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Use of Pilou and Shannon Diversity Indexes in Description of Edaphic Fauna in Forests in South America

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Abstract

The recognition and identification of the fauna and flora of an area, in particular a conservation unit, is of fundamental importance to protect and conserve local biodiversity. Agroforestry Systems (AFSs) are forms of use of land or management, in which tree species (fruit and timber) are combined with agricultural crops. When compared to conventional agriculture, AFSs such as advanced systems for supplying green fertilizers, controlling weeds and mainly, recovering and maintaining soil fertility, since it maintains a great variety in the fauna, simultaneously or in temporal sequence promoting the economic and ecological benefits. A diversity index is a mathematical measure of species diversity in a community. Measuring diversity is important in understanding the structure of the community. Diversity indexes are important because they provide more information about a community than just species richness. Diversity indexes also consider the relative abundance of different species and provide information on the rarity of the species, as the number of different species present as well. The biodiversity of edaphic fauna can be measured using statistical parameters derived from the idea of Entropy. In the present work the following parameters were used: the Pielou index, Pielou Equability, Pielou Equitability and Shannon-Wiener index. Five areas were selected: one for Agroforestry (AFS), one Pasture Area and one Preserved Forest area located at Private Reserve of Natural Heritage (RPPN) Serrinha Farmer (Serrinha Neighborhood - Bragança Paulista city, São Paulo State, Brazil).The fourth place was an area formerly used as a vegetable garden in a basic education school in the same city, and the fifth was an area for eucalyptus (Eucalyptus) in the rural zone of city of Pedra Bela, São Paulo.The area of the greatest biodiversity was the Eucalyptus Plantation, followed by the area of Preserved Forest and Agroforestry. The Pasture area was in fourth place, presenting the largest number of individuals, however, divided into a few groups. The area of lower biodiversity was the area represented by the vegetable garden.

Keywords: Agroforestry, Biodiversity, Edaphic Fauna, Shannon Index.

Introduction

The Edaphic Fauna is the set of animals that lives depending directly on the ground such as: earthworms, some species of beetles, worms, nematodes and the predators as for example the mole [1]. Some of these animals live on the surface, being named Epiedaphics: i.g. mites, collembula, insect larvae, centipedes, etc. Others animals inhabit the soil, such as earthworms [1]-[2]-[3]. The projects already developed previously in the Private Natural Heritage Reserve (RPPN) Serrinha Farmer (22°59'33.3" S, 46°26'22.6" W), aimed at surveying the fauna and flora in order to know the biodiversity and contribute to the elaboration of the management plan of the Conservation Unit. Among the activities developed in the Reserve, there was recently the implantation of an area of Agroforestry System (AFS). The intention is to develop a system of food production and production of seedlings in a sustainable manner, respecting the principles of nature itself. Agroforestry Systems (AFSs) are forms of land use or management, in which tree species (fruit and timber) are combined with agricultural crops. Integrating the forest with agricultural crops provides an alternative to address the chronic problems of environmental degradation and also reduces the risk of loss of production [4]. This system is associated with agriculture, combining production and conservation of natural resources, as seeking to meet the various needs of rural producers as well, such as obtaining food, extracting wood and growing medicinal plants, for example. Production is diversified, providing a more stable supply of products throughout the year, helping to conserve soils and forest areas. When compared to conventional agriculture, Agroforestry Systems have the main advantages of frequent supply of green manure, weed control and the easy recovery and maintenance of soil fertility, since it maintains a wide variety of soil fauna, either simultaneously or in time sequence, and which promote economic and ecological benefits [5]-[6]-[7].

Fertility Soil

Fertility can be defined as the ability of the soil to yield nutrients to the plants [8]. A fertile soil is one which contains, in sufficient and balanced quantities, all the essential nutrients in assimilable form. This soil must be reasonably free of toxic materials and possess physical and chemical properties that meet the demand of the plants. A productive soil is one that, being fertile, must be located in a climatic zone capable of providing sufficient moisture, nutrient and structure for the development of the roots and the plant in it [9]. The soil has an edaphic fauna that is inserted in all layers of the soil, contributing to the existence of all living beings in the environment. It plays a fundamental role in the decomposition of plant material, in the cycling of nutrients and in the indirect regulation of soil biological processes. The relationships established between the different types of edaphic fauna (micro, meso and macrofauna) are fundamental for the maintenance of fertility and

ecosystem productivity [10].

According to [11] the characteristics of a soil, as well as its quality are determined in great part by the organisms present in it. Such interference may be clear in processes such as decomposition, or less obvious as in the case of texture and soil structure or water retention capacity. Both microorganisms and soil fauna are capable of modifying physical, chemical and biological soil properties. Biota is also affected by the type of land use, being a reflection of the management [7]-[11]-[12]. The main objective of this project was to quantify the density and diversity of soil fauna groups (especially meso and macrofauna) under different production and occupation systems, comparing the types of soils analyzed. Five areas were selected: Agroforestry (AFS), pasture area and a Preserved Forest area located in the RPPN Serrinha Farmer Neighborhood, located in the rural region of Bragança Paulista, in a mountainous region bordered by the Jaguari-Jacareí water reservoir, in the Serra da Mantiqueira (Brazil), 22°48'07.6"S, 46°26'14.3"W. The fourth area was a space used, until recently as a vegetable garden in a Basic School. The fifth and last area was a plantation of eucalyptus, implanted about 12 years ago in the rural area of city of Pedra Bela, São Paulo State.

Materials and Methods

Figure 1. *Studied Regions, Area of Property (in Yellow) - Permanent Protection Areas (in Blue) - Areas in which Samples were Collected for Analysis of the Edaphic Fauna (in Red) at 22°59'33.3" S, 46°26'22.6" W*

Source: Google Earth.

The research was carried out in five different anthropic areas. Three of

them are located in the Serrinha neighborhood in Bragança Paulista - SP: an Agroforestry System (AFS), which has about 800m^2 and was relocated in January 2016, an area dedicated to the pasture of cattle, which has long been used for cattle ranching and a forest area that has been preserved for about 30 years with approximately 5 hectares. Figure 1 shows these areas cited above.

Another analyzed area was one used for a long time as a vegetable garden in the courtyard of the School of Basic Education "Viverde", currently used as a deposit of organic materials and being restored and the fifth analyzed area was a property destined to the plantation of eucalyptus showed in Figure 2.

Figure 2. *Area of Eucalyptus Plantation, Used for about 12 Years Located in Rural Zone of Pedra Bela – SP, 22°59'45.0" S, 46°26'26.1" W*

To collect the species, the trap *Provid* was used [13], a specific trap for the collection of organisms with vertical displacement, showed in Figure 3.

Figure 3. *Provid Trap Design and Photo Showing that*

The *Provid* trap for the collection of vertical edaphic macrofauna consists of a two-liter Pet type plastic bottle containing four window openings measuring 6cm x 4cm at a height of 20cm from its base. Each trap was exposed in the field for a period of seven days, containing within it 200 ml of alcohol 70% plus 3 to 5 drops of 2% formaldehyde. They were buried in the soil so that the edges of the flasks were level with the soil surface, showed in the Figure 3.

Five sample points were used in each study area with spacing of 10 meters between the points. After each collection, the organisms were identified and counted in the Laboratory of Chemistry and Microscopy of the University. Some larger species found during the trapping were also collected manually with tweezers. The individuals were identified with the help of a hand magnifying glass and a stereoscopic microscope (electronic magnifying glass). The obtained fauna data were submitted to statistical analysis using the Shannon and Pilou indexes for diversity and equitability, respectively.

Results

The traps were installed from June to September 2016 in the five areas chosen. After being collected and already stored in bottles with 70% alcohol and 2% formaldehyde, the animals were taken to the faculty laboratory to be separated and identified, as showed in Figures 4 and 5.

Figure 4. *Animals Trapped in the Agroforestry System of Serrinha Farmer (Increase with Hand Magnifying Glass)*

Figure 5. *Separation and Identification of Animals in the Laboratory, Carried out with the Help of Students of the High School of Viverde - School of Basic Education, 22°54'07.7"S, 46°32'32.7"W*

forestry, Pasture, Preserved F on traps, respectively. Since alcohol solution, the total volume for density calculation is therefore 1000ml. Figure 6 shows the distribution of the number of individuals found in each of the five sampled areas. Figure 7 shows the distribution of different groups of fauna found in each sampled area. Comparing the number of different species present in each sampled area, it can be observed that in the Agroforestry there are 11 different groups; in the areas of forest preserved 10 groups; in the eucalyptus plantation 09 groups; in the garden appear 08 different groups and in the pasture area only 06 groups. Table 7 shows the results of the descriptive statistics for the parameters Sp (number of species) and H' (Shannon-Wiener Diversity index) for all regions, allowing to compare the variations of these indices with each other. We can observe although the pasture area had the largest number of individuals (1150), the lowest number of different species groups (only 6 groups) was found in this area. In contrast, the garden area presented only 54 individuals collected, but distributed in 08 different groups of species.

Table 1. *Soil Fauna Found in Traps in the Agroforestry Serrinha Farmer*

Edaphic Fauna	Agroforest
Isopoda	34
Arachnid (spider)	54
Amphipoda	13
Orthoptera (grasshoper)	04
Hymenoptera (ant)*	130
Insect Larva	05
Dictyoptera (cockroach)	04
Coleoptera (beetle)	04
Acarids (mite)	07
Diptera	10
Collembolans /Diplura/Protura	about 600
11 different groups	865 beings/liters (b/l)

*Ants are of Different Species, Requiring Specific Identification.

Table 2. *Edaphic Fauna with Identification of the Organisms and Quantity Found in the Traps of the Soil Placed in the Pasture of Serrinha Farmer*

Edaphic Fauna	Pasture
Coleoptera (bettle)	667
Hymenoptera (ant)	118
Acarids (mite)	16
Orthoptera (grasshopper/cricket)	02
Arachnid (spider)	08
Collembolans /Diplura/Protura	339
06 different groups	1.150 b/l

Table 3. *Edaphic Fauna with Identification of the Organisms and Quantity Found in the Soil Traps Placed in the Preserved Forest of Serrinha*

Edaphic Fauna	Preserved Forest
Orthoptera(grasshoper)	5
Arachnid (spider)	12
Hymenoptera (ant)	72
Coleoptera (bettle)	36
Anelid (worm)	1
Dictyoptera (cockroach)	3
Amphipoda	3
Diptera	58
Insect Larva	3
Lepidoptera (owl face butterfly)	2
10 different groups	195 beings/liter

It is consensus among several authors that the diversity of edaphic fauna should be measured not only by the richness of the number of individuals but also by the different groups that appear in the soil, thus indicating greater balance and maintenance of the fertility of this one [14]-[15]-[16]. The number of individuals in the Agroforestry was not the largest (865 individuals compared to 1150 individuals found in the pasture), but the diversity presented by the agroforest represents greater wealth because 11 groups of different living beings were identified against only 6 groups of the pasture area. It can also be identified in the native forest area with 195 individuals divided into 9 different groups.

Table 4. *Soil Fauna Found in Soil Traps Placed in Vegetable Garden of the Viverde Basic School*

Edaphic Fauna	Vegetable Garden
Amphipoda	10
Diplura	1
Hymenoptera (ant)	9
Arachnids (spider)	4
Orthoptera (grosshopper)	1
Diptera	24
Coleoptera (bettle)	2
Symphyla	1
8 different groups	52 beings/liter

Table 5. *Soil Fauna Found in Soil Traps Placed in Eucalyptus Plantation in Rural Zone of City of Pedra Bela*

Edaphic Fauna	Eucalyptus Plantation
Coleoptera (bettle)	27
Dictyoptera (cockroach)	1
Homoptera (cicada)	1
Hymenoptera (ant)	48
Arachnids (spider)	14
Orthoptera (grasshoper)	3
Isopoda (woodlouse)	3
Diptera	30
Collembolans /Diplura/Protura	17
09 groups	144 beings/liter

Figure 6. *Distribution of the Number of Individuals Found in the Five Sampled Areas. Agroforestry with 865 Individuals, Pasture with 1150 Individuals, Preserved Forest with 192 Individuals, Eucalyptus Plantation with 144 and Vegetable Garden with 54 Individuals*

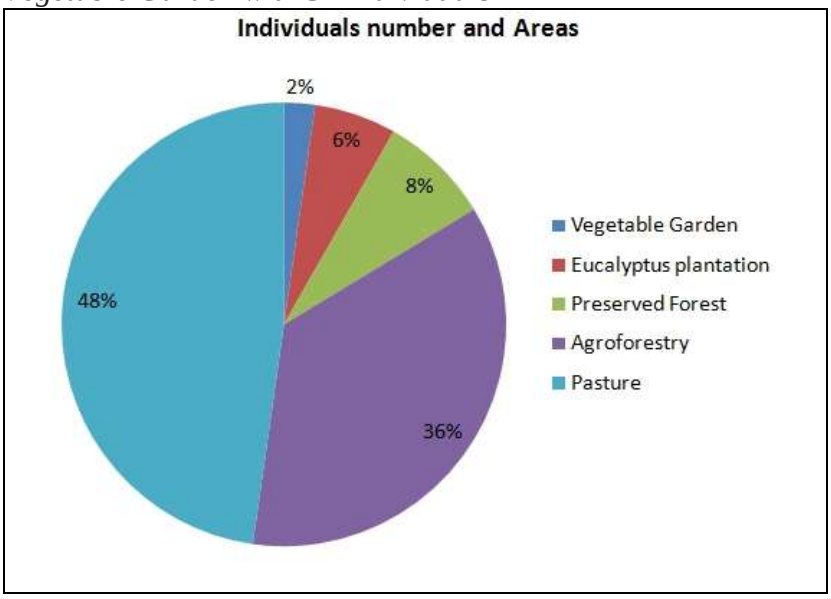


Figure 7. *Number of Different Species Found in the Sampled Areas: Agroforestry (11 Different Groups); Preserved Forest (10 Groups) Eucalyptus Plantation (09 Different Groups); Vegetable Garden (08 Groups) and Pasture (06 Different Groups)*

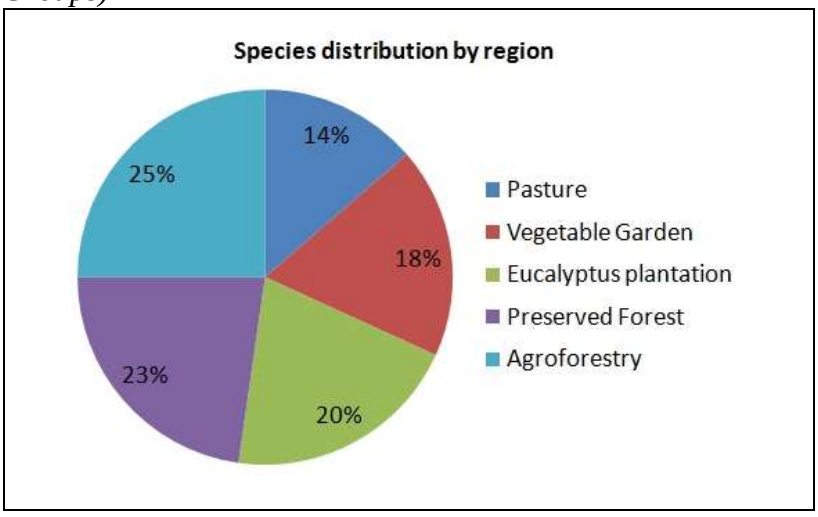


Table 6. *Group of Living Beings Found, their Respective Quantities and Locations*

Edaphic Fauna	Agroforestry	Pasture	Preserved forest	Vegetable Garden	Eucalyptus Plantation
Mite	07	16	-	-	-
Amphipoda	13	-	03	10	-
Spider	54	08	12	05	14
Cockroach (Dictyoptera)	04	-	03	01	01
Bettle (Coleoptera)	04	667	36	02	27
Butterfly (Lepidoptera)	-	-	02	-	-
Cicada (Homoptera)	-	-	-	-	01
Collembolans / Diplura/Protura	± 600	339	-	-	17
Diptero	10	-	58	24	30
Diplura	-	-	-	01	-
Ant (Hymenoptera)	130	118	72	09	48
Grasshopper/ Cricket (Orthoptera)	04	02	05	01	03
Isopoda (woodlouse)	34	-	-	-	03
Insect Larva	05	-	03	-	-
Earthworm	-	-	01	-	-
Symphyla	-	-	-	01	-
Total	**865**	**1150**	**195**	**54**	**144**
Diversity	11 groups	06 groups	10 groups	08 groups	09 groups

Table 7. *Descriptive Statistics for the Parameter Sp and H' for All Regions*

Variable	Average	Median	V. Max.	V. min.	S^2	S	Assymmetri	Skewness	VC%
Sp	481	192	1150	54	243609	493,6	0,9	0,4	102,6
H'	0.0542	0.476	0.768	1.631	0.986	0.993	1.697	0.326	1832.2

Sp=number of species; H '= Shannon-Wiener Diversity index; V. Max.= Maximum value; V. min.=Minimum value; S^2=Variance; S=Standard deviation; VC% = Coefficient of Variation.

The diversity of species is originally associated with a relation between the number of different species found (species richness) and the distribution of the number of individuals among the species (equitability). However, in a broader sense, species richness itself can be used as a general measure of diversity [17]-[18]. The Shannon index measures the level of uncertainty to predict to what species belong to one individual chosen at random from a sample of S species

and N individuals. The lower the value of the Shannon index, the lower the degree of uncertainty and therefore the diversity of the sample is low. The diversity tends to be higher the higher the index value [19]. In despite Shannon's index is widely use to describe communities, Pielou (who was mathematical ecologist) did not believe that Shannon's index has any biological theoretical basis, because plants and animals are not distributed randomly [20]. The Pielou Equability and Equitability Indexes are derived from the Shannon diversity index and allows to represent the uniformity of the distribution of individuals among existing species [20]-[21]. Them values have an amplitude of 0 (minimum uniformity) to 1 (maximum uniformity).

We have written a Python language software to calculate Diversity indexes: Pielou index (H), Pielou Equability (J) Pielou Equitability (J') and Shannon-Wiener index (H') [20]-[21]-[22]-[23]-[24]. The Pielou index (H) is given by (1):

$$H = -\sum_{i=1}^{N} p_i . \log(p_i) \quad (1)$$

Pielou Equability (J) is calculated by (2):

$$J = \frac{H}{Hmax} = \frac{-\sum_{i=1}^{N} p_i . \log(p_i)}{\log(S)} \quad (2)$$

Pielou Equitability (J') is given by (3):

$$J' = \frac{H'}{H'max} = \frac{-\sum_{i=1}^{N} p_i . \ln(p_i)}{\ln(S)} \quad (3)$$

and Shannon-Wiener index (H') is defined by (4):

$$H' = -\sum_{i=1}^{N} p_i . \ln(p_i) \quad (4)$$

where:

log( ): logarithm base "10"
ln( ): Natural logarithm (logarithm base "e")
$p_i = \frac{n_i}{N}$, where n_i: number of individuals of specie "i";
N: total number of individuals of each sample, by region;
S: the total number of species in each region.

Table 8 shows the calculated indexes. According to the Shannon Indexes that represents the Diversity and Pielou Index that represents the Equitability, the most biodiverse area is Eucalyptus Plantation, followed by the area of Preserved Forest and Agroforestry. The less biodiverse is the area represented by the Vegetable Garden. The graphs in the Figures 8 to 11 show the distribution of the indexes in the different areas.

Table 7. *Calculated Indexes of Diversity and Equability*

Edaphic Fauna	Agroforestry	Pasture	Preserver Forest	Garden	I. Eucalyptus Plantation
H	1.097	1.015	1.516	1.609	1.716
H'	0.476	-0.036	0.694	-1.631	0.768
J	0.457	0.566	0.690	0.732	0.781
J'	0.457	0.046	0.728	-1.709	0.805
Total of individuals	**865**	**1150**	**192**	**54**	**144**
Species number	**11**	**06**	**09**	**08**	**09**

Figure 8. *Variation of the Shannon H Index for the Various Regions, where they are Represented: 1-Agroforestry, 2-Pasture, 3-Forest, 4-Vegetable Garden and 5-Eucalyptus Plantation*

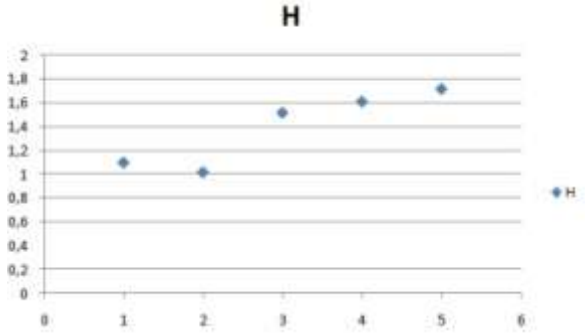


Figure 9. *Variation of the H' Shannon-Wiener Index for the Various Studied Regions, where 1-Agroforestry, 2-Pasture, 3-Forest, 4-Vegetable Garden and 5-Eucalyptus Plantation*

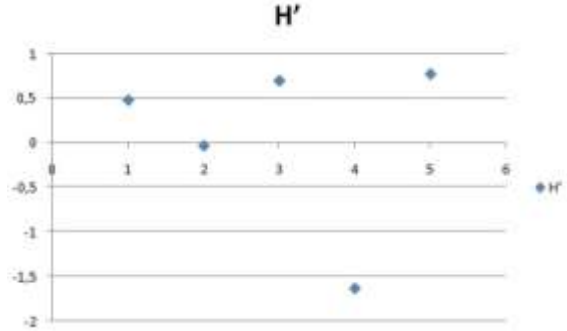


Figure 10. *Variation of the Pielou Equability J for the Various Studied Regions, where 1-Agroforestry, 2-Pasture, 3-Preserved Forest, 4-Vegetable Garden and 5-Eucalyptus Plantation*

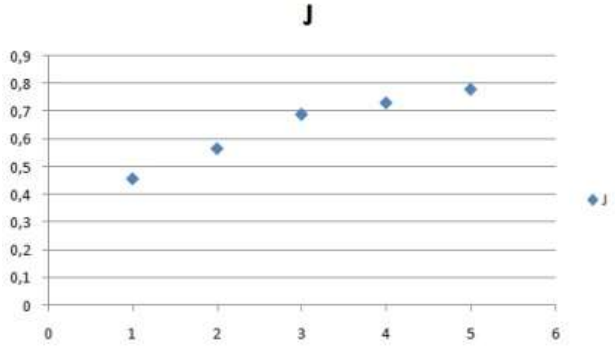
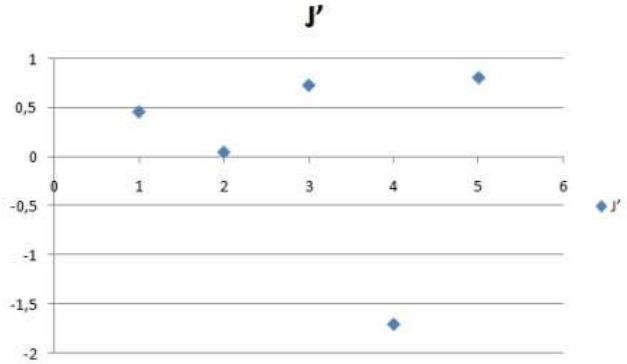


Figure 11. *Variation of the Pielou Equitability J' for the Various Studied Regions, where 1-Agroforestry, 2-Pasture, 3-Preserved Forest, 4-Vegetable Garden and 5-Eucalyptus Plantation*



Conclusions

The present work showed the representatives of the edaphic fauna appear in all types of soil. They are important animals in maintaining soil fertility, as they fragment debris, control populations of causative agents and vectors of diseases, provide nutrients for fungi and bacteria, and are important indicators of soil integrity [7]. Among the animals described it is worth highlighting some that are not commonly known. Amphipods, for example, are small crustaceans often found in large numbers and high diversity in humid environments. On the other hand, insects and prides are insects without eyes and without wings that measure from 0.5 to 2.5 mm and feed on bacteria and fungi. They are not, however, very importants for the maintenance of soil biology [25]. The same authors refer to Collembolans as important insects indicators of soil quality because they are dedritivores feeding on decomposing organic matter, algae, fungi and bacteria. They exist in large quantities in the superficial layers of the soil, help to control and disperse fungi, serve food to other arthropods and are sensitive to environmental changes.

The organisms of the macro and mesofauna of the soil are decomposers and contribute to the improvement of the physical conditions of the soil, promoting the initial fragmentation of deposited vegetal residues and facilitating the attack by the microorganisms (protozoa, fungi and bacteria), that have the function of the decomposition of the residues, cycling of nutrients and formation of organic matter [26]. The most important fauna groups, due to their number, diversity, abundance of species and activity, are Acarina (Acari Oribatei) and Collembola. The relevance of both is due mainly to their participation in processes such as the decomposition of organic matter and the recycling of soil nutrients, besides functioning as indicators of the environment conditions. In the present study, the Collembolans were abundant in the Agroforestry System (AFS) when compared to other areas. The number of mites, however, was lower in all surveyed areas, appearing more in pasture (16 individuals) and in Agroforestry (7 individuals). The spiders and beetles that also appear frequently, serving as biological controllers of pests, whereas the "siriri" (winged phase of termites) indicates that the earth is very dry, and the ants, by cutting the leaves, create an underground garden of fungi which is extremely important for the soil that cockroaches help in the decomposition of organic matter and mites consume organic dead matter. The soil, including the deepest horizons and the rhizosphere, might constitute a huge reservoir for biodiversity [27].

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