COMPOSITION OF THE SOIL FAUNA COMMUNITY AND LEAF LITTER STOCK IN AGRO-FORESTRY SYSTEMS AND SECONDARY FORESTRY

COMPOSIÇÃO DA COMUNIDADE DA FAUNA DO SOLO E ESTOQUE DA SERAPILHEIRA FOLIAR EM SISTEMAS AGROFLORESTAIS E FLORESTA SECUNDÁRIA

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ABSTRACT: Agro-Forestry Systems (AFS), in addition to being a means of providing income, can be considered an alternative way of helping conserve biodiversity, both above and below ground. The aim of this study was to evaluate the accumulation of tree leaf litter and its nutrient content as well as the composition of fauna in the soil-litter layer in two Agro-Forestry Systems (AFS-1 and AFS-2), using as reference an area of secondary Forest (SF), in the Quilombola do Campinho da Independência community, Paraty, in the state of Rio de Janeiro (RJ), Brazil. The collection of accumulated leaf litter and soil-litter fauna was carried out from four sample points in each area and at two different seasons of the year, the rainy and the dry season. The leaf litter stock and its nutrient content (Ca, Mg, P, K and N) were measured. The extraction of fauna was carried out according to Tüllgren's method, modifying the Berlese funnel. The stock of accumulated leaf litter differed between the two areas only in the rainy season; the amounts were smaller in AFS-2. In general, the Agro-Forestry Systems were very similar to the secondary forest in terms of levels and/or stock of nutrients in the majority of cases, at least in one of the seasons studied. The composition of the soil fauna groups in the Agro-Forestry System (AFS-1 and AFS-2) had a high degree of similarity to that found in the forest, and these systems mainly favour the populations of groups like Collembola and Formicidae.

KEYWORDS: Agro-ecology. Soil conservation. Environmental services.

INTRODUCTION

For a long time, agricultural development was linked to environmental degradation (TSCHARNTKE et al., 2011) since, in order to carry out agricultural activities, it was necessary to remove vegetation from forested areas. In tropical ecosystems, as a result of the reduction in nutrient cycles, this practice has led to soil exhaustion, simplification of the forest environments and new challenges for agricultural sustainability (TSCHARNTKE et al., 2011). In Brazil, this cycle of land-occupation and land-use has resulted in the fact that many biomes are at different stages of degradation, and one of these biomes is the Atlantic rainforest (DEAN, 1996).

In the Atlantic rainforest, a large part of the remaining vegetation is protected through the Units of Conservation (UC). However, the majority of these units are populated by traditional communities, and the agricultural and extractive activities of these communities are often carried out in conflict with the UC managers. One of the proposals put forward to minimize these conflicts is the use of agricultural practices, such as Agro-Forestry Systems (AFS), which integrate the use of arboreal and agricultural species and which contribute to reconciling conservation with food production (MULLER, 2015; DOLLINGER; JOSE, 2018).These systems help encourage sustainability, as they use practices which are oriented by the principles of the ecological processes present in areas of production and in the wider context, of which these areas are a part (GLIESSMAN, 2001; SOUZA et al., 2012).

Therefore, it is essential to understand in what ways the different systems of use and management affect the quality of the environmental and ecosystem processes. Biological attributes, such as the abundance, diversity and composition of soil fauna as well as the dynamics of leaf litter, can be used as quality indicators, either in characterizing the state of degradation in a specific area or in accompanying the evolution of an environmental recuperation process (ZHANG et al., 2013; SILVA et al., 2016; N'DRI et al., 2018).

Leaf litter is directly related to the nutrient cycle as it is the main way organic material and

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mineral elements can be transferred from the vegetation to surface soil (XU; HIRATA, 2002). Its accumulation on top of the soil depends on rates of deposition and decomposition, factors which are affected by the type of vegetation, the quality of the substrate, the nature of the decomposer community, the soil and weather conditions, as well as the land use and land management systems (SANCHES et al., 2009; SILVA et al., 2012a; LIMA et al., 2015). Systems which have the greatest diversity of species lead to higher rates of accumulation of good quality plant residue, thus improving the nutrient cycle. The accumulation of leaf litter gives the system greater stability, and, together with the soil, controls various processes that are fundamental in the dynamics of the ecosystems, such as primary production and the liberation of nutrients (PIRES et al., 2006).

Soil fauna can be described as the group of invertebrate organisms which colonize the environment formed by the layer of surface organic residue (leaf litter) and the soil itself (DONNAGEMA et al., 2010). There is a great diversity among these organisms, which means they affect processes that are important both for the soil and the functioning of the ecosystem (MOÇO et al., 2010; MANHÃES et al., 2013). Soil fauna is sensitive to the changes which occur in the environment, whether these are natural, seasonal, or those resulting from the type of soil management adopted (BARETTA et al., 2014; CAMARA et al., 2017; SILVA et al., 2018). Studies have shown the impact on these organisms of different types of land management (MOÇO et al., 2010; MANHÃES et al., 2013; SILVA et al., 2013; BARETTA et al., 2014), pointing out that those based on the contribution of organic material and the maintenance of a layer (leaf litter) covering the soil, have the best chances of maintaining abundance and diversity in soil fauna (MOÇO et al., 2009).

There have been very few studies into the effects of different land-use systems on the abundance and diversity of soil fauna, and on the dynamics of leaf litter in areas belonging to small landowners or traditional communities (PAULI et al., 2011; SILVA et al., 2016). The hypothesis is that agroforestry systems are able to promote the restoration of the litter dynamics and biological soil attributes. Therefore, the aim of this study was to evaluate the stock of accumulated leaf litter and its nutrients, in addition to the composition of fauna in the soil-litter layer, in two Agro-Foresty Systems (AFS-1 and AFS-2), using as reference an area of secondary forest (SF) in the Quilombola do Campinho da Independência community, Paraty - RJ.

MATERIAL AND METHODS

Study area

The research was carried out at the Quilombo do Campinho da Independência (QCI), situated in the Paraty-Mirim district, part of the Paraty municipality in the state of Rio de Janeiro (RJ), Brazil, located at the geographical coordinations44º 42’ W, 23° 17’ S, at an altitude of 60 m above sea level. The climate of the region is CWa, according to the Köppen classification, with moderate temperatures and hot, wet summers. The Quilombolies in the centre of the Environmental Protection Area (EPA) of Cairuçu on the margins of the Carapitanga and the BR 101 highway. The native vegetation which remains are slope forests, classified as Submontane Dense Ombrophylous (Projeto Radam, 1983). The rainfall during the six driest months (April-September) of 2012 was 360 mm and during the wettest (October-March) 2012/2013it was 476 mm (Inmet, 2013).

The study area was composed of two Agro-Forestry Systems (AFS-1 and AFS-2), located in the same area and near (approximately 15 meters) from a section of secondary forest which is about one hectare in size. The chemical attributes of the soil in all three areas are shown in Table 1.

Table 1. Chemical attributes of the soil (layer 0-0.05 m) in the Agro-Forestry Systems (AFS-1 and AFS-2) and in the secondary forest (Forest), in the municipality of Paraty/RJ.

Systems	pH (H_2O)	Ca	Mg	Al	K	P	TOC*
		$cmol_c\ kg^{-1}$				$mg\ kg^{-1}$	$g\ kg^{-1}$
Forest	4.69	3.89	2.55	0.59	0.18	4,27	43,40
AFS-1	4.91	4.30	2.75	0.45	0.29	4,02	35,55
AFS-2	5.32	2.90	2.08	0.16	0.13	3,68	32,65

*TOC – total organic carbon

The Agro-Forestry Systems are located inside an Area of Permanent Preservation (APP) on the margins of the river Carapitanga. In 2003, these Systems were set up as experimental units by the Sistemas Agroflorestais Regenerativos e Análogos, with the aim of finding sustainable alternatives for income generation in traditional communities (PIÑA-RODRIGUES, 2006). The area taken up by the AFS was used for the production of banana (*Musa* sp.) and cassava (*Manihotesculenta*). The AFS were planted with plots of 20 × 20 m, with single plantations (one seedling per hole), using tree leguminous species (in AFS-1) and non-leguminous species (in AFS-2). At the present time, as a result of forest regeneration, these two Systems have a composition (Table 2) which is somewhat different from the one originally planted, which can be found in Tavares (2014).

Table 2. Species taken from the Agro-Forestry Systems (AFS-1 and AFS-2) in the community of Campinho da Independência in the municipality of Paraty/RJ in 2013.

AFS-1	AFS-2
Species which help renew fertility	
Ingá (*Inga laurina*) (Leguminosae); Embira de sapo (*Lochocarpus huilleminianus* (Tull.) Malme) (Leguminosae)	Urucum (*Bixa orelana* L.); Pau viola (*Cytharexyllum myruanthum* Cham)
Species which have long-cycles and are fruit-bearing	
Abiu (*Pouteria macrophylla* Radkl.); Jackfruit (*Artocarpus heterophyllus* Lam.); Star (*Averrhoa carambola* L.); Guava (*Psidium guajava*); Soursop (*Annona muricata*)	Abiu (*Pouteria macrophylla* Radkl.); Lemon (*Citrus* sp.); Jackfruit (*Artocarpus heterophyllus* Lam.); Star (*Averrhoa carambola* L.); Guava (*Psidium guajava*); Soursop (*Annona muricata*)
Species which can be potentially used for their seeds, oils and hardwood	
Guapuruvu (*Schizolobium parahyba* (vell) Blake) (Leguminosae); Araribá (*Centrolobium tomentosum* Guill. Ex Benth.) (Leguminosae); Jatobá (*Hymenaea courbaril* L.) (Leguminosae); Copaíba (*Copaíba langsdorfii* Desf) (Leguminosae)	Cedro (*Cedrelaodorata*); Canela (*Nectranda lanceolata* Ness et Mart. ex Nees); Jequitibá (*Cariniana legalis* (Mart.) Kuntze); Bicuiba (*Virola bicuhyba* (Schott) Warb.);
Species which come from natural regeneration	
Terminalia sp.	*Clidemia urceolata*; Embira de sapo (*Lochocarpus huilleminianus* (Tull.) Malme); Ingá (*Inga edulis* e *Inga laurina*) (Leguminosae); *Miconia calvescens*; *Piptadenia paniculata*; *Schinus terebinthifolius*
Species which entered the system after the original planting	
Jussara (*Euterpe edulis* Mart.)	Paineira (*Ceiba speciosa*); Jussara (*Euterpe edulis* Mart.)

Adapted of Tavares (2014)

Samples and Analyses

The collection of samples was carried out nine days after the AFS were planted, in September 2012 (dry season) and then in February 2013 (rainy season). Four sample points in each area were set up for the collection of the accumulated leaf litter, using a metal gauge measuring 0.25 × 0.25 m. The leaf litter was divided up into three groups: leaves and the other types of debris. The leaf group was dried in a forced-air circulation oven at 70 °C, until dried to a constant weight, and then weighed on high-precision weighing scales (ARATO et al., 2003) to obtain a stock of leaf litter. This material was later ground and analyzed to measure the levels and stocks of N, P, K, Ca and Mg, following sulphuric acid digestion (TEDESCO et al., 1995).

In each area, near the leaf litter sample points, four more samples were taken in order to evaluate the soil fauna with the help of a specific probe, with a height of 17.5 cm and a diameter of 8.0 cm and a cutting head orifice to facilitate penetration of the earth (AQUINO et al., 2006). After collection, the samples were immediately taken to the laboratory, taking care not to expose them to sunlight or to stack them up. The extraction was carried out straightaway, using Tullgren’s method, modified but based on the Berlese funnel, called the Berlese-Tullgren method. The samples were exposed to light and heat for seven days, in order to make a temperature and humidity gradient. The microarthropods, as a result of the heat to which they were subjected, moved from the high to the low areas, eventually leading to them falling into the collecting flask which contained preservation solution. This method is only used for the collection of live individuals and is the most suitable for ecological research (GARAY, 1989).

The organisms obtained through the Berlese – Tullgren method were classified into large taxonomic groups, also taking into consideration the larvae, as these have differences in terms of function and habitat from the adult individuals. The arthropods from the classes Arachnida and Insecta were classified to the level of Order. Within Insecta distinctions were made between larvae and adult Holometabola, due to the differences in function carried out by these organisms at these two different stages of life. The ants were classified as Formicidae, distinct from the other Hymenopteras, given that these form an important soil-quality indicator group (ARMBRECHT; ULLOACHACÓN, 1999; LAVELLE, 1997).

The classification of taxonomic groups into functional groups (Holometabola – Coleoptera and Diptera; Saprophagous - Gastropoda, Diplopoda, Isopoda, Symphyla, Oligochaeta; Saprophagous/Predators – Thysanoptera, Formicidae, Larvae of Diptera and Larvae of Coleoptera; Predator – Araneae and Pseudoscorpionida; Phytophaga – Heteroptera, Auchenorrhyncha and Sternorrhyncha; Parasitoids – Hymenoptera excluding Formicidae; Microphagous – Entomobryomorpha, Poduromorpha and Symphypleona) took into consideration food habitat, food resources and habitat use (MOÇO et al., 2005; COPATTI; DAUDT, 2009).

From the results obtained, the following were calculated: the abundance (number of individuals per square meter), the Shannon diversity and Pielou's evenness indices for each area, and the relative distribution of each taxonomic and functional group. The Shannon Diversity Index (H) was calculated using the formula: H = - Spi log pi, in which pi = ni/N; ni = importance value of each species or group; and N = total of all importance values. In addition, the Pielou Evenness Index (e) was defined as: e = H/log S, in which H = Shannon Index; and S = Number of species or groups.

Data analysis

The data were subjected to the Cochran Test, in order to verify the hypothesis of Homogenous Distribution (homocedasticity) sampling error variance, and the Lilliefors test, in order to evaluate the normal distribution of residuals. When homogeneity and normality were established, the data were subjected to variance analysis and the Bonferroni T test (a=0.05), and when they were not established the non-parametric Kruskal-Wallis test ($P<0.05$) was used to make comparisons between the treatments, and the Mann-Whitney ($P<0.05$) test to make comparisons between seasons, using the BioEstat program version 5.3. To analyze the Cluster grouping, the statistical program PAST was used.

RESULTS

Leaf Litter

Leaf litter stock and levels and stocks of nutrients

In the dry season, the average amount of accumulated leaf litter did not differ between the Agro-Forestry Systems and the area of forest studied (Table 3). In the rainy season, however, larger amounts were found in the forest than in AFS-2 (Table 3). Forested areas may have denser and more varied vegetation than certain AFS (SANTOS et al., 2004), since they have several different strata (tree, bush and herbaceous plants) and lianas, which could be reflected in the number of options for the production and depositing of leaf litter, either throughout the whole year, or at certain times of the year. In addition, the speed with which the leaf litter decomposes can vary between land use systems as a result of other factors, such as the chemical quality of the leaf litter (TEIXEIRA et al., 2012; SILVA et al., 2014), macro- and micro-organism activity (Werneck et al., 2001), the quality of the microenvironment (SILVA et al., 2014), among other factors, leading to the greater or smaller accumulation of organic material on the ground (PEGADO et al., 2008).

The amounts of accumulated leaf litter in the AFS-1 area were similar to those observed by Lima et al. (2010) in an AFS which was ten years old and in an area of transition from Cerrado and mixed secondary forest. These authors found that stocks of leaf litter in this AFS were similar to those in an area of native forest, in both seasons of the year (dry and rainy), and this is the same as was observed in the present study with regard to AFS-1 and the forest (Table 2). Arato et al. (2003) measured the production and deposition of leaf litter in an AFS area in Viçosa/MG (Minas Gerais) and found that the amounts produced of total and fractions of leaf litter were similar to those found in seasonal semi-deciduous forests in the South-East of Brazil, which suggests that AFS behave like active forest in terms of leaf litter.

Only in the AFS-2 area was the stock of leaf litter significantly different at the two collection times, showing a greater accumulation in the dry season (Table 3). This fact could be associated with the physiological characteristics of the plant species in this area and the hydric deficit, given that the fall of the leaves would reduce water loss through transpiration (ARATO et al. 2003; LIMA et al., 2010). Another explanation could be that microbial activity is less intense in the dry season, due to more restrictions on the levels of humidity in the soil, contributing to a lower rate of leaf litter decomposition and a greater amount of biomass on the ground (HOLANDA et al., 2015). Silva et al. (2012a), in this same area (AFS-2 when it was one year old), observed lower rates of soil respiration in the dry season, indicating lower rates of decomposition (HOLANDA et al., 2015) in this season than in the rainy one.

Table 3. Amount (kg ha^{-1}) of biomass and levels (g kg^{-1}) and amounts (kg ha^{-1}) of nutrients in leaf litter accumulated on the ground in Agro-Forestry Systems (AFS-1 and AFS-2) and in secondary forest (SF), in the dry (D) and rainy (R) seasons in the municipality of Paraty/RJ.

Systems	Ca				Mg			
	Amount		Level		Amount		Level	
	D	R	D	R	D	R	D	R
Forest	46.01a	20.25a*	2.02a	0.84b*	5.54a	4.00a*	0.24a	0.17a*
AFS-1	78.55a	41.56a*	2.77a	1.82a*	3.60b	2.67ab	0.13b	0.12b
AFS-2	65.29a	32.97a*	2.91a	2.07a*	4.51ab	1.93b*	0.20a	0.12ab*
Systems	P				K			
	Amount		Level		Amount		Level	
	D	R	D	R	D	R	D	R
Forest	0.27a	0.33a	0.01a	0.01a	742a	266a*	32.71a	11.60a*
AFS-1	0.27a	0.31a	0.01a	0.01a	332b	186a*	11.88b	8.19a
AFS-2	0.32a	0.21a	0.01a	0.01a	179b	118a	8.15b	7.28a
Systems	N				Leaf litter biomass de serapilheira			
	Amount		Level		Amount			
	D	R	D	R	D		R	
Forest	563a	471a	24.77a	20.02a*	2299a		2344a	
AFS-1	529a	533a	18.91b	23.68a*	2752a		2270ab	
AFS-2	298b	217b	13.48c	13.85b	2192a		1594b*	

Averages followed by the same letters in the column show no difference according to Bonferroni's T test at 5%; *Indicates significant difference between seasons in the samples from each area according to Bonferroni's T test at 5%.

The behavior of decomposer arthropods (which are directly responsible for the fragmentation of the leaf litter) is also modified as a result of the reduction of soil humidity levels, since the arthropods tend to move down to lower levels of the soil, leading to a reduction in decomposition and, consequently, in leaf litter accumulation (SANCHES et al., 2009).

With regard to the stocks and levels of nutrients (Ca, P, Mg, K and N) in the accumulated leaf litter, it was found that, in general, for P and Ca, there were no differences between the AFS and the forest, except for levels of Ca in the rainy season, which were lower in the forest area (Table 3).The stock of Mg was larger in the forest area, no different from AFS-2 in the dry season and no different from AFS-1 in the rainy season (Table 2). In the case of AFS-2, this can be explained by similarities with the forest in terms of levels of this nutrient in the leaf litter, while in the case of AFS-1, similarity with the forest (AFS-1 and SF) can be explained by the stocks of biomass in the leaf litter, as the amount of Mg was significantly smaller in AFS-1 than in the forest (Table 2).With regard to the stocks and levels of K, it was observed that two AFS and the forest were all similar in the rainy season. In the dry season, however, these levels were significantly higher in the forest area (Table 3).

The stocks and levels of N were greater in AFS-1 and the forest than in AFS-2, in both seasons (Table 3). This pattern could be a reflection of the plant composition in the forest and in AFS-1, which have a large number of species from the Fabaceae family (TAVARES, 2014; CUNHA NETO et al., 2013). This family has species which are capable of associating with nitrogen fixing bacteria in the atmosphere, which means that the leaf litter is richer in N (FREITAS et al., 2013).

In a survey of the plants in the three areas of the present study, TAVARES (2014), found that, while in AFS-2 each species identified belonged to a different family, in the forest the Fabaceae family was the one found most, corresponding to 21% of all species. Several studies (PEIXOTO et al., 2005; GUEDES-BRUNI et al., 2006) have shown that

Fabaceae (leguminous) is one of the richest and densest families found in the Atlantic Rainforest, according to surveys carried out there. A similar pattern was observed in AFS-1, in which the Fabaceae family had the greatest number of species (45% of the total). Because it has species which are capable of nitrogen (N_2) fixing in the atmosphere, this family is generally used in AFS areas (MOÇO et al., 2005; FREITAS et al., 2013). This means that it is used more in degraded areas and assists the nutrient cycle, promoting and helping to maintain the quality of the soil (FRANCO; FARIA 1997; MOÇO et al., 2005).

In relation to seasonal variations, when there are differences between the dry and rainy seasons, larger stocks and/or higher levels of nutrients (Ca, Mg, K and N) are found in the dry season (Table 3), and the same is true regarding the stock of biomass in accumulated leaf litter (Table 3). This could be linked to the lower rates of decomposition and/or mineralization of organic residue which result from less stimulation of microbial activity in this season, as mentioned above, which enable a greater accumulation of nutrients in the leaf litter (SANCHES et al., 2009; HOLANDA et al., 2015).

In general, it can be seen that the AFS (AFS-1 and AFS-2) have more similarities with the forest than they do differences. (Table 3), showing that with the passing of time and the evolution of the AFS, these can become equivalent to the forest with regard to stocks and levels of nutrients and biomass, which reinforces the contribution these areas make to the cycling of nutrients. Duarte et al. (2013) underlined the fact that the incorporation of arboreal species in productive systems, such as the Agro-Forestry Systems, enables the introduction of diverse organic material and can contribute to the maintenance and improvement of soil functions, resulting also in improvements in soil quality.

Fauna in the soil-litter layer

Composition of the soil fauna community

The most common groups, taking into consideration all three areas and both sampling seasons (dry and rainy), were Poduromorpha (Collembola) and Formicidae, which, together, make up 64% of the total. The remaining 36% belonged to 18 different taxonomic groups. When the two seasons are looked at together, but the areas looked at separately, it can be seen that in AFS-1 the groups with the greatest relative frequency were Entomobryomorpha (17%), Pseudoscorpionida (17%) and Sternorryncha (21%); while in AFS-2 they were Entomobryomorpha (25%), Formicidae (22%) and Poduromorpha (22%); and in the forest area, Formicidae (26%) and Poduromorpha (56%) were the most common (Figure 1A).It can be seen, therefore, that the Collembola group, represented by the Entomobryomorpha and Poduromorpha Orders, predominates in all areas, while Formicidae prevails only in the forest area and AFS-2 (Figure 1A). Manhães et al. (2013) observed that Collembola and Formicidae were the most populous groups when they conducted a study into the soil and leaf litter of degraded pasture lands, which had been recuperated using leguminous trees and secondary forest in the northern part of the state of Rio de Janeiro.

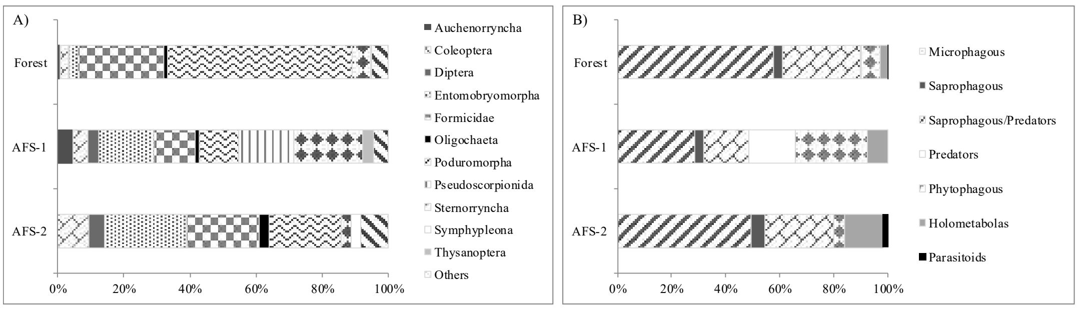

Figure 1. Relative frequency of taxonomic (A) and functional (B) groups of soil fauna in Agro-Forestry Systems (AFS-1 and AFS-2) and secondary forest (Forest), without taking the season of collection into consideration, in the municipality of Paraty/RJ.

Collembola, according to Franklin et al. (2001), is one of the organisms which best carries out important functions in the soil, such as controlling the microorganism population and indirectly contributing to the decomposition of organic material. With regard to Formicidae, it is considered to be one of the main agents involved in the fragmentation of leaf litter and the incorporation of organic material into the soil, being responsible for soil aeration, as it increases infiltration and gas exchange (SOUZA et al., 2008). This group has been found to be the most abundant in the soil in studies into fauna (disregarding mites) (CALVI et al., 2010).

It is important to emphasize that in the AFS-1 area, the position of Formicidae is among the most commonly found groups, but Pseudoscorpionida was the one which really stood out, together with the Collembola (Entomobryomorpha) and Sternorryncha groups (Figure 1A). In addition, this group was only found in this area (Figure 1A). Moço et al. (2005), Cunha-Neto et al. (2012) and Pereira et al. (2013) suggest that the occurrence of the Pseudoscorpinida group is associated with good environmental structuring and indicates better control of the trophic structure. Oliveira Filho et al. (2014) claim that Pseudoscorpionida are good bioindicators, as they are sensitive to anthropic events and are found in greater population densities in environments that have greater ecological balance. Evaluating the invertebrate community in soils under preserved and non-preserved secondary forest in the northern part of the state of Rio de Janeiro, Moço et al. (2005) only found Pseudoscorpionida in the soil community in areas of preserved forest.

The group classified as “Others” had nine taxonomic groups with a frequency of less than 2 %. In all the areas, the proportion of this category was less 10% (Figure 1A). The Heteroptera and Larva de Coleoptera were found in all areas but Gastropoda (AFS-2), Araneae (forest), Diplopoda (forest) and Isopoda (forest) were found in only one of the areas. Larvae from Diptera and Hymenoptera were only found in the forest and in AFS-2, while the Symphyla group, considered by some authors (SILVA et al., 2013; SOUZA et al., 2008) to be an indicator of a low degradation index, was found in AFS-1 and AFS-2.

In general, there were no differences between the three areas in terms of the functionality of the groups, as the following organisms were all found: microphagous, saprophagous, saprophagous/predator, predator, phytophagous and parasitoid (except in AFS-1) (Figure 1B). Microphagous organisms were the functional group with the highest relative frequency in AFS-2 (50%) and the forest area (58%) (Figure 1B). In AFS-1, although the frequency of this group was significant (29%), there was a more balanced distribution between the different functional soil fauna groups, with quite high percentages of phytophagous (27%), saprophagous/predator (17%) and predator organisms (17%) (Figure 1B). Although they do not play an important role in the decomposition of leaf litter, the phytophagous organisms have an indirect effect on the decomposition system as they form part of the food chain and as they affect the aeration of the soil and also act in the transport of microorganisms in the soil (in the case Heteroptera) (SILVA et al., 2012b).

In Figure 2, it is possible to see the degree of similarity between the areas with regard to the composition of the soil fauna community, in the dry (A) and in the rainy (B) seasons. It can be seen that that the three areas (AFS-1, AFS-2 and the forest) were similar, ranging from, approximately, 72% to 86%. The high degree of similarity between the AFS and the forest could be linked to the fact that, in addition to them all being very close to each other, there is no disturbance of the soil in any of the three areas, and the plant residue (leaf litter) remains on top of the ground. This is essential for the survival, increase in activity and development of biotic associations of the fauna (MOÇO et al., 2005).

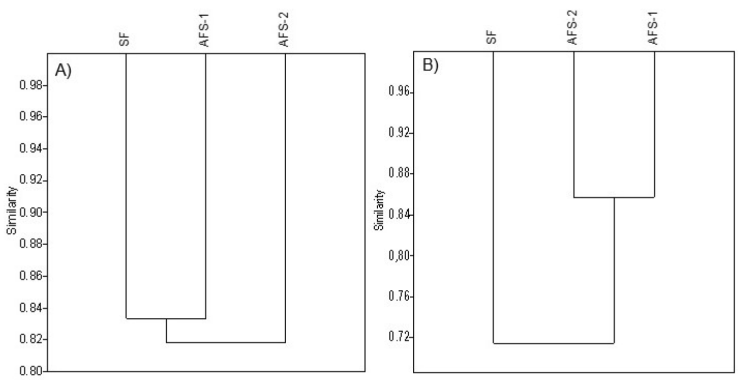

Figure 2. Diagram resulting from Cluster analysis (simple association; similarity measure: Simpson) for the functional groups of soil fauna in Agro-Forestry areas (AFS-1 and AFS-2) and in secondary forest (SF), in dry (A) and rainy (B) seasons, in the municipality of Paraty/RJ.

In addition, the stock and the quality of the leaf litter is generally similar, in particular between AFS-1 and the forest, and this could promote similar microclimatic conditions of humidity, temperature and habitat (MOÇO et al., 2005; 2010). According to Decaëns et al. (1998), more importantly than being a source of food, the leaf litter provides a suitable habitat for the majority of invertebrate groups in the soil.

Density, richness and ecologic indices

The average total density of fauna individuals in the soil-leaf litter layer varied significantly between the three areas but only in the dry season, when the forest had the largest numbers, followed by AFS-1 with intermediate numbers, and finally AFS-2 with the lowest numbers (Table 4). In contrast, in the same season (dry) it could be seen that the Shannon diversity index and the Pielou evenness índex were lower in the forest than in the AFS (Tabela 4). The Shannon index measures the richness of species and their relative abundance while the Pielou evenness index describes the distribution pattern of individuals between the species (MOÇO et al., 2005). Consequently, although the forest had the greatest abundance and total richness of organisms (Table 4), there was disproportion between the abundance of organisms within each taxonomic group. In other words, while some groups were very populous, (Poduromorpha – 56%), others were hardly noticeable, and this led to lower indices of diversity and evenness. Pereira et al. (2012) and Silva et al. (2012b) emphasize that the greater the density of individual soil fauna in the environment, the greater the possibility that one group will dominate, thus reducing evenness.

Table 4. Total density of soil fauna (ind. m^{-2}), average richness (AR) and total richness (TR) and ecological indices (Shannon – H' e Pielou – J') in the Agro-Forestry Systems 1 and 2 (AFS-1, AFS-2) and in the secondary forest (Forest) in the municipality of Paraty/RJ.

Systems	Density		AR		H'		J'	
	D	R	D	R	D	R	D	R
Forest	28009±6660a*	1901±322a	16	7	1.75	2.36	0.44	0.84
AFS-1	4943±1047ab	2376±316a	12	10	2.91	2.84	0.81	0.86
AFS-2	3089±565b	1996±424a	13	7	2.78	2.25	0.75	0.80

Averages followed by the same letters in the column show no difference according to Bonferroni's T test at 5%; *Indicates significant difference between seasons in the samples from each area according to Bonferroni's T test at 5%.

If the two AFS are compared, it can be seen that in the dry season AFS-1 had higher indices of diversity and evenness than AFS-2 (Table 4) which, although there was not much difference, indicates a tendency toward a greater evenness in the fauna community in AFS-1 than in AFS-2. Nevertheless, it is important to stress that both systems had good indices of diversity and evenness compared to the forest, showing the role these systems play in boosting ecosystem functions and contributing with evenness of soil fauna. When evaluating soil microfauna, Pereira et al. (2012) observed that Shannon diversity indices were found to be equal or higher in Agro-Forestry systems than in native forests.

It could be seen that there was a large reduction in the density of individuals from the dry to the wet season although only in the forest was this reduction (of 92%) significant. This pattern is not often found in the literature, since the majority of studies (SILVA et al., 2012b; 2016) have found increases in fauna in the rainy season compared to the dry one, as a result of higher levels of humidity and temperature in the soil.

CONCLUSIONS

The Agro-Forestry Systems (AFS-1 and AFS-2), generally demonstrate the ability to stock equivalent amounts of leaf litter and nutrients above the soil when compared to the forest, which demonstrates the contribution of these areas to the cycling of nutrientes.

The composition of the soil fauna community in the Agro-Forestry Systems (AFS-1 andAFS-2) had a high degree of similarity to that of the forest, which suggests that the AFS can perform the same functions as the forest. These Systems favours the populations of the Collembola and Formicidae groups in particular.

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RESUMO: Os sistemas agroflorestais (SAFs) além de proporcionarem geração de renda, podem ser considerados como uma alternativa para conservação da biodiversidade, tanto acima quanto abaixo da superfície do solo. O objetivo desse estudo foi avaliar o estoque de serapilheira acumulada e seus estoques de nutrientes, bem como, a composição da fauna do conjunto solo-serapilheira, em dois sistemas agroflorestais (SAF-1 e SAF-2), utilizando como referência uma área de floresta secundária (FS), na comunidade Quilombola do Campinho da Independência, Paraty - RJ. A coleta da serapilheira acumulada e da fauna do sistema solo-serapilheira foi realizada a partir de quatro pontos amostrais em cada área, em duas épocas do ano, seca e chuvosa. Foi quantificado o estoque de serapilheira foliar, e seus estoques e teores de nutrientes (Ca, Mg, P, K e N). A extração da fauna foi realizada a partir do método modificado de Tüllgren, baseado no funil de Berlese. O estoque de serapilheira foliar acumulada só variou entre as áreas na estação chuvosa, sendo os menores valores quantificados no SAF-2. De maneira geral, os sistemas agroflorestais apresentaram semelhanças em comparação com a floresta para a maioria dos teores e/ou estoques de nutrientes, em pelo menos uma das épocas de avaliação. A composição dos grupos da fauna do solo dos sistemas agroflorestais (SAF-1 e SAF-2) apresentou um elevado grau de similaridade com a floresta, e estes sistemas favoreceram principalmente as populações de grupos como os Collembola e Formicidae.

PALAVRAS-CHAVE: Agroecologia. Conservação do solo. Serviços ambientais.

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