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***Edaphic macroinvertebrates in productive systems of Coffea arabica in
Garzón, Huila, Colombia***

*Macroinvertebrados edáficos en sistemas productivos de Coffea arábica en Garzón, Huila,
Colombia*

*Macroinvertebrados do solo em sistemas de produção de Coffea arabica em Garzón, Huila,
Colômbia*

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SUMMARY

Agroforestry systems are an increasingly implemented alternative for coffee production in Colombia due to the multiple socioeconomic and environmental benefits. They generate an ideal habitat for soil macrofauna. The objective of this research was to evaluate the incidence of two coffee production systems on the population behavior of edaphic macroinvertebrates. In order to do this, the composition, richness, abundance and vertical



distribution of soil macroinvertebrate families in Secondary Forest (Bs), Coffee Agroforestry Systems (SAFc) and Coffee Monoculture (Mc) systems were evaluated in four strata (leaf litter, 0-10 cm, 10-20 cm and 20-30 cm). 22 orders and 53 families of edaphic macroinvertebrates were identified, presenting the highest abundance of Lumbricidae, Formicidae, Porcellionidae and the lowest of Forficulidae, Geophilidae and Polydesmidae, with Bs > SAFc > Mc, except Forficulidae, Polydesmidae and Porcellionidae, which were found in greater abundance in Mc than in SAFc; in all systems the abundance was higher in the first 10 cm of the soil ($p < 0.05$). Wealth showed a similar behavior, although without statistically significant effects. Although there are soil macroinvertebrates that are tolerant to the disturbances caused by forest cover changes to establish coffee production systems, some families of macroinvertebrates are susceptible to these cover changes, which makes them potential indicators of soil disturbances.

Keywords: abundance, coffee, edaphic fauna, richness, agroforestry system

RESUMEN

Los sistemas agroforestales son una alternativa cada vez más implementada para la producción de café en Colombia debido a los múltiples beneficios socioeconómicos y ambientales. En ellos, se genera un hábitat ideal para la macrofauna del suelo. El objetivo de esta investigación fue evaluar la incidencia de dos sistemas productivos de café sobre el comportamiento poblacional de los macroinvertebrados edáficos. Para ello, se evaluó la composición, riqueza, abundancia y distribución vertical de las familias de macroinvertebrados del suelo en sistemas de Bosque secundario (B.s), Sistemas agroforestales de café (S.A.F.c) y en Monocultivo de café (M.c), en cuatro estratos (hojarasca, 0-10 cm, 10-20 cm y 20-30 cm). Se identificaron 22 órdenes y 53 familias de macroinvertebrados edáficos, presentándose la mayor abundancia de Lumbricidae, Formicidae, Porcellionidae y la menor de Forficulidae, Geophilidae y Polydesmidae siendo B.s > S.A.F.c > M.c, salvo Forficulidae, Polydesmidae y Porcellionidae que se encontraron en mayor abundancia en M.c que en S.A.F.c; en todos los sistemas la abundancia fue mayor en los primeros 10 cm del suelo ($p < 0,05$). La riqueza mostró un comportamiento similar,



aunque sin efectos estadísticamente significativos. Si bien hay macroinvertebrados del suelo tolerantes a las perturbaciones ocasionadas por los cambios de cobertura boscosa para establecer sistemas productivos de café, algunas familias de macroinvertebrados son susceptibles a estos cambios de cobertura lo que las convierte en indicadores potenciales de alteraciones en el suelo.

Palabras clave: abundancia, café, fauna edáfica, riqueza, sistema agroforestal.

RESUMO

Os sistemas agroflorestais são uma alternativa cada vez mais implementada para a produção de café na Colômbia devido aos múltiplos benefícios socioeconômicos e ambientais. Eles criam um habitat ideal para a macrofauna do solo. O objetivo desta pesquisa foi avaliar o impacto de dois sistemas de produção de café no comportamento populacional de macroinvertebrados edáficos. Para tanto, foram avaliadas a composição, riqueza, abundância e distribuição vertical de famílias de macroinvertebrados do solo em sistemas florestais secundários (B.s), sistemas agroflorestais cafeeiros (S.A.F.c) e em monocultura de café (M.c), em quatro estratos (folha serapilheira, 0- 10 cm, 10-20 cm e 20-30 cm). Foram identificadas 22 ordens e 53 famílias de macroinvertebrados edáficos, sendo a maior abundância de Lumbricidae, Formicidae, Porcellionidae e a menor de Forficulidae, Geophilidae e Polydesmidae sendo B.s > S.A.F.c > M.c, exceto Forficulidae, Polydesmidae e Porcellionidae que foram encontrados em maior abundância em Mc do que em S.A.F.c; Em todos os sistemas a abundância foi maior nos primeiros 10 cm do solo ($p < 0,05$). A riqueza apresentou comportamento semelhante, embora sem efeitos estatisticamente significativos. Embora existam macroinvertebrados do solo que são tolerantes às perturbações causadas pelas alterações na cobertura florestal para estabelecer sistemas de produção de café, algumas famílias de macroinvertebrados são suscetíveis a essas alterações na cobertura, o que os torna potenciais indicadores de alterações no solo.

Palavras-chave: abundância, café, fauna edáfica, riqueza, sistema agroflorestal.



INTRODUCTION

Coffee (*Coffea arabica* L.) is an example of the agricultural crops that have been developed in Colombia since the 18th century to the present. Currently, the departments of Huila, Nariño and Cauca make up the new 'Coffee Axis'. The cultivated surfaces have grown 63.6 % in the last 13 years, which leads to a greater expansion of the local agricultural territory, compromising the soil resource. Thanks to its agricultural vocation and coffee tradition, the department of Huila has established itself in recent years as the main coffee producer in Colombia (Cerquera *et al.*, 2020).

The transformation of native landscapes due to the intensification of coffee monocultures has been one of the main causes of the loss of biodiversity in high Andean ecosystems. Edaphic macroinvertebrates, which are soil invertebrates larger than 2 mm, can play an important role as bioindicators. Its abundance, taxonomic richness and vertical distribution vary depending on the vegetation cover, the different uses and management of the soil, as well as seasonal variations (Doblas *et al.*, 2009) ; Cabrera *et al.*, 2017 ; Velásquez and Lavelle, 2019).

Agroforestry systems (crop and tree association) represent an opportunity for coffee production with sustainability criteria. These systems are positively correlated with biodiversity Campera *et al.* (2022) and the abundance of soil macrofauna (Rojas *et al.*, 2021) . In contrast, in coffee monocultures bioindicator organisms predominate, that indicates imbalance and disturbance in the soil (Rodríguez *et al.*, 2019) .

The objective of this research is to evaluate the incidence of two coffee production systems on the composition, richness, abundance and vertical distribution of edaphic macroinvertebrates in the municipality of Garzón, Huila, Colombia.

MATERIALS AND METHODS

Study zone

It is located 15 km east of the municipality of Garzón - Huila (Colombia). Nine farms with an average area of 1.0 ha were identified. These were located between the coordinates 02°20'52" north latitude and 75°54'17" west longitude of Greenwich, at an altitude of 1,460 to



1,668 masl. All the farms are within the Premontane Humid Forest life zone. (Bh-P) according to the Holdridge classification. Average temperatures between 18 °C and 24 °C predominate and annual rainfall ranges between 2,000 and 3,500 mm. The soils of the area are superficial to deep, well drained, slightly acid and of moderate fertility (IGAC, 1994 and 2014).

Systems evaluated

Coffee monocultures (MC) were evaluated with a planting distance of 1.2 mx 1.8 m and a density of 4,630 trees per hectare, agroforestry systems of coffee and plantain (*Musa paradisiaca* L.) (SAFC), established at a distance of 1.2 mx 1.8 m and 5.6 mx 3 m, respectively, and areas of secondary forest (BS) moderately intervened as positive control. The coffee plantations corresponded to plantations of the Catimor variety, established 11 years ago, two years after the last stumping (total pruning of the stems 30 centimeters from the ground to stimulate the regrowth of new stems).

The agronomic management of MC and SAFC was carried out by the producers following the recommendations of the technical assistants in the area, thus: applications of 100 cm³ of glyphosate in 20 L of water to control weeds, twice a year and pruning with a scythe every four months. Pest control was carried out through applications of pesticides based on Phenylpyrazole, Chlorpyrifos and Thiamethoxam + Ciproconazole, in doses of 25 ml per 20 L of water, with annual applications in SAFC and biannual in MC. Fertilization was performed with urea, diammonium phosphate (DAP) and calcium oxide (CaO). In each case, a dose of 50 grams per plant was used, every four months.

The secondary forest (Bs) is approximately 40 years old; Ararat and Prager (2002) found in these forests in the area, species such as *Goupia glabra* A. (white cedar), *Cedrela odorata* L. (pink cedar), *Erythrina poeppigiana* W. (cachingo), *Persea caerulea* R&P (aguacatillo), *Chrysophyllum cainito* L. (caimo), *Inga marginata* W. (guamo) and *Jacaranda copaia* A. (gualandai).

Establishment of the design and sampling in the field

A Randomized Complete Blocks (BCA) design was established in a factorial arrangement with four (4) replicates. Factor A corresponded to the evaluated systems (Mc, SAFC and Bs)



and factor B to the four invertebrate sampling depths (leaf litter, 0-10 cm, 10-20 cm and 20-30 cm).

The samplings were carried out in the month of October 2018 (there was a collection permit, according to Resolution 01140 of 2016), in the rainy season, before starting the second significant coffee harvest of the year to avoid anthropic disturbances.

The edaphic macroinvertebrates were collected using the method suggested by Velasquez and Lavelle, (2019). In each system, three monoliths (25 x 25 cm) or subsamples per replicate were collected; the monoliths were divided into four strata: litter, 0-10, 10-20 and 20-30 cm. For the collection of edaphic macroinvertebrates, they used entomological tweezers and brushes. These were preserved in 70 % alcohol, with the exception of the worms, which were preserved in vials with 5 % formalin. Subsequently, they were transferred to the Entomology Laboratory of the University of the Amazon (LEUA) for their characterization at the order and family level. The taxonomic keys and descriptions of Ruiz *et al.* (2008) and Borrer *et al.* (1992) were used.

Response variables and analysis of biological data

For the analysis of macroinvertebrates, the values of richness (number of families), specific abundance (individuals m⁻²), density (number of individuals m⁻²) and vertical distribution of the macroinvertebrates were determined as a function of abundance in each profile or soil layer. The overall results in each of the systems were calculated and presented.

In addition, the assumptions of normality and homogeneity of the variances of the data were validated by means of an exploratory residual analysis (QQ plot, Shapiro-Wilk test, and plot of predicted values against residuals). The data that presented a normal distribution and homogeneity of variance (richness) were analyzed using Fisher's LSD test (p<0.05) and the data that did not present a normal distribution were analyzed using the non-parametric Kruskal-Wallis test. (p<0.05).

A multivariate analysis was used in order to reduce the information and facilitate its interpretation. In the case of diversity, a correspondence analysis (CA) was carried out based on the presence - absence of soil macrofauna families. This allowed us to identify those families that were exclusive or shared between systems. All analyzes were performed with the InfoStat software, version 2018.



RESULTS AND DISCUSSION

Composition of the richness and abundance of edaphic macroinvertebrates.

The taxonomic richness was represented by two phylums, seven classes, 22 orders and 53 families of edaphic macroinvertebrates. The greatest richness was found in Bs, followed by SAFc and Mc. Despite this, the evaluated systems did not present statistically significant differences ($p > 0.072$) in the richness of taxonomic groups (Table 1). This type of behavior may correspond to a sampling effort or insufficient statistical power; however, these results present a trend in which richness decreases as the degree of disturbance and differences in vegetation increase, as occurs with high Bs heterogeneity and Mc homogeneity. The foregoing coincides with reports by Delgado *et al.* (2011) and Cabrera *et al.* (2011) who indicate that the richness of species is higher in the forest and in agroforestry systems than in production systems without the presence of trees, thanks to the diversity of the vegetation, the availability of food for the species, the complex structure of the vegetation that provides habitat sites and offers better protection than in simpler agricultural systems. Rojas *et al.* (2021) also affirm that coffee agroecosystems with complex vegetation help maintain a high richness of macroinvertebrates, which allows a greater similarity with the forest, as is the case of SAFc (Table 1).

Table 1. - Abundance (individuals m^{-2}) and richness of soil macrofauna in coffee production systems (Mc and SAFc) and in secondary forest (Bs) in the department of Huila

Family	Mc	SAFc	B.s	<i>p</i> -value†	<i>p</i> -value††
Amaurobiidae	1.33 ± 1.33	2.67 ± 1.8	-	ns	
Anisolabididae	1.33 ± 1.33	5.33 ± 5.33	-	ns	
Araneidae	2.67 ± 2.67	-	-		
Bdellidae	-	-	5.33 ± 1.54		
Cantharidae	-	1.33 ± 1.33	-		
Carabidae	4 ± 2.28	1.33 ± 2.28	10.67 ± 4.55	ns	ns
Cheliferidae	-	-	5.33 ± 1.54		
Chthoniidae	-	1.33 ± 1.33	-		
Cixiidae	1.33 ± 1.33	-	-		
Clubionidae	-	2.67 ± 2.67	-		
Coccinellidae	-	1.33 ± 1.19	5.33 ± 2.37		ns
Chrysomelidae	8 ± 6.95	10.67 ± 6.95	5.33 ± 13.9	ns	ns



Cryptopidae	8 ± 3.96	10.67 ± 3.96	16 ± 7.93	ns	ns
Curculionidae	-	8 ± 3.68	-		
Cybaeidae	1.33 ± 1.33	2.67 ± 1.8	-	ns	
Cydnidae	-	5.33 ± 4.1	10.67 ± 10.67		ns
Dictynidae	12 ± 9.26	4 ± 2.09	-	ns	
Ectobiidae	8 ± 6.3	9.33 ± 6.3	42.67 ± 12.59	ns	ns
Elateridae	1.33 ± 1.33	4 ± 2.87	-	ns	
Forficulidae	1.33B ± 1.19	-	10.67 A ± 2.37		**
Formicidae	205.33b ± 75.99	325.33 to ± 75.99	138.67 ± 151.99	*	ns
Geometridae	2.67 ± 1.8	-	-		
Geophilidae	1.33B ± 3.33	1.33B ± 3.33	21.33 A ± 6.67	ns	*
Gryllidae	-	-	10.67 ± 1.54		
Hubbaridiidae	2.67 ± 2.67	-	-		
Isotomidae	21.33 ± 8.22	5.33 ± 8.22	5.33 ± 16.44	ns	ns
Julidae	-	-	10.67 ± 1.54		
Labiduridae	6.67 ± 5.38	16 ± 16	-	ns	
Largidae	-	8 ± 2.83	-		
Lepidopsocidae	1.33 ± 1.33	-	-		
Linyphiidae	17.33 ± 8.77	25.33 ± 8.77	10.67 ± 17.54	ns	ns
Lumbricidae	165.33 bB ± 43.38	352 BC ± 43.38	666.67 A ± 133.7	**	*
Lycosidae	1.33 ± 1.33	-	-		
Mycetophagidae	2.67 ± 1.8	5.33 ± 3.01	-	ns	
Nabidae	1.33 ± 1.33	1.33 ± 1.33	-	ns	
Noctuidae	5.33 ± 2.27	17.33 ± 6.67	-	ns	
Nymphalidae	13.33 ± 13.33	5.33 ± 5.33	-	ns	
Parajulidae	-	17.33 ± 17.33	-		
Pentatomidae	1.33 ± 1.33	-	-		
Pisauriidae	-	13.33 ± 4.33	-		
Polydesmidae	8B ± 3.17	2.67 B ± 3.17	21.33 A ± 6.35	ns	*
Porcellionidae	13.33B ± 7.68	10.67B ± 7.68	80A ± 15.36	ns	*
Ptiliidae	-	5.33 ± 4.10	-		
Salticidae	-	-	5.33 ± 5.33		
Scarabaeidae	8 ± 8.36	13.33 ± 8.36	48 ± 16.72	ns	ns
Siphonotidae	-	8 ± 8	-		
Spirobolidae	-	1.33 ± 1.19	5.33 ± 2.37		ns



Staphylinidae	45.33 ± 14	52 ± 14	53.33 ± 28.01	ns	ns
Superstitioniidae	-	-	5.33 ± 1.54		
Tetragnathidae	2.67 ± 3.16	6.67 ± 3.16	5.33 ± 6.32	ns	ns
Theridiidae	4 ± 4.35	8 ± 4.35	16 ± 8.69	ns	ns
Trogositidae	-	1.33 ± 1.33	-		
Trombidiidae	1.33 ± 1.33	-	-		
Total abundance	586.67 bB ± 130.41	969.33 aA ± 130.41	1216 A ± 260.81	*	*
Wealth	8.58 ± 0.84	10.17 ± 0.84	13 ± 1.69	ns	ns

* = $P < 0.05$; ** = $P < 0.01$; ns = not significant. † corresponds to comparisons between production systems; †† corresponds to the comparisons between Bs, Mc and SAFc

Means ± standard error. Means followed by the same lowercase letter do not differ significantly between Mc and SAFc; and means followed by the same capital letter do not differ significantly between Bs, Mc and SAFc according to Fisher's LSD test $p < 0.05$.

Correspondence analysis (Figure 1) showed that eight families (Araneidae, Lycosidae, Hubbardiidae, Trombidiidae, Cixiidae, Pentatomidae, Geometridae and Lepidopsocidae) were associated with a single system, the Mc; ten families (Clubionidae, Pisauriidae, Chthoniidae, Parajulidae, Siphonotidae, Cantharidae, Curculionidae, Ptiliidae, Trogositidae and Largidae) were only recorded in SAFc, while Salticidae, Superstitioniidae, Cheliferidae, Bdellidae, Julidae and Gryllidae were only recorded in Bs (Figure 1). The low representativeness of the reported families indicates that they are more susceptible to environmental disturbances. Families associated with Mc and SAFc were also recorded (Table 1 and Figure 1), this may be due to the fact that *C. arabica* is found covering most of the soil, providing a similar habitat in the two ideal systems for these organisms (Campera *et al.*, 2022).



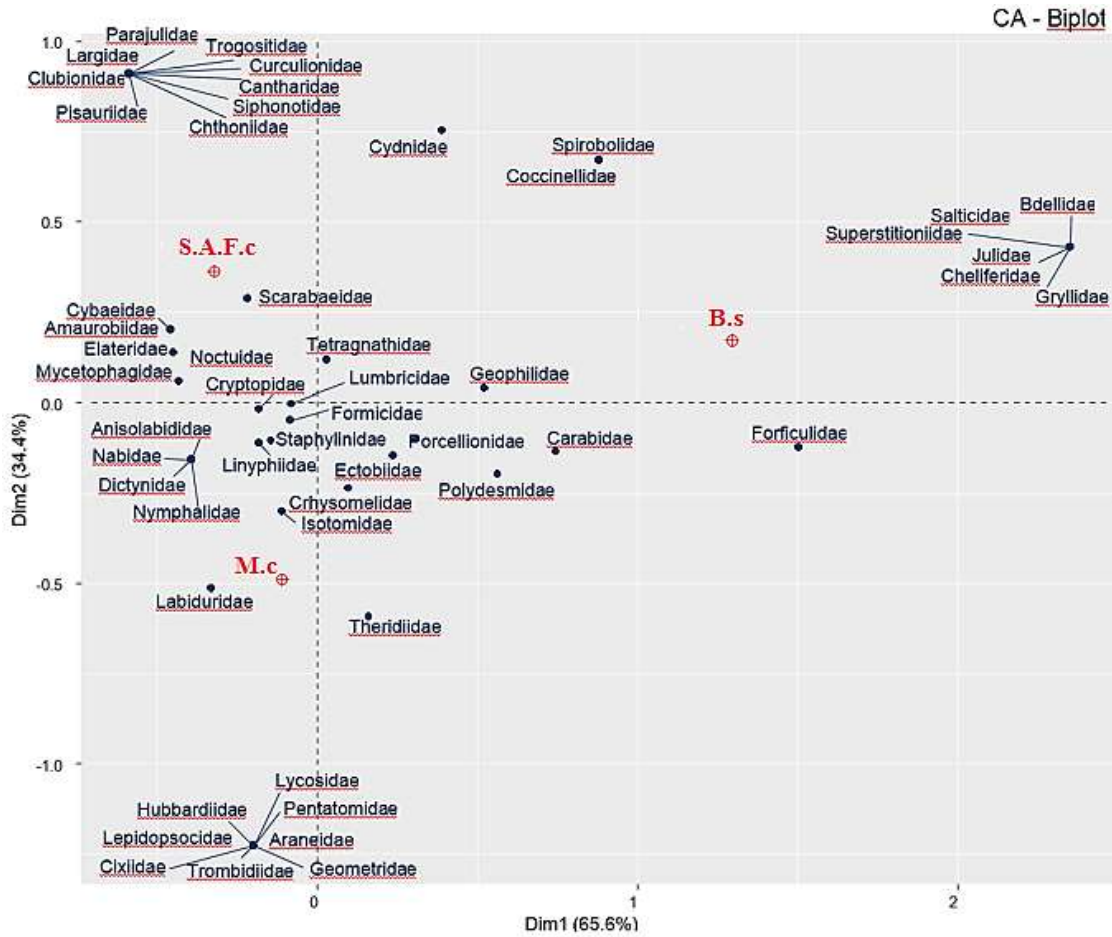


Fig. 1. - Correspondence analysis of soil macrofauna in coffee productive systems and secondary forest of Garzón, Huila

Abundance of individuals per system

22.320 individuals m^{-2} were recorded (Figure 2), with a general average of 826.7 individuals m^{-2} per monolith. The highest abundance on average occurred in B.s, followed by S.A.F.c, these two systems being statistically similar, but presenting significant differences with Mc ($p < 0.014$) (Table 1).



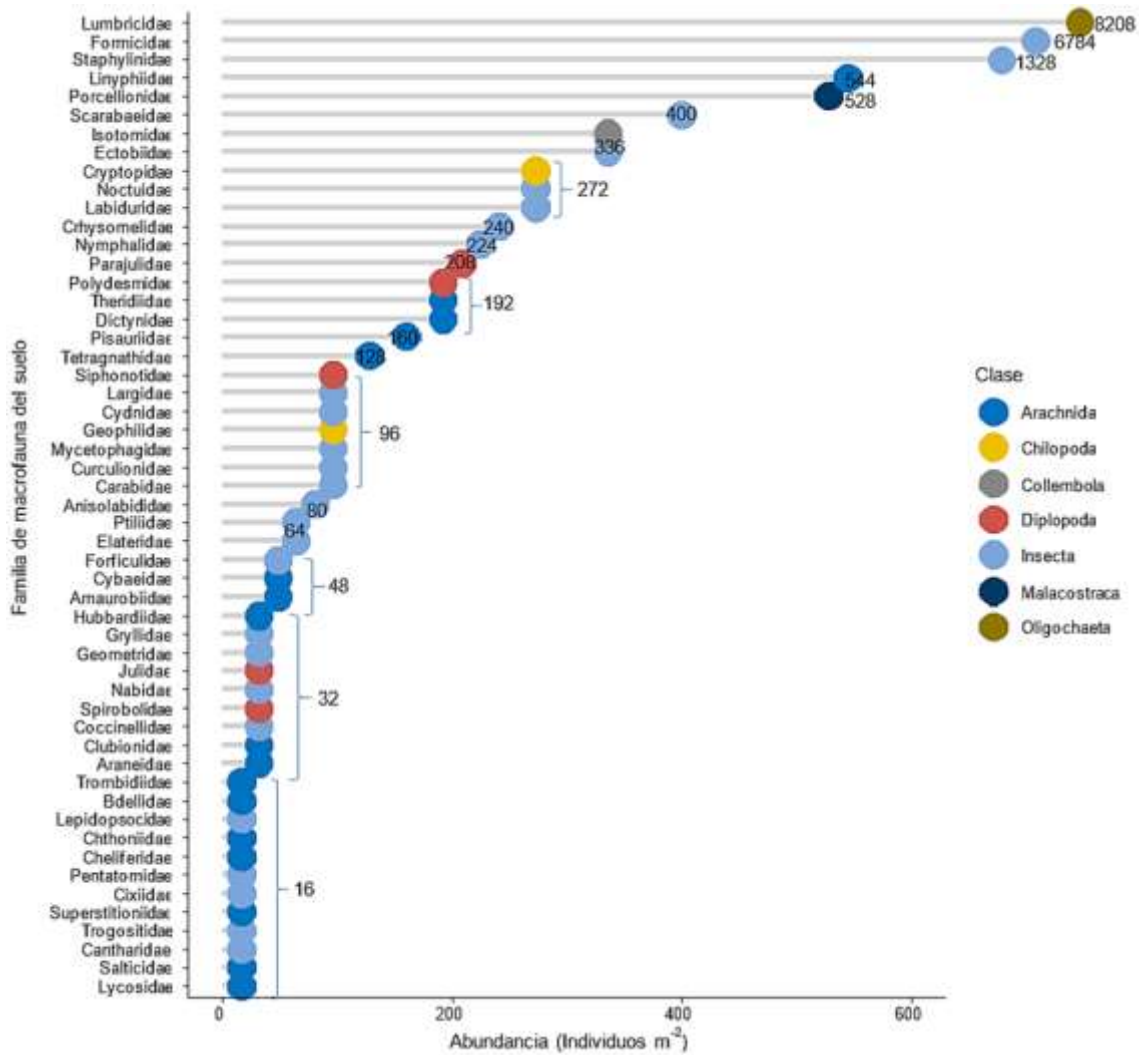


Fig. 2. - Total abundance of soil macrofauna (at family level) in coffee production systems and secondary forest

There were differences ($p < 0.049$) between the coffee production systems (Table 1, Figure 2), showing that the macroinvertebrate communities present in the soil use systems are determined by the availability of resources for their survival and the levels of soil intervention in the development of agricultural activities. The results show that there is a direct positive relationship between less disturbed systems with the abundance of edaphic macroinvertebrates, as argued by other authors (Delgado *et al.*, 2011).



differences between them ($p < 0.001$) (Table 1); mainly because they are organisms that are sensitive to land use because they often live in deep tunnels (Cabrera, 2011).

The Others group corresponds to the remaining 47 family groups that individually contribute less than 2 % each. The abundance of individuals in S.A.F.c did not present statistical differences with B.s, a similar result was presented by Delgado *et al.*, (2011) in a coffee-banana agroforestry system, showing that the macrofauna present in the different land use systems is determined by the availability of resources for their survival and by the intensity of agricultural activities, which suggests that agroforestry systems with coffee can be a viable option to conserve the abundance of edaphic macroinvertebrates.

Vertical distribution of the abundance of macroinvertebrates in general and for each system

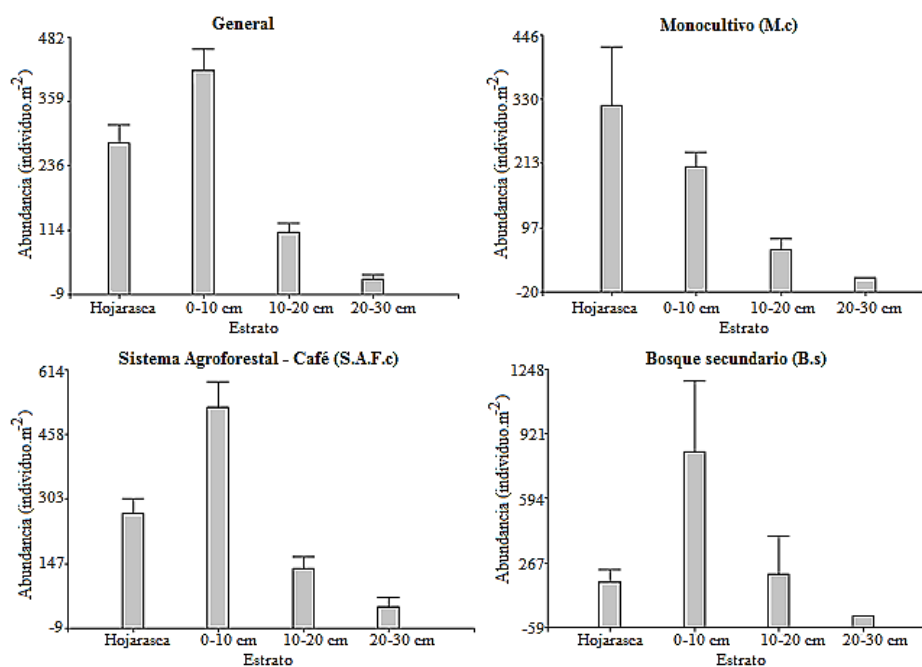


Fig. 3. - Vertical distribution of soil macrofauna in forest and coffee production systems in Garzón, Huila

General

The greatest abundance was found in the 0-10 cm stratum, with significant differences with respect to the litter stratum and other depths (Figure 3); this agrees with the findings of Olayemi *et al.*, (2022) who establish that the macrofauna is confined to the upper part, in the



first centimeters of the soil. Similarly, there were significant differences in the litter in relation to the depths of 10-20 cm and 20-30 cm. These last two strata were statistically similar to each other.

M.c

Greater abundance was found in the litter layer, probably due to the greater contribution of litter in the superficial part, thus influencing the formation of a more favorable habitat for the development of these organisms. However, it is statistically similar to the depth of 0-10 cm, nevertheless, there was a statistically significant difference in litter with respect to the strata of 10-20 cm and 20-30 cm; also, between the 0-10 cm stratum compared to the 20-30 cm stratum (Figure 3). This decrease in macrofauna in the deep strata may be due to the fact that as the soil profile deepens, the porosity, oxygen and organic matter content that provides habitat and food decrease (Vanolli *et al.*, 2023).

The foregoing supports what was mentioned by Armbrrecht and Perfecto (2001), that the coffee monoculture is an exemplary case of how the intensification of agriculture negatively affects tropical biodiversity, because by reducing the presence of shade trees, fauna associated with crops also diminishes. In part, this is explained by the decrease in the structural complexity of the crop and, therefore, of the ecological niches of the fauna resident in it (Rodríguez *et al.*, 2019). In this context of simplification, it is possible to study how the interspecific relationships between the macroinvertebrates that inhabit agroecosystems are affected and how these relationships can favor or harm the interests of the farmer.

S.A.F.c.

Greater abundance was found in the 0-10 cm stratum, presenting statistically significant differences with respect to the litter stratum and other depths. Similarly, there were significant differences in the litter in relation to the depths of 10-20 cm and 20-30 cm; these last two depths, despite having different abundances, were statistically similar (Figure 3). Doblaz (2009) point out that one of the causes that leads to a greater presence of organisms in the first strata (superficial and 0-10 cm) is due to the amount of organic matter due to the plant cover which provides biomass and generates microhabitats favorable for the life of the macrofauna. Duran *et al.* (2023), suggest that the greater structural complexity and botanical composition of agroforestry systems promote the richness and diversity of the edaphic



macrofauna by improving the physical conditions, the organic matter content of the soil, enhancing this by improving its processes of aggregation and porosity.

B.s

The stratum that presented the greatest abundance was 0-10 cm deep (Figure 3). This behavior may be related to the soil that is formed by the addition of leaf litter, in addition, the presence of the tree in the systems makes temperatures and the impact of rain decrease compared to open land, constituting alternatives to achieve the colonization (Lavelle *et al.*, 2022).

CONCLUSIONS

The abundance and distribution of the edaphic macrofauna are highly sensitive attributes when the forest is replaced by coffee production systems. However, the implementation of coffee cultivation in agroforestry systems emerges as an important strategy for the conservation of these organisms.

The most abundant families (Lumbricidae, Formicidae and Porcellionidae) and less abundant (Forficulidae, Geophilidae and Polydesmidae) present a high susceptibility to changes in coverage in the systems.

In the coffee agroforestry system, the greatest diversity of macroinvertebrates is observed in the first 10 cm of soil, while in the monoculture the greatest diversity is found in the litter.

THANKS

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The authors FVC, GRP and VSC have participated in the design and development of the research, data analysis and writing of the manuscript, in a proportion of 33% for each author for the achievement of the article.



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