fauna as indicator. The invertebrate community was evaluated in areas with different vegetation covers.

1. *Acacia mangium* Wild stands of 0.12 ha, initiated in November 2004, inter-row spacing of 2 x 2 m, fertilization with 100 g phosphate per seed hole. Saplings inoculated with arbuscular mycorrhiza fungi and with fungi from the rhizobium strain;

2. *Mimosa artemisiana* Heringer & Paula stands with the same area, starting date, fertilization, and type of sapling inoculation as in the *Acacia mangium* stand;

3. Stands of *Eucalyptus grandis* x *E. urophylla* of 8 ha, planted in November 2004, inter-row spacing of 2.5 x 2.0 m, and fertilization with 200 g N-P-K (04-31-04) per seed hole;

4. *Brachiaria* pasture (*Brachiaria* sp.), 15 year-pasture for dairy heifers, according to the property owner;

5. Secondary forest in an initial stage of succession; stand with the most complex structure (20 tree species identified in a flora survey) (Abel et al., 2009). According to the oldest farm residents, the secondary forest stand used to be a pasture. Grazing had ceased about 40 years before, which made the secondary succession process possible.

The fauna of the five management systems was sampled with pitfall traps (Moldenke, 1994) using the modified model of Price & Shepard (1980), as proposed by Aquino et al. (2006). This method allows measuring the abundance of groups of the soil mesofauna and macrofauna, as the traps can catch animals that move about on the soil. Nine traps containing 4 % formaldehyde, for the preservation of the organisms, were installed in each stand. Sampling was conducted in September 2008 (end of dry season) and in March 2009 (end of the rainy season), since the season influences the environmental quality in the different systems and properties of the soil fauna community such as density, spatial distribution, richness and diversity (Moço et al., 2005; Menezes et al., 2009; Silva et al., 2009). The traps were buried in the soil (top end even with the soil surface) and left in the field for 10 days. Thereafter, the samples were taken to the laboratory and the captured animals washed with running water to remove the preserving agent. The samples were kept in plastic pots with alcohol (70 %) for the preservation of the morphological structure of the organisms.

Arthropods were identified in the largest taxonomic groups. The term group refers to either taxonomic levels (class, order or family) or stage of development (larva or adult, in some cases). This classification is necessary because invertebrates may have different functions in the nutrient cycling process, depending on their development stage. The data were converted into number of individuals per trap per day. This parameter indicates the fauna abundance, depending basically on the mobility of the groups (Moldenke, 1994), calculated by the equations:

$$\text{Group abundance} = \Sigma\, (\text{n}^o \text{ of ind./n}^o \text{ of traps})/\text{n}^o \text{ of days} \quad (1)$$

$$\text{Total abundance} = \Sigma\, (\text{total n}^o \text{ of ind./n}^o \text{ of traps})/\text{n}^o \text{ of days} \quad (2)$$

where group abundance = mean number of individuals of each group caught per trap per day (ind. per trap day^{-1}); total abundance = mean number of individuals caught per trap per day (ind. per trap day^{-1}); nº of ind. = number of individuals of the group; nº of traps = number of traps; total nº of days = number of days the traps remained in the field; total nº of ind. = total number of individuals of the soil fauna.

Aside from the abundance of the soil fauna, diversity was also assessed as a parameter of soil quality. In the diversity analysis, ecological indices of mean richness (mean number of groups caught per stand), total richness (total number of groups found per stand, regardless of the trap), Shannon's diversity index and the Pielou equitability index were used. Shannon's diversity is a function of the community group richness and the relative distribution of abundance of individuals between the groups (Moço et al., 2005). The diversity obtained from Shannon's index varies with the equitability obtained from the Pielou uniformity index. The Pielou index has been reported as the most stable parameter, and is therefore better suited for comparisons of soil fauna community in litter than other diversity measurements (Moço et al., 2005). In addition to these indexes, the change index (V) was determined for the evaluation of the changes in the soil fauna under the different soil management systems (Wardle & Parkinson, 1991). The change index (V) is a good indicator of management conditions, as it can indicate disturbance or stability of the soil fauna (Correia, 2002). The following equation was used to calculate the change index:

$$V = \frac{2dM}{dM + dNM} - 1 \quad (3)$$

where V = change index; dM = density of individuals in managed systems; dNM = density of individuals in non-managed systems.

The secondary forest was taken as a non-managed system and used as a reference. The groups were ranked based on the V index (Table 1).

Statistical analysis

The sampling design in the five stands (acacia, mimosa, eucalyptus, pasture, and secondary forest) was random, with nine repetitions. The influence of litter on fauna abundance and diversity was evaluated by the analysis of abundance and mean richness data with the Kruskal-Wallis test ($p < 0.05$). Two evaluations were performed: stands in each seasons and seasons in each stand. To explain the fluctuation in the population of soil fauna individuals (Mussury et al., 2008), multivariate cluster analysis was performed by the Ward method with software STATISTICA 7.0 (StatSoft, 2004). Clustering was done based on abundance in the rainy season, as the differences between management systems were greater in this season (Moço et al., 2005). The Euclidian distance was also used as a measure of dissimilarity and to cluster the five stands in a dendrogram (Costa & Aquino, 2005). Principal Component Analysis (PCA) was also carried out to evaluate possible patterns of groups of response variable data (soil fauna in this case) in relation to the treatment (management system) (ACP). Canoco for Windows, version 4.5, was used (Ter Braak & Smilauer, 2002).

RESULTS AND DISCUSSION

Abundance, composition and diversity

Fauna abundance ranged from 17.5 ± 1.8 to 111.3 ± 10.7 ind. per trap day^{-1} in the dry season and from 40.3 ± 4.9 to 80.1 ± 9.5 ind. per trap day^{-1} in the rainy season. In the dry season, fauna was most abundant in the secondary and mimosa forest and lowest in the acacia stand. The pasture and eucalyptus stands had intermediate abundance, in comparison with the others. In contrast to the dry season, fauna abundance increased in the four management systems in the rainy season. This pattern was clearer in mimosa and acacia stands, which were similar to the secondary forest stand in this season (Table 2).

Values followed by the same small letter in columns and the same capital letter in rows are statistically equal by the Kruskal-Wallis test ($p < 0.05$). Individuals per trap per day and mean number of individuals collected per trap per day ± standard error.

Several factors influenced the soil invertebrate community, particularly season and microclimate conditions of the sampling site and resource availability (Menezes et al., 2009; Calvi et al., 2010). With regard to the seasons, rain contributes to a more favorable environment for the biota and stimulates biological activity (Moço et al., 2005). In contrast, microclimatic conditions had a lower influence on the vertical distribution of invertebrates in the soil-litter system (Correia & Oliveira, 2000; Silva et al., 2009). The litter production in forest stands was reduced in the drier periods (Fernandes et al., 2006; Diniz et al., 2011), decreasing the food availability for fauna (Correia & Oliveira, 2000). The reduction of litter leads

Table 1. Ranking according to the change index V, indicating inhibition or stimulation of abundance of soil fauna groups in response to the soil management system (modified by Wardle, 1995)

Category	Index V
Extreme inhibition (EI)	$V < -0.67$
Moderate inhibition (MI)	$-0.33 > V > -0.67$
Slight inhibition (MdI)	$-0.05 > V > -0.33$
No change (NC)	$-0.05 < V < 0.05$
Slight stimulation (MdS)	$0.05 < V < 0.33$
Moderate stimulation (MS)	$0.33 < V < 0.67$
Extreme stimulation (ES)	$V > 0.67$

Table 2. Soil fauna abundance ± standard error in the dry and rainy seasons in *Acacia mangium* (acacia), *Mimosa artemisiana* (mimosa), *Eucalyptus grandis x E. urophylla* (eucalyptus), pasture, and secondary forest

Stand	Abundance	
	Dry season	Rainy season
	ind. per trap day^{-1} ± e	
Acacia	17.5 ± 1.8 cB	44.8 ± 5.5 abA
Mimosa	31.7 ± 1.9 abB	76.5 ± 9.7 abA
Eucalyptus	19.9 ± 1.9 bcB	39.7 ± 7.8 bA
Pasture	29.6 ± 4.3 bcB	40.3 ± 4.9 bA
Secondary forest	111.3 ± 10.7 aA	80.1 ± 9.5 aB

to reduction in moisture and makes the fauna migrate to soil layers below the surface, resulting in a decrease in the biological activity at the surface of the soil-litter system (Silva et al., 2009).

Thus, it is possible that the seasonal reduction in the variation of abundance from the dry to the rainy season is related to the creation of more favorable environments in the different stands by rain. This hypothesis becomes more plausible when one analyzes the variation of the standard error of abundance from the dry season to the rainy season. The abundance standard error increased in the three stands, mainly in the eucalyptus (9.9 %) and mimosa (6.6 %) stands, where the variation was greater. The variation of the standard error of abundance was lower in the pasture stand (Figure 1).

The standard error of abundance represents the variability of fauna abundance around the mean abundance in the different management systems and seasons. An increase in the standard error with season in the three forest stands indicates the spatial variability of the soil invertebrate community from the dry to the rainy season. This pattern illustrates the effect of the seasons. In the rainy season, the high rainfall resulted in an increase in resource supply and created microenvironments more favorable to soil fauna (Moço et al., 2005). In the case of the legume stands, acacia and mimosa, this pattern was greater due to the greater availability of resources. The biomass of acacia and mimosa species has a lower C-to-N ratio and therefore provides the fauna with a better litter quality (Dias et al., 2007). Thus, the establishment of better conditions and a greater resource supply stimulate the biological activity in the dry season. This pattern may be due to the vertical migration of some fauna groups to the surface of the soil-litter system (Silva et al., 2009).

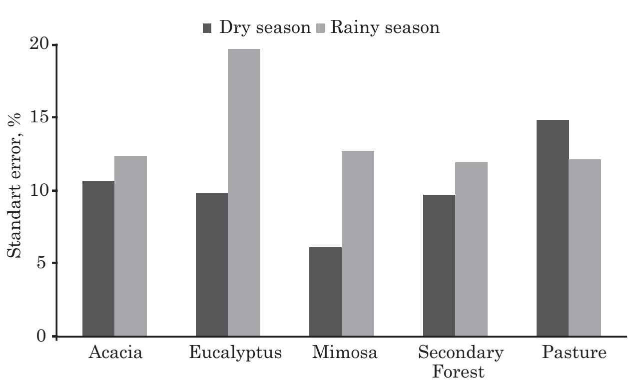

Figure 1. Seasonal variation of the standard error of total abundance of the soil fauna in *Acacia mangium* (acacia), *Mimosa artemisiana* (mimosa), *Eucalyptus grandis* x *E. urophylla* (eucalyptus) stands, pasture, and secondary forest.

The fauna abundance was therefore greatest in the mimosa stand in both seasons. This indicates greater biological activity in the soil under this litter, mainly in the rainy season. This greater biological activity of the fauna influences the soil quality in the mimosa stand, which basically depends on the relative abundance of fauna groups and the function they fulfill in the environment. The groups with the highest abundance of fauna groups in the mimosa stand were Acari, Collembola (Entomobryomorpha) and Formicidae. This pattern was similar in the other stands (Table 3).

Acari and Collembola are microphagous, that is, they act influence the nutrient cycling process indirectly by controlling the populations of decomposer bacteria and fungi (Wardle & Lavelle, 1997; Moço et al., 2005). Formicidae can be either saprophagous and influence nutrient cycling directly, or predators and regulate the populations of other invertebrate groups of the fauna (Moço et al., 2005). The mimosa stand had a good trophic community structure, with great population control, especially of decomposers, and reduced saprophagous activity. This pattern also applied to the other stands, which had similar soil fauna communities to those of the mimosa stand and greater abundance of Collembola suborders, e.g., of Poduromorpha and Symphypleona.

With regard to the group composition, it is important to point out that the predator group Pseudoscorpionida was found only in the soil fauna of the secondary forest. Moço et al., (2005) also reported the occurrence of Pseudoscorpionida in the invertebrate community of a preserved forest stand, but not in non-preserved, secondary forest fragment (capoeira), eucalyptus and pasture stands. This pattern may be due to the type of environment. Forest systems evolve and tend toward a dynamic equilibrium, with a greater structural complexity, functional redundancy, and greater control of ecologic processes (Begon et al., 2005). In this stage, the occurrence of predators like Pseudoscorpionida indicates a more controlled trophic structure, with redistribution of energy among a greater number of species (Begon et al., 2005). This good fauna community structure pattern is evident in the greater abundance of Araneae in the secondary forest soil. Araneae is also a predator group, indicating the functional redundancy of the system. The occurrence of Pseudoscorpionida in the invertebrate community of the secondary forest only suggests the potential of this group as an indicator of good soil quality.

In relation to the fauna diversity, the ecological indexes also varied with season in the management systems. In the dry season, the invertebrate groups of pasture were less rich than in the secondary forest. The soil fauna richness in acacia, mimosa and eucalyptus stands was intermediate in relation to those of pasture and secondary forest stands. In the rainy season, fauna richness increased in the pasture and mimosa stands and was greater than in the

Table 3. Soil fauna abundance of taxonomic groups in the dry (DS) and rainy seasons (RS) in *Acacia mangium* (acacia), *Mimosa artemisiana* (mimosa), *Eucalyptus grandis* × *E. urophylla* (eucalyptus), pasture, and secondary forest (SF)

Taxonomic group	Acacia		Mimosa		Eucalyptus		Pasture		Secondary forest	
	DS	RS	DS	RS	DS	RS	DS	RS	DS	RS
	ind. per trap day^{-1}									
Acari	2.32	3.31	8.69	14.45	0.84	3.36	6.14	6.02	16.12	8.08
Araneae	0.54	0.23	0.91	0.36	0.64	0.28	0.78	0.39	1.66	0.69
Auchenorryncha	0.20	0.09	0.78	0.21	0.40	0.00	0.16	0.43	0.39	0.14
Blattodea	0.03	0.06	0.00	0.13	0.03	0.31	0.01	0.04	0.10	0.03
Chilopoda	0.00	0.06	0.00	0.04	0.00	0.01	0.00	0.03	0.04	0.10
Coleoptera	0.76	0.26	1.07	0.25	1.06	0.24	0.54	0.26	2.50	1.39
Diplopoda	0.02	0.08	0.03	0.06	0.00	0.05	0.05	0.04	0.22	0.14
Diptera	0.64	0.16	0.67	0.06	0.45	0.03	0.23	0.18	1.36	1.19
Entomobryomorpha	1.97	32.50	3.43	43.79	3.54	27.66	2.69	20.16	43.96	39.70
Formicidae	5.98	5.63	9.36	11.65	4.08	6.05	16.30	7.02	6.68	7.57
Heteroptera	0.02	0.01	0.08	0.16	0.00	0.00	0.00	0.06	0.46	0.03
Hymenoptera	0.80	0.21	1.49	0.36	0.35	0.06	0.84	0.46	0.74	1.77
Isopoda	0.32	0.25	1.60	0.36	0.45	0.24	0.25	0.22	0.03	0.14
Isoptera	0.04	0.00	0.01	0.09	0.05	0.08	0.05	0.11	0.06	0.04
Coleoptera larva	0.13	0.23	0.10	0.39	0.11	0.05	0.06	0.71	0.59	0.29
Diptera larva	0.00	0.24	0.04	0.73	0.00	0.03	0.00	0.19	0.19	1.14
Lepidoptera larva	0.00	0.15	0.02	0.44	0.01	0.05	0.05	0.03	0.00	0.03
Neuroptera larva	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.29
Hymenoptera larva	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Trichoptera larva	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Lepidoptera	0.01	0.01	0.02	0.01	0.04	0.00	0.00	0.01	0.14	0.07
Mantodea	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Orthoptera	0.20	0.34	0.23	0.23	0.19	0.15	0.28	0.47	0.61	0.24
Poduromorpha	2.48	0.51	1.19	1.55	3.00	0.20	0.61	1.39	5.52	4.06
Pseudoscorpionida	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04
Psocoptera	0.24	0.00	0.21	0.08	0.61	0.06	0.10	0.06	0.02	0.01
Sternorryncha	0.02	0.00	0.04	0.10	0.03	0.05	0.03	0.44	0.02	0.00
Symphyla	0.00	0.05	0.03	0.05	0.00	0.05	0.00	0.00	0.00	0.00
Symphypleona	0.71	0.43	1.66	0.30	3.99	0.70	0.51	0.81	29.91	14.01
Thysanoptera	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Trichoptera	0.06	0.06	0.06	0.48	0.03	0.03	0.00	0.82	0.03	0.09
Total	17.52	44.86	31.72	76.54	19.91	39.73	29.66	40.36	111.37	80.13

secondary forest, but decreased in the eucalyptus stand (Table 4).

Litter is a variable that has a great influence on fauna group richness (Moço et al., 2005). Management systems with homogeneous vegetation do not attract native fauna organisms as much as systems with forest species (Ribas et al., 2011). Silva et al., (2009) investigated the effects of soil management systems on the soil invertebrate community of a secondary forest and manioc monoculture and reported that richness was lower in the manioc culture, particularly in the dry season. They attributed this pattern to the uniformity of the manioc monoculture, which reduces the diversity of habitats available to the fauna, when compared to the secondary forest. This pattern was also found in eucalyptus and pasture stands, where the fauna group richness was half of that of secondary forest (Moço et al., 2005). In contrast, in forest systems, the greater vegetation diversity resulted in a more heterogeneous litter layer (Menezes et al., 2009; Machado, 2011). This allows the environment to sustain a greater diversity of niches and, therefore, a greater number of fauna groups (Bazzaz, 1975; Tews et al., 2004; Menezes et al., 2009).

Table 4. Group richness, Shannon's diversity index (H'), and the Pielou uniformity index (U) in dry and rainy season in *Acacia mangium* (acacia), *Mimosa artemisiana* (mimosa), *Eucalyptus grandis* x *E. urophylla* (eucalyptus), pasture, and secondary forest

Stand	Richness		U	H'	Richness		U	H'
	Mean	Total			Mean	Total		
	Dry season				Rainy season			
Acacia	14.6 abA	22	0.69	3.09	14.9 abA	22	0.35	1.57
Mimosa	15.9 abB	23	0.66	2.99	18.9 aA	28	0.41	1.97
Eucalyptus	14.4 abA	23	0.70	3.19	12.4 bA	22	0.35	1.57
Pasture	13.0 bB	19	0.51	2.18	17.5 aA	24	0.53	2.45
Secondary Forest	17.0 aA	24	0.54	2.46	17.0 aA	25	0.52	2.44

Values followed by the same small letter in columns and the same capital letter in rows are statistically equal by the Kruskal-Wallis test ($p < 0.05$).

The soil fauna community richness in management systems which have grasses as main vegetation tends to be lower than in forest systems (Moço et al., 2005; Menezes et al., 2009). This is the case of the pasture, which is covered with brachiaria. Pasture has no understory, nor is litter formed, as in the managed mimosa, acacia and eucalyptus forests. One consequence is that pasture tends to form a less heterogeneous habitat, compared to the other systems. Thus, it is probable that the heterogeneity of the pasture habitat was limited by the capacity of the system to attract or support a larger number of fauna groups. This led to lower fauna richness in the pasture stand during the dry season. In the rainy season, the better environmental conditions and the creation of more favorable microenvironments resulted in an increase in the soil fauna richness of the pasture stand (Moço et al., 2005), especially due to vertical migration of fauna groups to the surface of the soil-litter system (Silva et al., 2009). Besides the vertical migration, the fauna organisms can move horizontally between adjacent ecosystems. Thus, the increase in the pasture fauna richness can also be related to migration from adjacent environments.

In contrast to the fauna group richness of the other systems, there was a decrease in the eucalyptus stand, which was probably associated with litter production. In the evaluation of litter production in 7 - 10-year-old *E. saligna* stands by Poggiani (1985) and in 7-year-old *E. grandis* stands by Schumacher (1992), the deposition of deciduous material and nutrients was greatest at the end of spring and summer, in the warmest and wettest periods. This pattern shows that the season of greatest litter production in eucalyptus stands coincides with the rainy season, while in areas with native species, litter production is greatest in drier periods (Fernandes et al., 2006; Diniz et al., 2011). Litter input in eucalyptus stands tends to be less varied in the rainy season, which results in greater homogeneity of the soil-litter system, in comparison to the dry season. As a result, the soil fauna group richness decreased in the eucalyptus stand in the rainy season.

Seasonal variation of the diversity index was also observed. In the dry season, the diversity index of soil invertebrate communities in forest stands was greater even than of secondary forest. The opposite was observed in the rainy season, when the soil fauna diversity in the forest stands decreased (Table 4).

In contrast to group richness, the diversity index takes into account the community equitability, given by the Pielou uniformity index. In the dry season, the fauna communities of the forest stands were more uniform than those of the pasture and the secondary forest. However, in the rainy season, the uniformity of the forest stands decreased due to the variation in the abundance of some groups from the dry to the rainy season. In the eucalyptus stand, Acari became four times more abundant than in the rainy season. The abundance of Entomobryomorpha increased significantly, 16 times in the acacia stand, and over 12-fold in the mimosa stand (Table 3). This increase in the frequency of some groups in the rainy season led to a lower equitability of the soil fauna community in forest stands, which resulted in lower community diversity.

Variations in the fauna community diversity affect the management systems and the soil quality. An increase in diversity is related to an increase in functional redundancy. The important groups of the system can be replaced by others from the community with the same functional role (Begon et al., 2005). Thus, there is a greater possibility that the community will respond differently to environmental disturbances, resulting in greater environment stability (Correia, 2002; Begon et al., 2005). The greater diversity observed in the rainy season indicates an increase in stability in the forest stand management systems in the dry season. This may be related to the characteristic conditions of the dry season, which is less favorable to the fauna. This greater stability of the soil fauna in forest stands increases either the resistance or the regeneration capacity of the systems to environmental disturbances. As the soil fauna is formed by a decomposer system and other organisms, one can infer that greater resilience is mainly related to organic matter decomposition, nutrient transfer to the soil, and thus, OM recycling and energy flow in the systems.

V Index

The fauna community of the four stands had a V index of extreme or moderate inhibition in both the dry and rainy seasons. In the dry season, inhibition was not extreme in the pasture only. In this system, the variation of the V index between extreme and moderate inhibition was low in relation to the other systems. In contrast to the dry season, in the rainy season, only the eucalyptus stand did not have a greater number of groups with moderate inhibition. In this system, a seasonal increase in extreme inhibition was observed from the dry to the rainy season. Inhibition was lower in the rainy season, when a greater number of groups became moderately inhibited in the pasture and in the mimosa stand (Table 5).

In the dry season, inhibition was lower in the pasture area only. In this system, the variation of the V index between extreme and moderate inhibition was low in relation to the other systems. In the evaluation of the inhibition or stimulation of the soil fauna using the V index in crop, pasture, fallow, and rain forest stands with different ages, Correia et al. (2004) demonstrated that this index is a good indicator of management conditions, as it expresses the disturbance or stability level. In crop and pasture stands, they found that 50 % or more of the fauna groups were extremely inhibited. In the 5-year-old fallow areas, the inhibition/stimulation pattern was similar to that found in forests after 15 and 30 years of recovery. In a 1-year-old fallow area, the soil fauna community inhibition was lower. According to the authors, this reduction in inhibition in younger fallow areas was due to the recovery of the richness and the density of the soil fauna groups in the first year of evaluation.

In the rainy season, there is a greater amount of litter-forming material in eucalyptus stands (Fernandes et al., 2006; Diniz et al., 2011). It is possible that this factor reduces the heterogeneity structure and composition of the litter layer. Similarly as observed for group richness, the greater inhibition of the soil fauna in the eucalyptus stand during the rainy season may be due to a greater litter production in this season.

The difference between these two types of inhibition in the other systems was lower in the rainy season due to the better conditions and resources available to the fauna, with lower temperature and moisture variation and a greater food supply (Moço et al., 2005; Menezes et al., 2009; Silva et al., 2009).

Table 5. Change index (V) of *Acacia mangium* (acacia), *Mimosa artemisiana* (mimosa), *Eucalyptus grandis* x E. *urophylla* (eucalyptus) and pasture compared to secondary forest, as a reference of an unmanaged system

Manage. system	EI*	MI**	EI*	MI**
	Dry season		Rainy season	
	% (nº of groups)			
Acacia	40 (10)	60 (15)	39 (10)	61 (16)
Eucalyptus	40 (10)	60 (15)	50 (13)	50 (13)
Mimosa	36 (9)	64 (16)	23 (6)	77 (20)
Pasture	48 (12)	52 (13)	27 (7)	73 (19)

*EI - Extreme inhibition, **MI - Moderate inhibition (given as number of groups and percentage of groups per category).

Cluster analysis

In general, the clustering of the fauna community in the management systems and secondary forest corresponded to the abundance, richness, diversity and stimulation/inhibition patterns of the soil fauna community. The systems with the values closest to those of the extremely inhibited groups were those nearest to each other. The eucalyptus and acacia stands were about 5 % nearer to each other. The mimosa stand, with a similar abundance and richness as in the secondary forest and lower than of the fauna groups between the systems in the rainy season, was clustered at a distance greater than 15 % from the secondary forest, and over 30 % further away from the other management systems. The pasture stand, with a diversity similar to that of the secondary forest and low fauna inhibition, was at an intermediate distance from the systems, but was more similar to the eucalyptus and acacia stands (Figure 2).

Principal Component Analysis (PCA)

Axis 1 explained 18.2 % of the data variability, while axis 2 explained 28.4 % (totaling 46.6 % of the total variability). A greater number of groups were associated with the secondary forest. The mimosa stand had the greatest fauna community, compared to the other stands, especially the acacia and eucalyptus stands. These two stands had a smaller number of groups. The pasture stand had a mean value (Figure 3).

The PCA results are consistent with the fauna richness and abundance data of the systems in the seasons evaluated. In general, the secondary forest and mimosa stands had greater total group abundance, as well as greater richness, while the eucalyptus and acacia stands had lower values. Figure 3 shows that the vectors of these two stands are

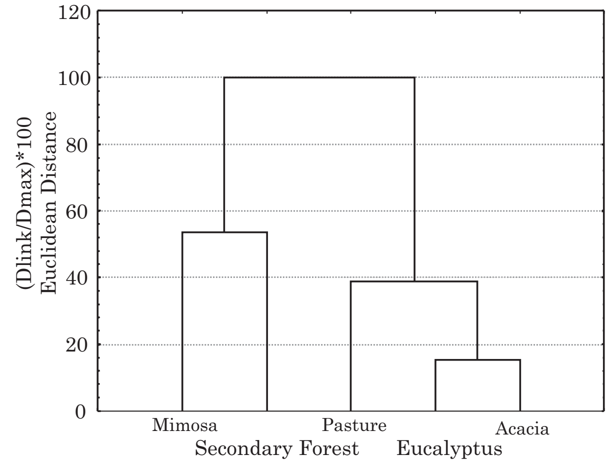

Figure 2. Dendrogram of dissimilarities of abundances and taxonomic groups of soil fauna in *Acacia mangium* (acacia), *Mimosa artemisiana* (mimosa), *Eucalyptus grandis* x E. *urophylla* (eucalyptus), pasture and secondary forest in the rainy season.

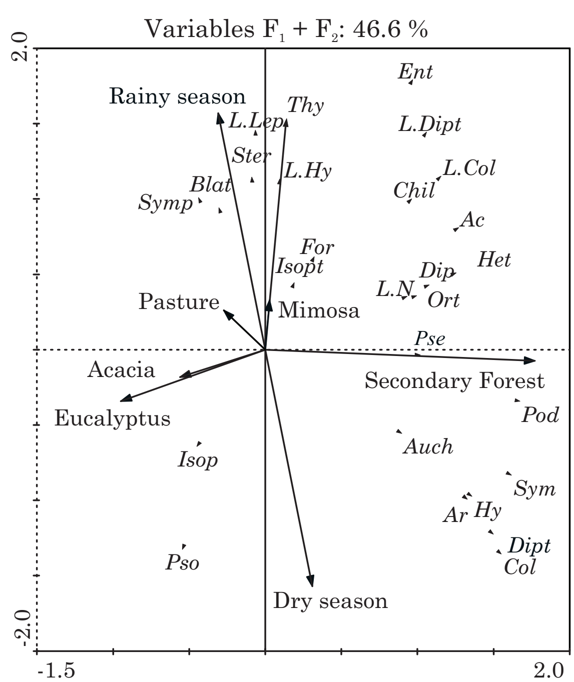

Figure 3. Principal Component Analysis (PCA) for the abundance of soil fauna groups in the stands studied in the dry and rainy seasons. Ac = Acari, Ar = Araneae, Auch = Auchenorryncha, Blat = Blattodea, Chil = Chilopoda, Col = Coleoptera, Dip = Diplopoda, Dipt = Diptera, Ent = Entomobryomorpha, For = Formicidae, Het = Heteroptera, Hy = Hymenoptera, Isop = Isopoda, Isopt = Isoptera, L.Col = L. Coleoptera, L.Dipt = L. Dipteran, L.Lep = L. Lepidoptera, L.N = L. Neuroptera, L.Hy = L. Hymenoptera, Ort = Orthoptera, Pod = Poduromorpha, Pse = Pseudoscorpionida, Pso = Psocoptera, Ster = Sternorryncha, Symp = Symphyla, Sym = Symphypleona, Thy = Thysanoptera.

opposite to those of the secondary forest and mimosa stands. Likewise, the rainy season had a greater number of groups than the dry season, indicating that the number of groups and individuals and the fauna community abundance in the rainy season were greater.

In terms of fauna composition, Diptera, Orthoptera, Neuroptera larvae, Pseudoscorpionida, Poduromorpha, Auchenorryncha, Symphypleona were more strongly represented in the secondary forest. Isoptera and Formicidae were better represented in the mimosa stand and Isopoda in the acacia stand, and Psocoptera, mainly in the eucalyptus stand (Figure 3).

CONCLUSIONS

1. Compared to the other systems, the trophic structure of the soil fauna community in the mimosa stand was good, with a great population control, particularly of decomposer organisms, and reduced saprophagia.

2. Pseudoscorpionida were found only in the invertebrate community of the secondary forest, which suggests the potential of this group as indicator of good soil quality.

3. The formation of more favorable environments in the rainy season reduced the variation of abundance and increased the diversity of the soil fauna community.

4. The greater stability of the soil fauna in the forest system in the dry season improved the soil quality, improved the soil quality by increasing increasing the resistance to environmental disturbances and the regeneration capacity of the system.

5. The variation in the soil fauna properties between the dry and the rainy seasons indicates that seasonal variation has a great influence on this community.

6. The differences in soil fauna were greater among stands in the rainy season, which is therefore more indicated for the assessment of soil quality.

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