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Artículo Original

Characterization of soil macrofauna in forest fragments in the municipality of Leticia, Colombian Amazon

Caracterización de la macrofauna del suelo en fragmentos forestales en el municipio de Leticia, Amazonía colombiana

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Resumen:

La caracterización y la abundancia de la macrofauna del suelo y su relación con la morfología del suelo, fueron evaluadas en áreas de fragmentos forestales de bosques secundarios en el Centro para la Biodiversidad y el Turismo del Amazonas, del Servicio Nacional de Aprendizaje - SENA, en Leticia, Amazonía colombiana. La macrofauna del suelo (invertebrados mayores o iguales a 2 mm de diámetro) fue evaluada en dos períodos estacionales (mayo y octubre) con diferentes registros de precipitaciones. Fue encontrado una abundancia total de 5332 individuos de la macrofauna del suelo, distribuidos en 14 órdenes taxonómicas. El fragmento forestal conservado (FFC) fue el área que registró una mayor diversidad florística, y presentó la mayor densidad de la macrofauna del suelo en ambos periodos de muestreo. Los grupos de insectos Isoptera y Formicidae, fueron predominantes, sobre todo, en el FFC. Las comunidades de macrofauna del suelo no detectaron correlaciones significativas con las variables de la morfología del suelo en los fragmentos forestales. Sin embargo, esa correlación se mostró significativa entre los dos periodos de muestreo, indicando que la estacionalidad de la pluviosidad puede afectar la densidad de la macrofauna del suelo dependiendo del periodo de muestreo.

Palabras clave: Bosque secundario, ingenieros del suelo, macroinvertebrados del suelo, morfología del suelo.

Abstract:

The characterization and the abundance of the soil macrofauna and its relation with the morphology of the soil, were evaluated in areas of forest fragments of secondary forests in the Center for Biodiversity and Tourism of the Amazon, of the National Service of Learning - SENA, in Leticia, Colombian Amazon. The soil macrofauna (invertebrates greater than or equal to 2 mm in diameter) was evaluated in two seasoning periods (May and October) with different rainfall records. A total abundance of 5995 individuals of the soil macrofauna was found, distributed in 14 taxonomic orders. The conserved forest fragment (FFC) was the area that registered the highest floristic diversity, and presented the highest density of the soil macrofauna in both sampling periods. The groups of insects Isoptera and Formicidae were predominant, especially in the FFC. The soil macrofauna communities did not detect significant correlations with the soil morphology variables in the forest fragments. However, this correlation was significant between the two sampling periods, indicating that the seasonality of the rainfall may affect the density of the soil macrofauna depending on the sampling period.

Keywords: Secondary forest, soil engineers, soil macroinvertebrates, soil morphology.

Introduction

The Colombian Amazon, with approximately 45% of the territory, is home to nearly 6500 plant species and is considered one of the most diverse regions in the country (1). However, the expansion of the agricultural frontier, extensive cattle ranching, forest fires and selective logging for the sale of timber, are the main drivers of deforestation of tropical forests in the world, while, in Colombia, other dynamics are added, such as colonization and displacement of populations, mining and planting of illicit crops, which increase the continuous pressure on the forest (2). A study conducted by the Forest Monitoring System of the Instituto de Hidrología, Meteorología y Estudios Ambientales (Institute of Hydrology, Meteorology and Environmental Studies) - IDEAM, established a total of 140,356 deforested hectares in 2014 (3).

One of the main consequences of deforestation is the creation of fragmented landscapes with completely transformed sizes and habitats (4), altering the microclimate of the forest and at the same time, causing the extinction of many species, both locally and regionally (5). Forest fragmentation contributes to habitat loss, isolation of small natural populations and increases the likelihood of extinction and loss of biodiversity (6). Thus, the monitoring of groups of organisms key to tropical forest ecosystems is a strategy that has been used to try to understand the impact of long-term environmental alterations (7). In this sense, soil macrofauna (invertebrates greater than or equal to 2 mm in diameter) represents a functional group that regulates important ecosystemic processes in the soil, such as the decomposition of organic matter, the formation of biogenic structures and the recycling of nutrients (8), which, with soil aggregation, determined through its morphology (biological and physical attributes), strongly relates to its properties, such as infiltration and the storage of water and carbon (9).

The main objective of this study was to evaluate the composition of the soil macrofauna community and its relationship with soil morphology in forest fragments of secondary forests, in order to gather information that can help in monitoring alterations in natural landscapes with urban growth.

Materials and methods

Area of study: The work was carried out in three areas of secondary forest, forest fragments for this study are: (i) Border forest fragment (FFB), near the road; (ii) conserved forest fragment (FFC), with greater diversity of tree species; (iii) transition forest fragment (FFT), located in an open area close to a ravine; and (iv) and altered grassland area (AP). All the landscapes studied were located in the Centro para la Biodiversidad y el Turismo del Amazonas del Servicio Nacional de Aprendizaje (Center for Biodiversity and Tourism of the Amazon of the National Learning Service) - SENA Regional Amazonas, in the Municipality of Leticia, Amazonas, Colombia (Figure 1).

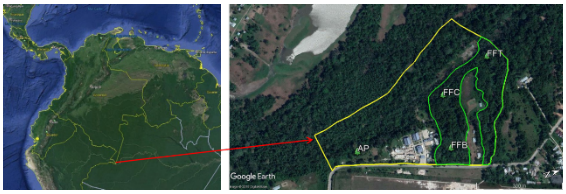

FIGURE 1
Location of the study area, at the southern end of the department of Amazonas, showing the fragments evaluated: border forest fragment (FFB), conserved forest fragment (FFC), transition forest fragment (FFT) and grassland area (AP) in the Centro para la Biodiversidad y el Turismo del Amazonas del Servicio Nacional de Aprendizaje, Amazonas Regional SENA, Leticia, Amazonas, Colombia.
Google Maps, adapted.

The predominant vegetation in the forest fragments was typical of secondary forest in a state of regeneration, with enrichment of tree species native to the region and the altered grassland area was covered with Brachiaria sp. (10) (Table 1).

TABLE 1
Geographical location and general description of forest fragments and grassland area evaluated at the Centro para la Biodiversidad y el Turismo del Amazonas del Servicio Nacional de Aprendizaje Amazonas Regional SENA, Leticia, Amazonas.

Forest Fragments	**Geographical Coordinates**	**Main species of the flora composition (10)**
Border Forest Fragment - FFB	W 69°56´46. 23" S 04° 11´51.61"	*Bellucia pentamera* Naudin *Cecropia ficifolia* Warb. ex Snethl. *Mauritia flexuosa* L.f. *Senna silvestris* (Vell.) H.S.Irwin & Barneby
Conserved Forest Fragment - FFC	W 69°56´52. 25" S 04° 11´50.74"	*Astrocaryum chambira* Burret *Foramea multiflora* DC. *Inga edulis* Mart. *Inga sertulifera* DC. *Miconia serrulata* (DC.) Naudin *Senna silvestris* (Vell.) H.S.Irwin & Barneby *Swartzia polyphylla* DC.
Transition Forest Fragment - FFT	W 69°56´55. 09" S 04° 11´44.58"	*Alchornea latifolia* Sw. *Bellucia pentamera* Naudin *Miconia radulifolia* (Benth.) Naudin *Vismia macrophylla* Kunth
Grassland Area (AP)	W 69°56´48. 82" S 04° 12´01.97"	*Brachiaria* sp.

Sampling: Soil macrofauna sampling was carried out during the months of May and October 2017, and according to IDEAM 2017 (11) a monthly precipitation of 435 mm was recorded with an average temperature of 27.17°C in May and a monthly precipitation of 137 mm with an average temperature of 27.29°C in October (Figure 2).

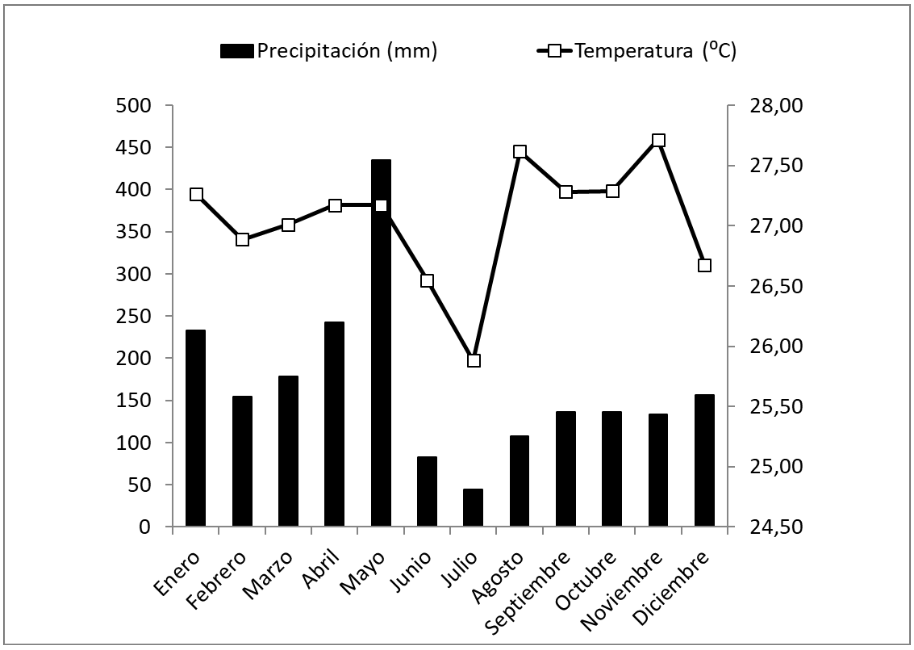

FIGURE 2
Variation in rainfall (mm) and average monthly temperature (oC) for 2017, municipality of Leticia, Amazonas, Colombia
www.ideam.gob.co (adapted for this study)

The experimental design was recommended by the detailed sampling protocol of the edaphic macrofauna of the Sustainable Amazonian Landscape project of the Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture) (CIAT) in Palmira, Colombia (12).

Soil macrofauna was evaluated using Tropical Soil Biology and Fertility (TSBF) methodology (13), suitable for this study up to a depth of 20 cm. In each of the areas, six monoliths (soil blocks) 25x25 cm on each side and a depth of 20 cm were removed where three strata were established: litterfall above the ground and two depth levels of 0-10 cm and 10-20 cm.

Soil macrofauna was separated in the field and conserved in 96% alcohol vials. Later, in the laboratory, the large taxonomic groups were identified (14) (Figure 3).

FIGURE 3
Soil macrofauna sampling sequence, field separation and identification (May and October, 2017) and laboratory identification process (November, 2017)
Photos: David Preciado, Mildreth Villarreal and Sandra Celia Tapia Coral.

Soil morphology was evaluated according to the methodology described by Velásquez et al (15) and soil sampling was performed using a 10x10 cm side and 10 cm depth metal frame at the same points where the macrofauna was sampled.

The process of separating the aggregates from the soil was carried out in the laboratory, and the attributes were separated into their various components: (i) biogenic aggregates produced by worms, termites, ants and some coleopteran larvae, which can be differentiated by their dark colors (mainly worm droppings), circular shapes, galleries and macropores; (ii) physical aggregates products of compaction produced by the trampling of animals and also, of the action of water, generally formed in clay soils and differentiated by their flat and angular forms; (iii) aggregates produced by the roots; (iv) organic matter (fragments of stems, leaves, wood, seeds, flowers, etc.).); (v) unadded soil, where the residual material from the separation of the components is sieved (0.5cm in diameter); (vi) plant roots; and (vii) stones (15).

After separation, the various soil components were dried at room temperature for 72 hours and weighed on a digital gravimetric scale (Figure 4) (16).

FIGURE 4
Sampling sequence of soil morphology and separation process of soil aggregates in the laboratory (May and October 2017)
Photos: Carolina Asencio and Sandra Celia Tapia Coral.

Data analysis: In order to evaluate the effect of the different seasonal periods in which the soil macrofauna sampling was performed, a descriptive statistical analysis was performed followed by Student's t-test with the probabilities corrected by Bonferroni's test (17) in Systat 12 (18).

A multivariate statistical analysis of main components (PCA) was also performed with the Monte Carlo test (17), according to the methodology indicated in several research studies (9,19, 20, 21, 22). These analyses are carried out with the purpose of identifying the predominant factors for the variables of soil macrofauna communities (density ind/m^2) and soil morphology (types of attributes) in forest fragments and in the grassland area. A statistical coinertia analysis was performed to determine correlations between the main component analysis (PCA) vectors for soil macrofauna and soil morphology variables in the areas studied in both sampling periods. Multivariate statistical analyses were performed on software R (23) and ACP on package ADE4 (24).

Results and discussion

Soil Macrofauna: A total of 5332 soil macrofauna individuals were found distributed in a total of 14 taxonomic groups, and in May (2329 individuals, distributed in 12 taxonomic orders), and October (3003 individuals, distributed in 14 taxonomic orders) (Table 2).

TABLE 2
Abundance of taxonomic groups of soil macrofauna (individuals) in May and October 2017, in the Border Forest Fragment (FFB), Conserved Forest Fragment (FFC), Transitional Forest Fragment (FFT) and Grassland Area (AP).

	May				October			
Group	**FFB**	**FFC**	**FFT**	**AP**	**FFB**	**FFC**	**FFT**	**AP**
Aranea	7	9	8	10	13	25	9	2
Blataria	4	3	1	4	14	4	0	2
Coleoptera	60	111	83	66	14	12	12	16
Chilopoda	4	8	4	5	3	16	13	6
Diplopoda	11	16	17	33	4	7	15	3
Formicidae	102	175	168	52	562	1066	350	12
Gastropod	4	0	1	12	1	7	1	4
Isopoda	16	14	9	52	6	10	19	13
Homoptera	0	0	0	0	0	1	0	0
Isoptera	20	680	197	34	223	82	143	26
Larvae	7	8	8	2	9	14	10	10
Oligochaeta	87	11	74	121	79	4	30	107
Orthoptera	0	0	0	0	4	1	9	0
Pseudoescorpion	0	5	5	0	0	10	1	0
Total	323	1040	575	391	932	1259	611	201

The total abundance of individuals recorded in the two sampling periods showed no significant difference [t=-0.75; GL=71; $p_{(Bonferroni)}$=0.45], being on average relatively lower in May (=40.6) than in October (=46.9). When analyzing the total abundance of individuals in forest fragments and grassland area between the two sampling periods, a significant difference was found only for grassland [t=2.19; GL=17; $p_{(Bonferroni)}$= 0.04], being on average higher in May (AP=24.66) than in October (AP=12.55). No significant differences were found for forest fragments.

The total wealth of the taxonomic groups recorded in the two sampling periods did not differ significantly [t=1.51; GL=71; $p_{(Bonferroni)}$= 0.13], with the average being relatively higher in May (=4.36) than in October (=3.87). The richness of taxonomic groups of soil macrofauna observed in this study (14 taxonomic groups) was similar to that reported by Marín and Feijoo (25), who found 15 groups in tillage systems in Valle del Cauca. Meanwhile, (26) reported 10 groups in potato tillage systems in Pasto in Nariño and (21) reported 10 groups in agroforestry systems in Caquetá, Colombian Amazon. However, (27) reported up to 21 taxonomic groups of soil macrofauna in agroforestry systems with different compositions also in Caquetá, Colombian Amazon. The studies carried out in Colombia focused on systems of chagras, agroforestry and crops with different forest arrangements in their composition (19, 21, 27). In the southern part of the Colombian Amazon, studies of soil macrofauna (16) are still scarce, being the present study one of the few carried out in areas of forest fragments of secondary forests.

Regarding the vertical distribution of soil macrofaunal density, the data showed that in May there was a predominant distribution of invertebrates in the litterfall layer and, above all, in the first horizon of the soil (0-10 cm) in all forest fragments and the grassland area (Figure 5). Indicating that during the wettest period the first horizons of the soil have a greater contribution as a source of energy and nutrients (28).

The second soil horizon (10-20 cm) showed a very low density of invertebrates in all areas and in the two sampling periods, which may indicate that below 10 cm depth there is a lower contribution of soil macrofauna activity in this horizon.

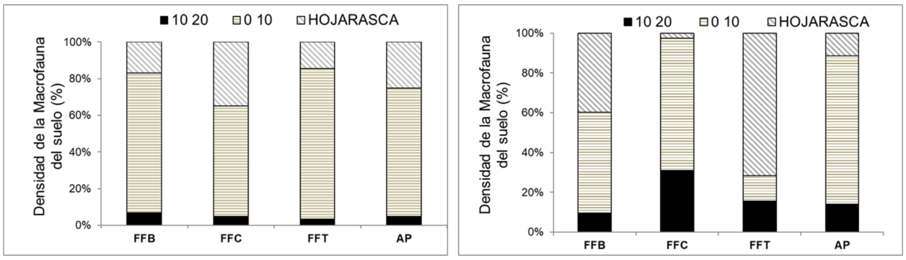

FIGURE 5
Vertical distribution of soil macrofauna (%) in the Border Forest Fragment (FFB), Conserved Forest Fragment (FFC), Transition Forest Fragment (FFT) and Grassland Area (AP) in the two sampling periods in May (left) and October (right) 2017

Results similar to those observed in this study on the vertical distribution of soil macrofauna density were reported for the Colombian Amazon (27) and in forest plantations in the Peruvian Amazon (29), with greater macrofauna activity reflected in the first soil horizons and in the leaf litter layer.

In October, during the period of lower humidity, soil macrofauna had a greater predominance in the conserved forest fragment (FFC) and the border forest fragment (FFB) (Figure 5). However, the transition forest fragment (FFT) and grassland area (AP) had a considerable decrease in soil macrofauna during this sampling period (Figure 5), which may indicate that the macrofauna was affected by lower rainfall during this period, mainly in grassland due to lack of soil cover. Similar results were reported in other studies where the soil macrofauna community was generally affected in periods with lower humidity (20, 21, 27).

In the conserved forest fragment (CFF), the highest density of soil macrofauna was observed in the two sampling periods, which may be related to the greater plant diversity of tree species in this fragment (10). Other authors (28, 30) reported that plant diversification offers greater diversity of microhabitats and thus contributes to greater soil diversity and biological density.

Earthworms (Oligochaeta) and groups of social insects, ants (Formicidade) and termites (Isoptera), were the most predominant in FFC and FFT (Table 2). These three groups of soil macrofauna are classified as "ecosystem engineers" (8) because they produce biological structures originating from their activities, which promote alterations in the micromorphological and physical attributes of the soil, such as water infiltration and soil aeration due to increased porosity. However, these groups are very sensitive to variations in land use and land cover and can therefore be studied as indicators of soil recovery from forests (19, 31).

Termites are opportunistic organisms that are resistant to induced disturbances, indicating less conserved habitats or with some level of degradation (32). In forest fragments the predominant termite genera (Isoptera) were: *Anoplotermes* sp. *Cylindrotermes* sp. and *Nasusitermes* sp.

The exotic earthworm *Pontoscolex corethrurus* was predominant in all forest fragments and even in the grassland area. Other studies have also shown the predominance of *P. corethrurus* in environments with a certain degree of disturbance or soil management (29, 33) and therefore, this worm is resistant and frequent in environments where the degree of disturbance is intensive as is the case of grasslands.

In the second sampling period (October) ants (Formicidae) were present in forest fragments, mainly in the forest with the highest tree diversity (FFC), and infrequent in the grassland area (Table 2). The climatic conditions and the food available due to leaf litter cover (20) in the forest fragments, probably determined a greater activity of ants, indicating the state of degradation of the pasture for the edaphic organisms, more affected due to the lack of soil cover (33).

The analysis of main components (ACP) presented a significant difference ($p = 0.002$) in the separation of forest fragments and grassland area according to indicators of soil macrofauna. The first factor explained 22% of the variability of the data and mainly separated the FFC from the other areas studied. The second factor explained 18% and separated the FFT and AP from the FFC and FFB (Figure 6).

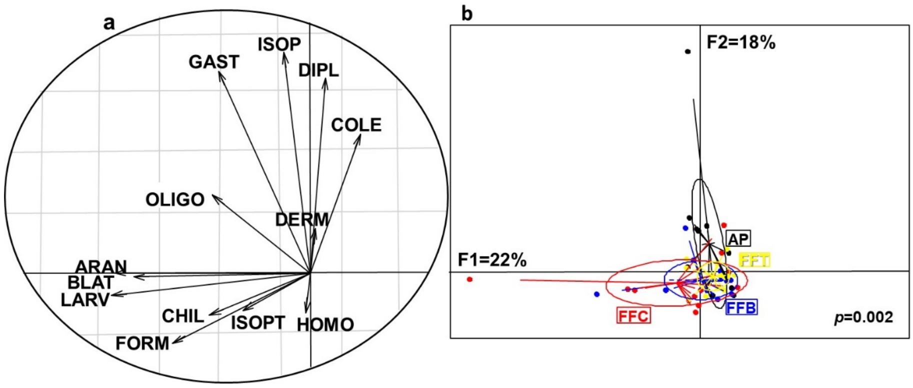

FIGURE 6
Analysis of main components (PCA) of soil macrofauna indicators. (a) correlation circle of the variables: ARAN (Araneae), BLAT (Blattodea), CHIL (Chilopoda), COLE (Coleoptera), DERM (Dermaptera), DIPL (Diplopoda), FOR (Formicidae), GAST (Gasteropoda), ISOP (Isopoda), ISOPT (Isoptera), LARV (larvae), OLIGO (Oligochaeta). (b) Projection of forest fragments: FFB (border forest fragment), FFC (conserved forest fragment), FFT (transition forest fragment) and AP (grassland area) according to indicators

The PCA also presented a significant difference (p = 0.001) of soil macrofauna variables between the two sampling periods (May and October) (Figure 7), indicating that the soil macrofauna community is sensitive to changes in precipitation on a short time scale, as already observed in other studies (20, 21, 32).

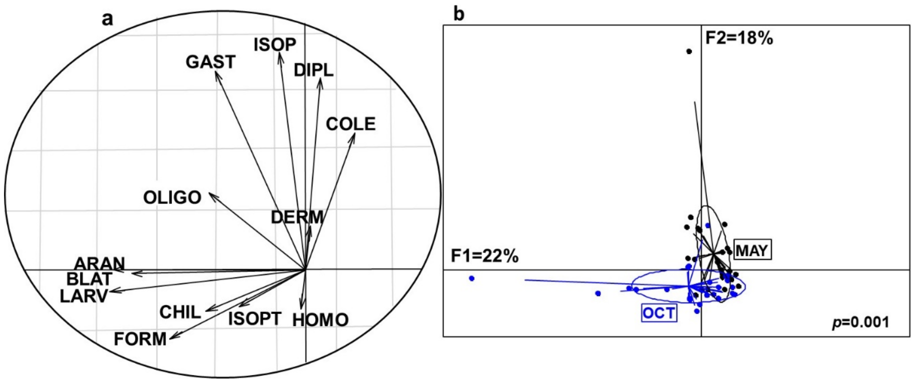

FIGURE 7
Principal Component Analysis (PCA) (a) Correlation Circle of soil macrofauna indicator variables (b) Projection of the May (MAY) and October (OCT) sampling periods as a function of soil macrofauna indicators (b) Projection of the May (MAY) and October (OCT) sampling periods as a function of soil macrofauna indicators

Soil morphology. In the May sampling, the composition of soil organic matter (MO) aggregates (%) was the most abundant in FFC. Biological aggregates (AB) were relatively similar in all forest fragments sampled and grassland area in the two sampling periods. However, in October a higher amount of AB was found in the FFC and FFB; and higher proportions of physical aggregates (PA) in all forest fragments and the PA (Figure 8).

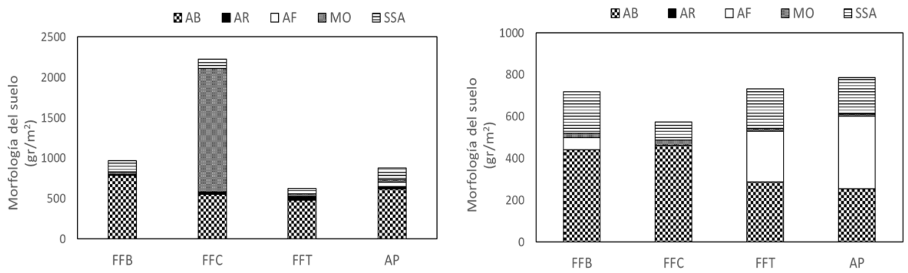

FIGURE 8
Composition of soil morphology (grm2) in biological aggregates (AB), root aggregates (AR), physical aggregates (AF), organic matter (MO) and unaggregated soil (SSA) in the border forest fragment (FFB), conserved forest fragment (FFC), transition forest fragment (FFT) and grassland area (AP) in both sampling periods, May (left) and October (right).

When analyzing soil morphology variables by means of PCA, a total of 58.2% of the variation in the first two factors was explained. However, there was no significant difference between the study areas assessed. Meanwhile, when we analyzed the soil morphology variables between the two sampling periods (May and October) we found a significant difference (p=0.001) (Figure 9).

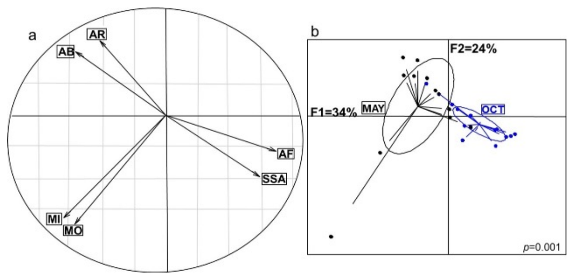

FIGURE 9
Principal component analysis (PCA) (a) Correlation circle of the variables of the soil morphology indicators of biological aggregates (AB), root aggregates (AR), physical aggregates (FA), organic matter (MO) and unaggregated soil (SSA) and (b) Projection of the May (MAY) and October (OCT) sampling periods as a function of the soil morphology indicators.

The statistical analysis of coinertia did not detect significant correlations between soil macrofauna variables and soil morphology in forest fragments and grassland area. However, our data demonstrated differences in macrofaunal composition between the two seasonal sampling periods. The study of (27) mentioned that the community structure of the soil macrofauna varies according to the sampling period, and that the minimum rainfall in agroforestry systems results in an abundant layer of litter in the soil, which provides shelter and food for macroinvertebrates. Also, the density and diversity of the macrofauna is affected, among other factors, by the composition of the systems (21). However, the FFC presented the highest densities of soil macrofauna in both sampling periods, and higher quantities of biological aggregates, these AB being related to greater biological activity and, above all, to the action of ecosystem engineers (31).

Final considerations. Soil macrofauna was predominant in the first soil horizons: litterfall and 0-10 cm depth in all forest fragments evaluated, with social insect groups, Isoptera and Formicidae, being the most predominant in the FFC. This fragment presented a greater diversity of tree composition and the greater density of soil macrofauna in both sampling periods. Meanwhile, the diversity of soil macrofaunal groups was relatively low in the sampling fragments, which may indicate that these areas have some degree of disturbance. On the other hand, these areas are in a state of forest regeneration and, therefore, they are permanent laboratories for the development of research and field practices of the environmental programs of the center of the Regional Amazonas SENA. We thus emphasize the importance of forest fragments as fundamental for the maintenance of biodiversity and soil ecosystem services, particularly urban forest fragments, which are increasingly affected by the growth of the city of Leticia.

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