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# Soil macrofauna associated to agroforestry systems in Colombian Amazon

## Macrofauna edáfica asociada con sistemas agroforestales en la Amazonía colombiana

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## Abstract

The density, richness and diversity of soil macrofauna are influenced by diverse factors such as the configuration of agroecosystems, seasonality, among others. In order to assess this influence, sampling was conducted in May and November 2011, corresponding to the periods of maximum and minimum rainfall respectively on the composition of soil macrofauna associated with agroforestry located in the Research Centre Macagual Cesar Augusto Estrada González property of the University of Amazonia. The experiment was conducted under a completely randomized bifactorial design with 4 treatments (agroforestry system) and 2 periods (maximum and minimum precipitation), with 4 replicates in split plots. Principal component analysis was performed to explore the relationships between the orders and the effect of the agroforestry arrangements was tested with a test of Monte Carlo. The results show that the density of the macrofauna was greater in the period of maximum precipitation compared to the minimum (1129 vs 598 subjects, respectively). The agroforestry arrangements influences the presence or absence of some taxonomic ($P<0.05$) as Homoptera and Raphidioptera, besides than UV and AB can favor the macrofauna of the stress due to the drought.

**Key words:** Soil fauna, agroforestry arrangement, period, density, richness, diversity, Amazon.

## Resumen

La densidad, riqueza y diversidad de la macrofauna edáfica son afectadas, entre otros factores, por la configuración de los agroecosistemas y la estacionalidad de la precipitación. Con el fin de evaluar estos efectos en mayo y noviembre de 2011, correspondientes a épocas de máxima y mínima precipitación, respectivamente, se realizaron estudios sobre la composición de la macrofauna edáfica asociada con los arreglos agroforestales ubicados en el Centro de Investigaciones Macagual Cesar Augusto Estrada González de Corpoica, Amazonia, Caquetá, Colombia. El experimento se dispuso en un diseño completo al azar bifactorial con cuatro tratamientos (arreglos agroforestales: AB = abarco – *Cariniana pyriformis*; CH = caucho *Hevea brasiliensis*; CP = caucho-parica *Schizolobium amazonicum* Huber; UV = uvito *Genipa Americana* L.) y dos épocas (máxima y mínima precipitación), y cuatro repeticiones en parcelas divididas. Para explorar las relaciones entre los órdenes de macrofauna, se realizó un análisis de componentes principales y se evalúo el efecto de los arreglos agroforestales con una prueba de Monte Carlo. Los resultados mostraron que la densidad de la macrofauna fue mayor en el periodo de máxima precipitación (1129 individuos) en comparación con el de mínima (598 individuos). Los arreglos agroforestales influyen sobre la presencia o ausencia de algunos grupos taxonómicos ($P < 0.05$) como Homoptera (Insecta) y Raphidioptera (Insecta); además los UV y AB pueden favorecer a la macrofauna del estrés por sequía.

**Palabras clave**: Edafofauna, fauna del suelo, arreglo agroforestal, época, densidad, riqueza, diversidad, Amazonía.

## Introduction

Soil macrofauna generates benefits for the sustainability of agricultural ecosystems, including the increase of the organic matter dynamic and changes in some of the soil physical properties (Lavelle *et al.*, 2006). The activity, richness and diversity of these organisms can be affected by variations in the type of vegetation, the quality of the vegetable litter and seasonal variations (Velasquez, 2004).

Changes in the cover vegetation of the Amazon region have led to changes in soil macrofauna (Barros *et al.*, 2002; Schon *et al*, 2012). On the other hand, agroforestry arrangements protect soil macrofauna that has been altered by variations in temperature and drought stress (Lavelle *et al.*, 2003); optimizing the management of these arrangements contributes to the stability of macrofauna populations (Barros *et al.*, 2003) and therefore, soil quality (Velazquez *et al.*, 2007).

According to Brown *et al.* (2004) there is a greater richness and abundance of invertebrate communities in agroforestry soils compared with grassland soils. This difference is due to the leaf litter of tree species, which is a source of power and micro-nutrients, and favors the microclimate for macrofauna species (Lavelle *et al.*, 2003; Velasquez, 2004; Huerta and Wal, 2012).

In the study area (Caqueta, Colombia) a monomodal rainfall regime is present with a short period of low rainfall between December and February. A rainfall period is present for the rest of the year, reaching their highest levels between April and August (Olaya *et al.*, 2,005). Periods of maximum and minimum precipitation affect the density of the soil macrofauna, which has a high correlation with the moisture in the soil, which decreases drastically with periods of low rainfall (Gamboa *et al.*, 2011). Due to the limited information regarding the factors that influence and determine the distribution of the soil fauna species and litter in agroforestry systems in the Colombian Amazon, and the need to identify the factors that influence the presence or absence of agroforestry trophic groups, the objective of this study was to estimate the population density and richness of the soil macrofauna associated with existing agroforestry systems in the Research Center Corpoica-Macagual Cesar Augusto Gonzalez Estrada.

## Materials and methods

### Place and study areas

The Research Center Macagual Augusto Cesar Estrada Gonzalez is located at 1 ° 37 'N and 75 ° 36' W, 300 MASL, with an AF climate according to Koppen. It has an annual rainfall of 3,793 mm, 1,707 hours/year of solar brightness, average temperature of 25.5 ° C and 84.25% relative humidity. It is located at 22 km far from the city of Florence, in the southern department of Caqueta (Colombia). The center covers an area of 380 hectares for livestock exploitation with some agroforestry arrangements: AB = abarco (*Cariniana pyriformis*); CH = rubber (*Hevea brasiliensis*); CP = parica rubber (*Schizolobium amazonicum* Huber); UV = Uvito (*American Genipa* L.) (Table 1). Other sesearch projects are also being developed in the research centre on issues related to the efficient management of production systems.

**Table 1.** Agroforestry systems in the Research Center Macagual Cesar Augusto Estrada Gonzalez. Caquetá, Colombia.

| Code of the Location | Description |
|---|---|
| AB | Agroforestry arrangement that includes timber species in superior court. Abarco (*Cariniana pyriformis*) associated with arazá amazonian fruit (*Eugenia stipitata*) and Flemingia shrub species (*Flemingia macrophylla*), which sometimes is incorporated as green manure. |
| CH | Agroforestry arrangement with natural rubber (*Hevea brasiliensis*) associated with copoazú amazonian fruit (*Theobroma grandiflorum*). |
| CP | Multipurpose agroforestry arrangement that includes paricá timber tree (S *Schizolobium amazonicum* Huber), rubber tree (*Hevea brasiliensis*) associated with Copoazu amazonian fruit (*Theobroma grandiflorum*). |
| UV | Agroforestry arrangement that includes timber species in superior court Uvito (*Genipa Americana* L.), peach palm (*Bactris gasipaes*) associated with copoazú amazonian fruit *(Theobroma grandiflorum*), arazá (*Eugenia stipitata*) and flemingia shrub species (*Flemingia macrophylla*), which sometimes is incorporated as green manure. |

### Collection and identification of macrofauna

To determine soil macrofauna the methodology proposed by the Tropical Soil Biology and Fertility (Anderson and Ingram, 1993) was used. In each agroforestry arrangement, four monoliths (blocks of 25 x 25 cm at a depth of 30 cm) were measured in May (rainy season) and November (time of low rainfall) 2011 in order to compare the effect of seasonality rainfall on the composition of the macrofauna. The macrofauna in each monolith was manually removed. The collected invertebrates were preserved in 70% alcohol and

separated according to their morphology. Their identification was to level of "order" under stereoscope, with the help of specialized manuals (Triplehorn and Johnson, 2005).

**Design and data analysis**

In the study, four treatments (agroforestry arrangement) were evaluated in periods of maximum and minimum rainfall, with four replications in a bi-factorial model with completely randomized split plot design. The main plot was the arrangement, and sub-plot was the season. The applied model was as follows:

$$Yijk = \mu + Si + \epsilon i + Ej + SEij + \epsilon k(ij)$$

where: $Yijk$ = one observation; $\mu$ = mean; $Si$ = effect of $i$-th distribution; $\epsilon i$ = error due to distribution; $Ej$ = effect of $j$-th season; $SEij$ = interaction distribution x season; $\epsilon$k(ij) = error due to season.

The comparison of agroforestry arrangements was based on the individual density by order, richness (Σpi), equity or uniformity -by Pielou Index (e) (Pielou, 1969). This index measures the proportion of the observed diversity at the maximum expected diversity and varies between 0 and 1, so that 1 represents situations where all the species are equally abundant, defined as:

$$e = D/Ln\, s$$

where, $D$ = Shannon index (Shannon and Weaver, 1949) and $S$ = number of species or taxonomical groups (Magurran, 1988).

Data of density and richness of taxa soil-fauna, from the different agroforestry arrangements and precipitation seasons, had a variance analysis and means comparison by LSD Fisher test ($p < 0.05$). Blattodea, Dermaptera, Hemiptera, Orthoptera and Raphidioptera taxas showed low density in the agroforestry distributions of both seasons. Therefore, they were grouped in the category 'other' and taken into account for the calculation of the complete taxonomic richness (RT). Besides, a Principal Component Analysis (PCA) was performed to determine the similarity between Agroforestry arrangements by the present taxas and explore the relations between the orders. These data were transformed by log10 (x 1) to reduce the range of variation for density, which was very high for social insects when compared to others. To evaluate the effect of agroforestry arrangements the Monte Carlo test was performed (Lavelle *et al.*, 2014). The analysis of principal coordinates was made by using the R package version 3.1.1 (R Development Core Team, 2014), using the library ade4 (Dray and Dufour, 2007; Chessel *et al.*, 2004).

## Results and discussion

In the evaluation, for the both seasons, 32 samples were collected with a total of 1727 individuals. The number of collected individuals was the highest by the time of maximal precipitation (1129 individuals) compared with those collected in the minimum precipitations season (598 individuals). Some agroforestry arrangements had higher densities in certain taxonomic groups, including: Oligochaeta (OLI), Diplopod (DIP) and Isoptera (ISO) in Abarco (AB); Oligochaeta (OLI) and termites (TER) in rubber (CH); Araneae (Arachnida) in Parica rubber (CP) and ants (HOR) and Coleoptera (COL) in Uvito (UV) (Figure 1).

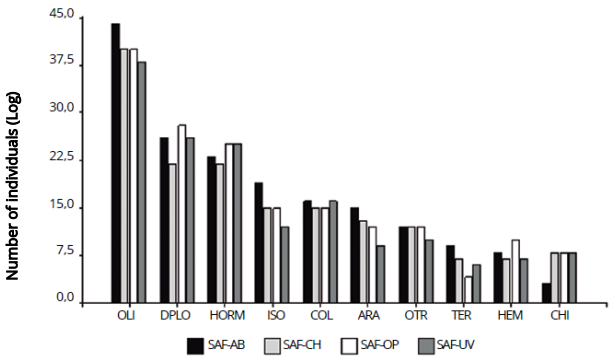


**Figure 1.** Total number of individuals collected during the study (periods of low and high precipitation) in the four studied agroforestry arrangements in the Research Center Macagual Cesar Augusto Estrada González. Caqueta, Colombia.

AB = agroforestry arrangement abarco; CH = agroforestry arrangement rubber; CP = agroforestry arrangement rubber-parica; UV = agroforestry arrangement uvito. TER: Termites, CHI: Chelicerata, ARA: Araneae, HM: Hymenoptera, MS: Hemiptera, ISO: Isoptera, DIPLO: diplopod, COL: Coleoptera, OLI: Oligochaeta, RT: Total richness, OTR: Others.

Interaction between season and type of agroforestry arrangement was observed for density ($P < 0.004$) y richness ($P < 0.0043$). The minimum precipitation season showed a contrast between richness and density, being the

**Table 2.** Fauna density (ind./m$^2$) and richness of taxa found in different agroforestry arrangements and rainfall seasons in the Research Center Macagual Cesar Augusto Estrada Gonzalez. Caquetá, Colombia.

| Arrangement | Density | | Richness | |
|---|---|---|---|---|
| | Max. prec. | Min. prec. | Maxi. | Min. prec. |
| AB | 38.5Aa* | 4.33Ba | 1.67Aa | 3.71Ba |
| CH | 11.00Aa | 10.29Aa | 1.89Aa | 3.24Aab |
| CP | 18.05Aa | 8.05Ba | 2.30Aa | 3.77Bab |
| UV | 22.36Aa | 9.55Aa | 2.41Aa | 2.45Ab |
| Season (E) | 0.0006 | | ns | |
| System (S) | ns | | ns | |
| E x S | 0.004 | | 0.0043 | |

* Data followed by the same capital letters (into each row), or by lowercase letters (into each column) for each sampling season are not significantly different, according to the LSD Fisher test (P < 0.05).
AB = agroforestry arrangement abarco; CH = agroforestry arrangement rubber; CP = agroforestry arrangement rubber-parica; UV = agroforestry arrangement uvito.

richness the higher in the arrangements AB and CP (P <0.05) (Table 2).

In the season of low rainfall, the Shannon Diversity Index was the highest for all the agroforestry arrangements (P <0.05). The Pielou index did not show differences (P >0.05) despite that it varied among the different agroforestry arrangements and seasons (Table 3). This is explained by the similarity in structure that was present in the arrangements, keeping stable climatic conditions (radiation and temperature), and favoring the homogeneous distribution of faunal communities.

**Table 3.** Shannon and Peilou index for the two seasons in the agroforesty arrangements of the Research Center Macagual Cesar Augusto Estrada Gonzalez. Caquetá, Colombia.

| Arrangement | Max. prec. | Min. prec. | Max. prec. | Min. prec. |
|---|---|---|---|---|
| | Shannon Index | | Peilou Index | |
| CH | 1.54Ba* | 0.49Aa | 0.52Aa | 0.73Aa |
| UV | 1.55Ba | 0.58Aab | 0.52Aa | 0.71Aa |
| CP | 2.21Ba | 0.68Aab | 0.59Aa | 0.66Aa |
| AB | 2.27Ba | 0.84Ab | 0.45Aa | 0.69Aa |

*Data followed by the same capital letters (into each row), or by lowercase letters (into each column) for each sampling season are not significantly different, according to the LSD Fisher test (P < 0.05).
AB = agroforestry arrangement abarco; CH = agroforestry arrangement rubber; CP = agroforestry arrangement rubber-parica; UV = agroforestry arrangement uvito.

Taxonomic groups analysis in each of the agroforestry arrangements for each period of precipitation, showed variations in the number of taxa and individuals. Orders with higher number of individuals, regardless of season and arrangement, were Oligochaeta and ants with 990 and 189 total individuals respectively.

Taxa groups as Homoptera in UV and Raphidioptera in CH were found only in one agroforestry arrangement. This is a response to the related configuration of the arrangement in accordance with temperature conditions and availability of organic matter (Figure 2). In the assessment of presence/absence, it was found that Hemiptera (HEM) was the only order during the period of maximum precipitation. It suggested that this group is sensitive to temperature changes and humidity. Due to their conditions as predators, some taxa such as Chilopoda are present in this season due to the availability of food (Zerbino *et al*, 2008; Cabrera *et al.*, 2011).

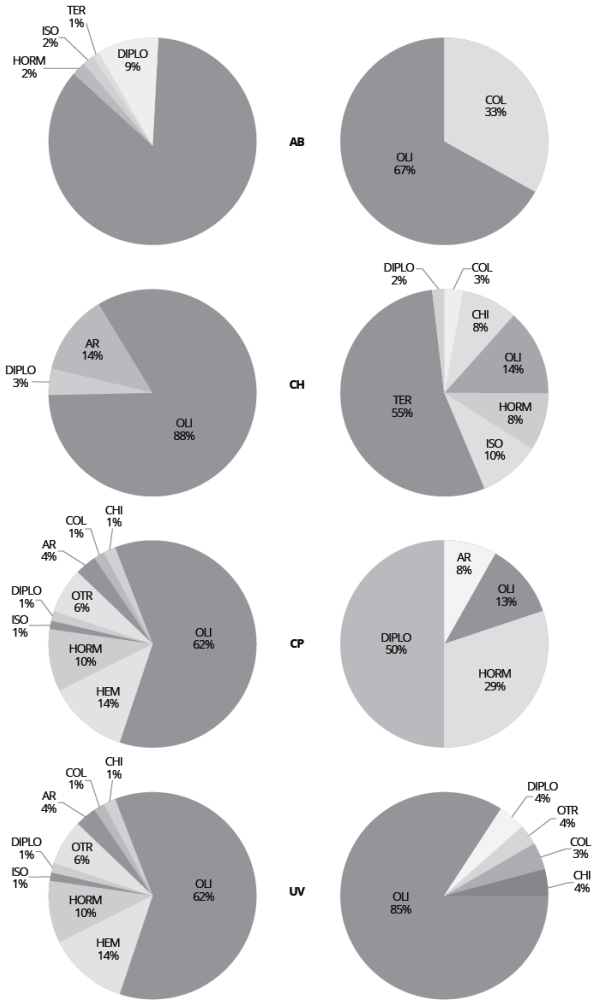


**Figure 2.** Population distribution of taxa identified in the four studied agroforestry arrangements. Research Center Macagual Cesar Augusto Estrada González. Caqueta, Colombia

TER: Termites, CHI: Chelicerata, ARA: Araneae, HM: Hymenoptera, MS: Hemiptera, ISO: Isoptera, DIPLO: diplopod, COL: Coleoptera, OLI: Oligochaeta, RT: Total richness, OTR: Others.

Figure 3 shows the arrangement of taxa in the factorial plane F1 / F2 of ACP macro/invertebrate communities. F1, explaining 26.9% of variance, opposes systems (especially CP and UV) with a higher density and diversity of macrofauna, especially Diplopoda, ants and litter invertebrates (many of them grouped in the category 'other') to the poorer systems (CH). Axis 2 separates the system AB from the others by the highest densities of earthworms (OLI), Coleoptera (COL) and Diplopoda, which are indicator groups of open systems. Diplopods (DIPL) are more common in forest systems, although some are associated with crops (Polydesmidae), and can act as pests. Monte Carlo test, with the permutation of the coordinated points, indicates that the gap between used systems is highly significant (P <0.001) and 36.9% explains the variance.

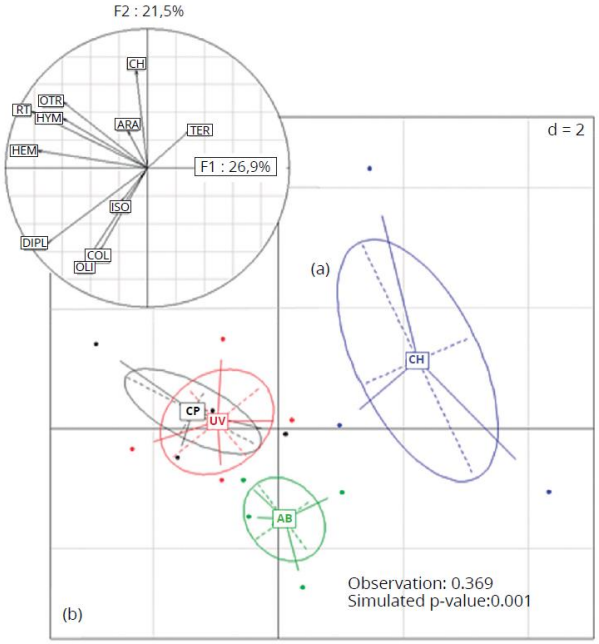


**Figure 3.** Agroforestry organization included in the factorial plane of a principal component analysis of the community structure. Research Centre Macagual Cesar Augusto Estrada González. Caqueta, Colombia.

(a) Correlation circle. TER: Termites, CHI: Chelicerata, ARA: Araneae, HM: Hymenoptera, MS: Hemiptera, ISO: Isoptera, DIPLO: diplopod, COL: Coleoptera, OLI: Oligochaeta, RT: Total richness, OTR: Others. (b). The ordering of agroforestry systems included in the defined plane sample by the first two axes. Letters correspond to the barycenters of the sampled agroforestry systems.AB = agroforestry arrangement abarco; CH = agroforestry arrangement rubber; CP = agroforestry arrangement rubber-parica; UV = agroforestry arrangement uvito. (Monte Carlo test in the

According to the analysis of principal coordinates, the CP and AB agroforestry arrangements share taxa, while CH and UV where the opposite (Figure 4). Exclusive taxa were found for some arrangements, for example: Homoptera

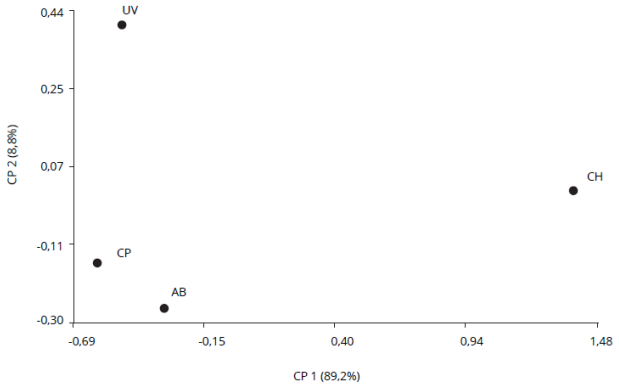


**Figure 4.** Ordination (principal coordinates) for soil macrofauna in relation to agroforestry arrangements in the Research Center Macagual Cesar Augusto Estrada González during minimum and maximum precipitation seasons. Caquetá, Colombia.

AB = agroforestry arrangement abarco; CH = agroforestry arrangement rubber; CP = agroforestry arrangement rubber-parica; UV = agroforestry

and Dermaptera in UV and Raphidioptera in CH. The distribution of taxa in each agroforestry arrangement is included in Table 4.

In general, agroforestry arrangements differ according to macrofauna taxa present in the soil, for example, predator, detritivore, herbivore and "soil engineers" functional groups (Zerbino *et al*, 2008; Cabrera *et al*, 2011). Isoptera (TER) is one of the dominant taxa in the CH group, which plays a beneficial role in promoting essential ecological processes in agro-ecosystems such as carbon and nitrogen flows and decomposition of vegetable matter, increasing soil fertility (Lavelle *et al.*, 1994). Diplopoda taxon, which belongs to the millipede, showed the highest density in agroforestry arrangements of abarco (AB) possibly due to the nitrogen content and carbohydrates of plants as legumes, which provide biomass in the arrangement (Kadamannaya and Sridhar, 2009). A similar case

**Table 4.** Taxon distribution in the different agroforestry arrangements and rainfall seasons in the Research Center Macagual Cesar Augusto Estrada González. Caquetá, Colombia.

| Arrangement | Taxonomic Group |
|---|---|
| AB | Araneae, Coleoptera, Oligochaeta, Diplopoda, Hemiptera, Hymenoptera (HOR), Isopodo, Isoptera, Orthoptera. |
| CH | Araneae, Blattodea, Coleoptera, Chilopoda, Oligochaeta, Diplopoda, Hymenoptera, Isopodo, Isoptera, Orthoptera, Raphidioptera. |
| CP | Araneae, Blattodea, Coleoptera, Dermaptera, Oligochaeta, Diplopoda, Hemiptera, Hymenoptera, Isopodo, Isoptera, Orthoptera. |
| UV | Araneae, Coleoptera, Dermaptera, Chilopoda, Oligochaeta, Hemiptera, Homoptera, Hymenoptera, Isopodo, Isoptera. |

AB = agroforestry arrangement abarco; CH = agroforestry arrangement rubber; CP = agroforestry arrangement rubber-parica; UV = agroforestry arrangement uvito.

occurred with Isopods which are detritus organisms (Zerbino *et al*, 2008; Cabrera *et al*, 2011), typical of agro-ecosystems where there is a high supply of biomass, favoring the moisture content (Hadjicharalampous *et al.*, 2002), a conducive condition to their development.

Due to the structure of the agroforestry arrangements, including CP that contributes to the regulation of temperature and water, allowing the presence of other individuals or prey (Bell *et al.*, 2001), there was a greater presence of order Araneae (Arachnida). These results indicate that agroforestry arrangements AB and CP have a lower density of macrofauna at the time of low rainfall, which is consistent with the results of Jimenez *et al.* (2003). They conclude that the monthly values of density were closely linked with soil moisture, while the presence of the dry season drastically reduced population density. Silveira *et al.* (2013) consider that the opening of the agroforestry canopy affects temperature and humidity, as same as the density and richness of some taxa as Hymenoptera. This is related to the results obtained in the interaction between seasons and arrangements of UV and CH. Velasquez (2004) and Pauli *et al.* (2011) found that there is a negative relationship between the density and richness of macrofauna in the soil, probably due to the presence of a dominant group, a situation that was presented in the AB and CP groups at the time of maximum precipitation.

Shannon index showed an evident effect of seasons on the soil macrofauna in all arrangements, with higher values in the period of maximum precipitation, which happens with those reported by Manhães *et al.* (2013). Despite the drastic reduction of this index at the time of low rainfall, the arrangement AB kept the highest diversity, which may be related to their level of complexity (Barros *et al.*, 2002).

## Conclusions

The results of this study show a significant effect of precipitation in the diversity and density of different taxa of soil macrofauna in the Colombian Amazon, showing lower values at the time of low rainfall.

Due to the structural complexity of agroforestry arrangement AB (agroforestry systems Abarco), this preserves more diversity, even during the drought season.

Exclusive taxa were present in some agroforestry arrangements, such as Raphidioptera in CH and Homoptera in UV. This condition is related to the agroforestry configuration that favors moisture by the contribution of biomass, which comes from species in the canopy and their spatial distribution. As consequence, higher density of individuals per m2 in the same agroforestry arrangements is related, regardless of the time of sampling.

## References

Anderson, J. M. and Ingram, J. S. I. 1993.Tropical soil biology and fertility: a handbook of methods. 2nd ed. Wallingford. CABI. p. 240.

Barros, E.; Neves, A.; Blanchart, E.; Fernandes, E.; Wandelli, E. and Lavelle P. 2003. Development of the soil macrofauna community under silvopastoral and agrisilvicultural systems in Amazonia. Pedobiologia 47(3):273 - 280.

Barros, E.; Pashani B.; Constantino R. and Lavelle, P. 2002. Effects of land-use system on the soil macrofauna in western Brazilian Amazonia. Biol. Fertil. Soils 35(5):338 - 347.

Bell, J. R.; Wheater, C. P.; and Cullen, W. R. 2001. The implications of grassland and heathland management for the conservation of spider communities: a review. J. Zool. 255:377 - 387.

Brown, G. G.; Moreno, A. G.; Barois, I.; Fragoso, V.; Rojas, P.; and Hernández, B. 2004. Soil macrofauna in SE Mexican pastures and the effect of conversion from native to introduced pastures. Agric. Ecosys. Environ. 103(2):313 - 327.

Cabrera, G.; Robaina, N. and Ponce de León, L. 2011.Composición funcional de la macrofauna edáfica en cuatro usos de la tierra en las provincias de Artemisa y Mayabeque, Cuba. Pastos y Forrajes 34(3):331 - 346.

Chessel, D.; Dufour, A.B., and Thioulouse, J., 2004. The ade4 package-I-One-table methods. R News 4:5 - 10.

Dray, S. and Dufour, A. B., 2007. The ade4 package: implementing the duality diagram for ecologists. J. Stat. Softw. 22:1 - 20.

Gamboa, J. A.; Suárez, J. C.; and Chaves, J. A. 2011.Macroinvertebrados edáficos asociados a rastrojos en paisaje de lomerío de la Amazonia colombiana. Valoración de rastrojos para la formación de sistemas silvopastoriles en la Amazonia colombiana. Universidad de la Amazonia p.116 - 128.

Hadjicharalampous, E.; Kalburtji, K. L.; and Mamolos, A. P. 2002. Soil Arthropods (Coleoptera, Isopoda) in organic and conventional agroecosystems. Environ. Manage. 29(5):683 – 690.

Huerta, E. and Wal, V. 2012. Soil macroinvertebrates abundance and diversity in home gardens in Tabasco, Mexico, vary with soil texture, organic

matter and vegetation cover. Eur. J. Soil Biol. 50:68 – 75.

Husson, F.; Josse, J.; Le, S.; and Mazet, J. 2012. FactoMineR: Multivariate exploratory data analysis and data mining with R. R package version 1.18. http://CRAN.R-project.org/package =FactoMineR.

Jiménez, J. J; Moreno, A. G; Decaëns, T; Lavelle, P; Fisher, M. J. and Thomas, R. J. 2003. Las comunidades de lombrices en las sabanas nativas y en los pastizales introducidos de los Llanos Orientales de Colombia. En: Jiménez, J. J. y R. J. Thomas (eds.). El arado natural: Las comunidades de macroinvertebrados del suelo en las sabanas neotropicales de Colombia. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. p. 57 - 75.

Kadamannaya, B. S and Sridhar, K. R. 2009. Leaf litter ingestion and assimilation by two endemic pill millipedes (Arthrosphaera). Biol. Fertil. Soils 45:761 - 768.

Lavelle, P.; Rodríguez, N.; Arguello, O. *et al*. 2014. Soil ecosystem services and land use in the rapidly changing Orinoco river basin of Colombia. agriculture, Ecosys. Environ. 185:106 - 117.

Lavelle, P.; Decaëns, T.; Aubert, M. 2006. Soil invertebrates and ecosystem services. Eur. J. Soil Biol. 42(1):3 - 15.

Lavelle, P.; Senapati, B.; and Barros, E. 2003. Soil macrofauna. In: Schroth, G. y Sinclair. F. L. (eds.). Trees, crops and soil fertility. CABI Publishing, Wallingford. p. 303 - 324.

Lavelle, P.; Dangerfield, M.; Fragoso, C. *et al*. 1994. The relationship between soil macrofauna and tropical soil fertility. In: Woomer, P. y Swift, M. (eds.). The Biological management of tropical soil fertility. John Wiley and Sons, Chichester. p. 137 – 170.

Manhães, C. M. C.; Gama-Rodrigues, E. F.; Moço, M. K. S.; and Gama-Rodrigues, A. C. 2013. Meso-and macrofauna in the soil and litter of leguminous trees in a degraded pasture in Brazil. Agroforestry systems, 87(5), 993-1004.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, New Jersey. p. 179.

Olaya, E. J.; Gaitan, A. E.; and Millan E. E. 2005. Revisión y ajuste a la propuesta de plan de ordenación y manejo ambiental de las microcuencas La Batea y San Joaquín, municipio de Florencia**.** Undergraduate thesis. Faculty of Engineering. Program of Agroecologic Engineering. Universidad de la Amazonia. 136 p.

Pauli, N.; Barrios E.; Conacher, A. J. and Oberthür, T. 2011. Soil macrofauna in agricultural landscapes dominated by the Quesungual slash-and-mulch agroforestry system, western Honduras. Appl. Soil Ecol. 47(2)119 - 132.

Pielou, E. C. 1969. An Introduction to mathematical ecology. Wiley-Interscience, Nueva York.

R Development Core Team. 2014. R: A language and environment for statistical computing. R. Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/

Schon, N. L.; Mackay, A. D. and Minor, M. A. 2012. Vulnerability of soil invertebrate communities to the influences of livestock in three grasslands. Appl. Soil Ecol. 53:98 – 107.

Shannon, C. E.; Weaver, W. 1949. The mathematical theory of communication. Urbaba: University of Illinois Press. p. 78.

Silveira, J. M.; Barlow, J.; Andrade, R. B. *et al*. 2013. The responses of leaf litter ant communities to wildfires in the Brazilian Amazon: a multi-region assessment. Biodiv. Conserv. 22:513 - 529.

Triplehorn, C. and Johnson, F. 2005. Borror and delong´s: introduction to the: study of insects. 7ª ed. Ed. Thomson. EE.UU. p. 864.

Velásquez, E. 2004. Bioindicadores de calidad de suelo basado en las poblaciones de macrofauna y su relación con características funcionales del suelo. PhD thesis. Universidad Nacional de Colombia - Palmira. 189 p.

Velásquez, E.; Lavelle, P.; and Andrade, M. 2007. GIQS: a multifunctional indicator of soil quality. Soil Biol. Biochem. 39:3066 - 3080.

Zerbino, S.; Altieri, N.; Morón, A.; and Rodríguez, C. 2008. Evaluación de la macrofauna del suelo en sistemas de producción en siembra directa y con pastoreo. Agrociencia 12:(1)44 - 55.