Edaphic macrofauna in the establishment of an agroforestry system in the High Andean region of Southern Colombia

Macrofauna edáfica en el establecimiento de un sistema agroforestal de la región Alto Andina del Sur de Colombia

Martín Alonso Muñoz-Rodríguez[1*]; Ana Carolina Santacruz-Ortiz[2]

Authors Data

1. Research professor, M.Sc. Universidad de Nariño, Pasto, Colombia, martinmunoz236@udenar.edu.co, https://orcid.org/0000-0003-3312-3608 (Correspondence)

2. Agroforestry Engineer, Universidad de Nariño, Pasto, Colombia, carolina-887@hotmail.com, https://orcid.org/0000-0002-0149-7755

ABSTRACT

Biological degradation of the soil due to inadequate agricultural practices that eliminate vegetative cover and, therefore, organic matter reduces the biological communities that perform important ecological functions in the soil. The objective of the study was to evaluate some biological properties of the soil in an agroforestry system with *Morella pubescens* intercropped with *Smallanthus sonchifolius* and in a degraded pasture of *Cenchrus clandestinum*. The trial was conducted at the Botana Experimental Farm, Nariño, at 2,820 meters above sea level. Density, richness, and Simpson and Shannon-Wiener diversity indices were determined. A Randomized Complete Block Design with three replications was used. The treatments corresponded to sowing distances of *S. sonchifolius*. T1: sown at 1x1m, T2: 0.8x0.8m, T3: 0.5x0.5m, and the control T4 corresponded to degraded pasture of *C. clandestinum*. The tree component *M. pubescens* was established at 4x4m between seedlings

and 9m between rows. Soil macrofauna sampling was carried out following the monolithic TSBF method, collecting at depths of (0-10, 10-20 and 20-30cm). A total density of 6,496i/m2 individuals was found. The highest value was obtained in T3 (3,168i/m2), represented by the taxonomic groups Diptera and Haplotaxida. Higher values of richness were observed in T1. The Shannon index was higher in T2 (0.66), while T1 (0.80) presented higher dominance in morphospecies. Density and richness were higher in the agroforestry arrangement than in the degraded *Cenchrus clandestinum* pasture. Treatments, depth, and their interaction did not significantly affect morphospecies diversity.

Key words: Density; diversity; morphospecies; biological properties; richness; soil.

RESUMEN

La degradación biológica del suelo debido a prácticas agrícolas inadecuadas que eliminan la cobertura vegetal y, por tanto, la materia orgánica, reducen las comunidades biológicas que cumplen funciones ecológicas importantes en el suelo. El objetivo del estudio fue evaluar algunas propiedades biológicas del suelo en un sistema agroforestal con *Morella pubescens* intercalado con *Smallanthus sonchifolius* y en pastura degradada de *Cenchrus clandestinum.* El ensayo se realizó en la Granja Experimenta Botana, Nariño a 2820 msnm. Se determinaron la densidad, la riqueza y los índices de diversidad de Simpson y Shannon-Wiener. Se utilizó el Diseño de Bloques Completos al Azar con tres repeticiones. Los tratamientos correspondieron a distancias de siembra de *S. sonchifolius.* T1: sembrado a 1x1m, T2:0.8x0.8m, T3:0.5x0.5m y el testigo T4 corresponde a pastura degradada de *C. clandestinum*. El componente arbóreo *M. pubescens* se estableció a 4x4m entre plántulas y 9m entre líneas. Los muestreos de macrofauna del suelo se realizaron siguiendo el método monolítico TSBF, recolectando en profundidades de (0-10, 10-20 y 20-30cm). Se encontró una densidad total de 6.496i/m^2 individuos. El mayor valor se obtuvo en el T3 (3.168i/m^2) representado por los grupos taxonómicos Diptera y Haplotaxida. Valores mayores de riqueza se observaron en T1. El índice de Shannon fue mayor en T2 (0.66) mientras que T1(0.80) presentó mayor dominancia en morfoespecies. La densidad y riqueza fue mayor en el arreglo agroforestal que en la pastura degradada de *Cenchrus clandestinum*. Los tratamientos, la profundidad y su interacción no afectaron de manera significativa la diversidad de morfoespecies.

Palabras clave: Densidad; diversidad; morfoespecies; propiedades biológicas; riqueza; suelo.

INTRODUCTION

Soils are indispensable for the provision of several important functions, but agricultural intensification, declining biodiversity, climate variability, greenhouse gases and their focus on increasing primary productivity pose a threat to soil quality (Vázquez *et al.,* 2020), affecting the macro and microorganisms that keep it rich in nutrients. Knowing the soil macrofauna and its distribution is important to predict the degradation state of soil as well as its physical properties and biological components (Navia *et al.,* 2021). Edaphic macrofauna (e. g., earthworms, termites, ants) have real importance in the transformations of organic matter and physical properties of the soil, establishing channels and pores that favor aeration, drainage, aggregate stability, and water retention capacity, and thus being considered micro- and macro-engineers of the soil and ecosystem (Cabrera-Dávila *et al.,* 2017). The edaphic fauna can be separated into the functional groups of detritivores, fungivores, herbivores, predators, and omnivores according to their feeding habits (Swift *et al*., 2012).

Soil macrofauna plays a key role in soil processes, regulating the provision of ecosystem services; however, their level of activity depends largely on soil and climatic conditions (Machado-Cuellar *et al.,* 2020). Among their benefits are improving nutrient recycling, decomposition processes, mineralization of organic matter, and improvement of soil structure (Lavelle *et al.,* 2006), of which the diversity, abundance and richness of invertebrates vary depending on the intensity of such agricultural practices (Julca *et al.,* 2006).

Soil macrofauna communities have begun to be considered as bioindicators of soil quality, as they are sensitive to environmental changes and soil conditions that can cause variation in their abundance and composition (Velasquez & Lavelle, 2019). It is understood that the composition of macrofauna depends on climatic factors, plant species and soil properties. In addition, these factors impact the structure, function and composition of soil biota (Karungi *et al.,* 2018).

The combination of trees with crops is a practice with great potential that can provide favorable conditions for soil macrofauna. To this extent, agroforestry systems with greater structural complexity and botanical composition promote the richness and diversity of edaphic macrofauna (Durán-Bautista *et al*., 2023).

Smallholder agroforestry systems often incorporate features associated with abundant and diverse soil macrofaunal populations (Pauli *et al.,* 2011). Mainly, agroforestry arrangements protect edaphic macrofauna altered by temperature variations and water stress, thanks to the cover they provide to the soil (Lavelle *et al.,* 2003).

In this sense, the implementation of agroforestry systems and the inclusion of promising species represent a sustainable alternative, practices that have been shown to improve the biological properties of the soil (Cabrera *et al.,* 2011).

Multipurpose woody perennials such as wax laurel *M. pubecens*, with high adaptability in the area and tolerance to external factors, present in their roots the actinomycete of the genus Frankia, which is responsible for nitrogen uptake (Molina *et al.,* 2000), allowing to incorporate this element naturally into the soil and crops (Morales, 2018; Cherubin *et al.,* 2019). For its part, yacon grows well under the shade of trees, shrubs and also in full sun (Seminario *et al.,* 2003); its reservoir roots store high contents of carbohydrates and water that makes them attractive to different species of macrofauna, especially of the order Haplotáxida.

Measuring the abundance, richness, and diversity of edaphic macrofauna in a yacon and wax laurel intercropped cropping system can provide important information for the design and implementation of production alternatives with sustainable practices that

generate favorable conditions to improve their ecological functions. Thus, the objective of this research was to evaluate the soil macrofaunal communities in the establishment phase of the silvoagricultural system of laurel *M. pubescens* intercropped with *S. sonchifolius* and in degraded kikuyo pasture at the Botana Experimental Farm in the high tropics of Nariño.

MATERIAL AND METHODS

Location. The research was conducted at the Experimental Farm of the University of Nariño, located in Botana. Pasto Altiplano is at 77°18'58''W, 1°10'11.4''N, an altitude of 2820m, an average temperature of 12°C, an average annual rainfall of 800 to 1000 mm, and a relative humidity of 70 to 80% with 900 hours of sunshine per year (IDEAM - Instituto de Hidrología y Meteorología y Estudios Ambientales, 2010). According to the IGAC - Instituto Geográfico Agustín Codazzi (2004), it belongs to the low montane humid forest life zone (bh - MB); taxonomically, this soil is classified as Acrudoxic Fulvudands with an undulating topography.

Soil preparation was carried out manually for the planting of the agricultural component, and for the planting of the tree component, the soil was hollowed out.

Experimental design. It consisted of a Randomized Complete Block design (BCA) with four treatments corresponding to different planting densities of *S. sonchifolius* intercropped with *M. pubescens* in an agroforestry system in the establishment phase. T1: *S. sonchifolius* sown at 1x1m between plants; T2: *S. sonchifolius* sown at 0.80 x 0.80m between plants; T3: *S. sonchifolius* sown at 0.50 x 0.50m between plants and a control T4: degraded pasture of *C. clandestinum*. The treatments were organized in a plot of 60x54m (3.240m2) with three replicates per treatment (12 subplots of 360m2 each); the tree component was sown at 4x4m between seedlings and 9m between rows.

Vegetal material. The vegetal material of *S. sonchifolius* was acquired from producers linked to the Red de Guardianes de las Semillas, in Nariño. *M. pubescens* seedlings were acquired from nurseries in the area with an average initial height of 15cm.

Sampling of edaphic macrofauna. For the treatments and control, sampling of edaphic macrofauna was carried out during the productive stage of *S. sonchifolius* (10 months) after the establishment of the agroforestry arrangement. The Tropical Soil Biology and Fertility (TSBF) methodology described by Anderson & Ingram (1993), modified for this study, was used. In each treatment, including the control, three replicates were selected, and in each one, a sample was taken for a total of nine monoliths. The area of the monolith was $0.0625m^2$ (0.25 x 0.25m), then this monolith was divided into three strata: 0-10cm, 10-20cm, and 20-30cm deep; the leaf litter stratum was not taken

into account due to its minimal contribution in the establishment phase of the system. Macrofauna (diameter ≥ 2mm) was extracted, preserved and labeled. Arthropods were preserved in 70% alcohol and annelids in 5% formalin.

The collected specimens were taken to the specialized Entomology laboratories of the Universidad de Nariño with the help of a Nikon smz 646 stereoscope. The organisms were identified by order and family level using the taxonomic keys of Doreste (1984), Fauchald (1977), and Triplehorn & Johnson (2005). From a functional point of view, the macrofauna was grouped into detritivores, soil engineers, herbivores, and predators according to the functional groups proposed by Cabrera *et al*. (2011).

Data analysis. Density, richness and diversity analyses were carried out to evaluate the state of the edaphic macrofauna community in the experimental units.

Density. The density of macrofauna associated with each treatment was determined by quantifying the number of individuals/m² (i/m²) of each taxonomic group.

Richness. The richness of the communities found was determined considering the total number of taxonomic groups identified per treatment and depth.

Diversity. Diversity was estimated taking into account the morphospecies of the individuals in each of the treatments evaluated, and the Shannon-Wiener (H) and Simpson's dominance indices were determined (Moreno, 2001).

The information collected in the field was processed in the InfoStat software version 2020. To evaluate the effect of treatment, depth and their interaction on morphospecies density, richness and diversity, a generalized linear mixed effects analysis was performed separately for count variables. Principal Component Analysis (PCA) was performed to determine the taxonomic groups that influence the variability of the data in the treatments.

RESULTS AND DISCUSION

Density. A total of 6,496 i/m² were collected in the sampling carried out (Table 1), composed of eight taxonomic groups with a higher density in T3, corresponding to 48.76% of the total collected, represented mainly by immature Diptera and adult Haplotaxida. T1 with 27.09%, conformed mainly by adult Haplotaxida and adult Coleoptera, followed by treatment T2 with 18.71%, represented mostly by adult Haplotaxida and adult Coleoptera, while T4 (control) presented the lowest density in the study 352 i/m², corresponding to 5.41%, with adult Haplotaxida and adult Coleoptera being the most outstanding.

Table 1. Density of the taxonomic groups by treatment in the agroforestry arrangement of *M. pubescens* and *S. sonchifolius* and control at Botana Experimental Farm. Productive stage of *S. sonchifolius.*

| Taxonomic Group | Treatment | | | | | | | | Total |
| | T1 | | T2 | | T3 | | T4 (control) | | |
	N° i.p.m^2	%	N° i.p.m^2	%	N° i.p.m^2	%	N° i.p.m^2	%	N° i.p.m^2
Coleoptera (adults)	320	18,2	160	13,2	96	3,0	112	31,8	688
Diptera (larvae)	32	1,8	32	2,6	1.712	54,0	0	0,0	1.776
Haplotaxida	1.296	73,6	896	73,7	1.312	41,4	144	40,9	3.648
Hemiptera	16	0,9	0	0,0	0	0,0	0	0,0	16
Hirudinea	0	0,0	16	1,3	16	0,5	16	4,5	48
Milacidae	64	3,6	80	6,6	32	1,0	32	9,1	208
Polydesmida	0	0,0	16	1,3	0	0,0	0	0,0	16
Scolopendromorpha	32	1,8	16	1,3	0	0	48	13,6	96
Total	1.760	100	1.216	100	3.168	100	352	100	6.496

The data obtained indicate a higher density of macrofauna with respect to land use with agroforestry systems compared to degraded pasture. This agrees with the data obtained by Marichal *et al.* (2014), where the density of edaphic macrofauna in the studied agroforestry arrangements presented higher values than those of degraded pastures, demonstrating that the negative effects of land use intensification on soil macroinvertebrate communities can be reduced by the implementation of agroforestry practices (Durán *et al.*, 2018).

Linear mixed effects analysis indicated that treatments (F=91.75, P=0.0001), depth (F=664.31, P=0.0001) and interaction (treatment x depth) (F=42.97, P=0.0001) affected the density of individuals. Density of edaphic macrofauna in the soil showed the highest mean values at depths of 0-10cm in treatments T3 and T1, with 928 and 421i/m², respectively, while in the 20-30cm stratum, all treatments, including the control, showed a mean density of 32i/m² (Figure 1). An inversely proportional relationship is observed since at a depth of 0-10cm, the greatest number of individuals is found, and this decreases as the depth increases.
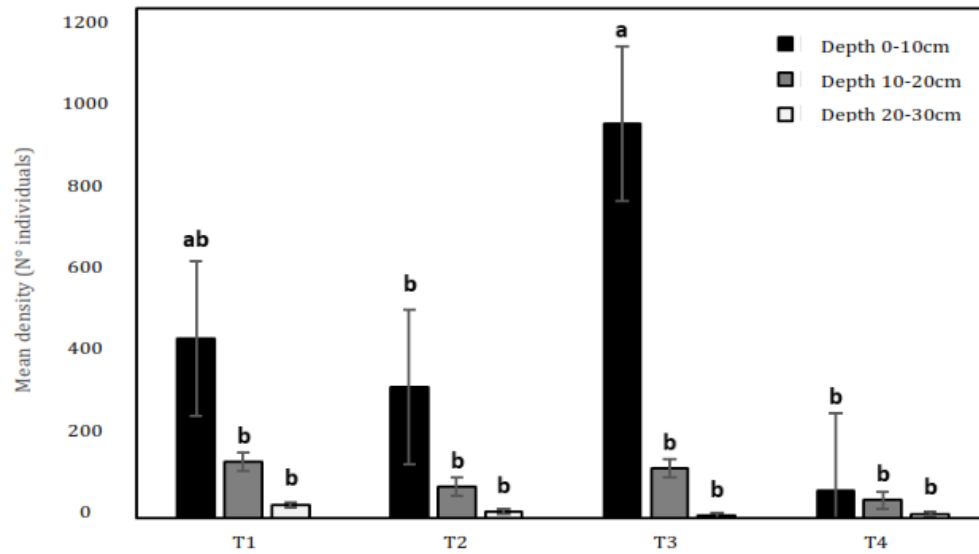
*Letters indicate significant differences according to Tukey's test (P<0.05). Vertical bars represent the standard error or the mean and difference.

Figure 1. Comparison of the mean density of taxonomic groups between each planting distance treatment and each soil depth at the Botana Experimental Farm.

It can be seen that the agroforestry arrangement of *M. pubescens* and *S. sonchifolius* presents the highest density of individuals in strata 1 and 2 compared to the control, *Cenchrus clandestinum*. A similar situation is reported by Rodríguez-León *et al.* (2021), where they found that the number of i/m² was higher in forested areas (7202 i/m²) than in degraded pastures (2334 i/m²).

The principal component analysis (PCA) allowed us to identify that the first two components explain 75% of the total variability of the data evaluated (Table 2).

Table 2. Eigenvalues per component of the taxonomic groups.

Components	Eigenvalues	Percentage	Cumulative Percentage
1	3.68	46	46
2	2.33	29	75
3	1.99	25	1

The first component explains 46% of the variability and is mainly composed of taxonomic groups such as adult Coleoptera, Hemiptera, Hirudinea, and Milacidae (Table 3), which presented a correlation factor between -0.96 to 0.96. The second component showed 29% of the explanation of the total variability, conformed mainly by taxonomic groups such as Haplotaxida (0.98), Diptera (0.68) and Scolopendromorpha with a correlation of -0.78.

Table 3. Contribution of the taxonomic groups for each of the principal components (PC) selected.

Taxonomic Group	PC1	PC2
Coleoptera	0,52	0,05
Diptera	-0,28	0,53
Haplotaxida	0,19	0,60
Hemiptera	0,50	0,11
Hirudinea	-0,50	-0,11
Milacidae	0,29	-0,03
Polydesmida	-0,04	-0,10
Scolopendromorpha	0,17	-0,57

On PC1 (Figure 2), the projection of Hemiptera, Coleoptera, and Milacidae vectors were related at T1 *S sonchifolius* sown at 1x1m, while Hirudinea is characterized at T2, T3, and T4; on PC2, Diptera makes the greatest contribution at T3 and Haplotaxida is characterized at T3 and T1, Scolopendromorpha makes its greatest contribution to variability at T1 and T4.
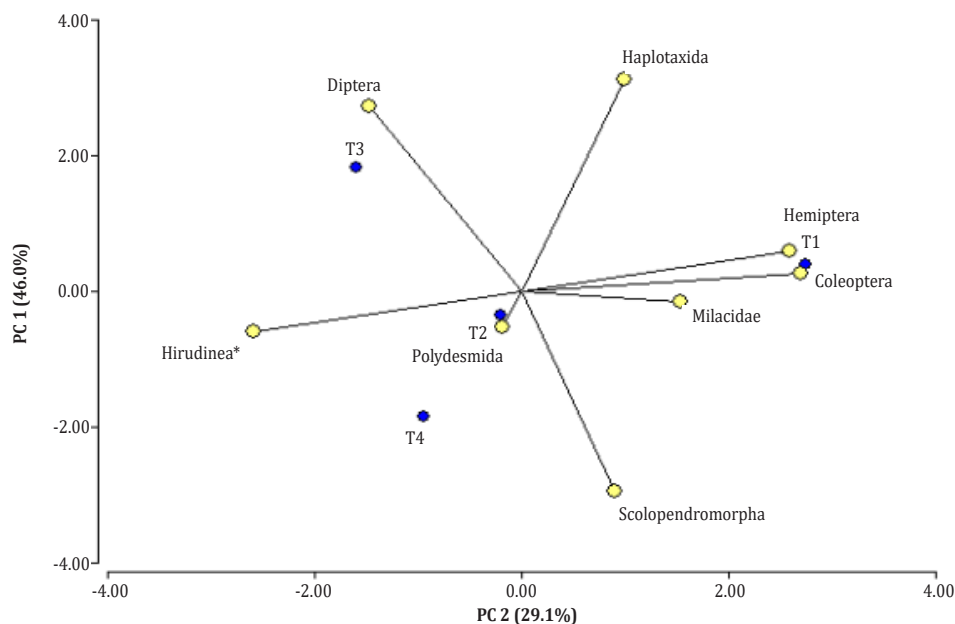

Figure 2. Biplot of the Principal Component Analysis (PCA) for the distribution of the density of taxonomic groups by treatment in the agroforestry arrangement of *M. pubescens* and *S. sonchifolius* and control at the Botana Experimental Farm.

In general, a higher occurrence of individuals was found in the treatments with the implementation of the agroforestry system compared to the control treatment (T4). The occurrence of numerous individuals may be due to the presence of strata (herbaceous,

agricultural, and arboreal), being a favorable habitat where the different species will fulfill different ecological functions related to the soil cover, the contribution of leaf litter from the trees, the microclimate that maintains appropriate values of temperature, and soil moisture (Granados & Barrera, 2007; Urbano *et al*., 2019).

In the 0-10cm stratum, the highest density of individuals was found. These results were consistent with Urbano *et al.* (2019), where the effect of seven green manures on the ecological structure of soil invertebrates was evaluated, finding that these were affected by soil depth and that the highest values in abundance and species richness were found at the soil surface (0-10cm). These results can be explained by the decrease in oxygen and organic matter with increasing soil depth characteristics that provide habitat, hindering the decomposition of humus and food for their development (Villalobos *et al*., 2000; Castro *et al*., 2007; FAO, 2019).

The results of this study for the establishment phase of the agroforestry system may be influenced to a greater degree by the agricultural component (*S. sonchifolius*), which is characterized by a tuberous root reservoir rich in carbohydrates and water, which may explain the greater presence of individuals in the first layer of soil. The arboreal component, on the other hand, over time can favor leaf litter inputs necessary for decomposition processes and biological activity, as reported by Sánchez & Milera (2002), where there was an increase in the density of individuals over nine years, from 194i/m² to 383i/m² due to the incorporation of the tree layer.

According to Wang *et al.* (2013), N-fixing trees contribute a large amount of organic matter, presenting a total N concentration of up to 50% in the top layer of the soil from 0-5cm. Soil arthropods and Leaf litter are some of the most abundant and diverse communities in forests and provide myriad ecosystem services from decomposition and mineralization to pollination and predation (Cole *et al.,* 2016; Hartshorn, 2021).

In the study by Tapia *et al.* (2019), they found that soil macrofauna was predominant in the first soil horizons. Leaf litter and 0-10 cm depth in all forest fragments were evaluated, indicating that the social insect groups, Isoptera and Formicidae, were the most predominant in the preserved forest fragment (FFC). The study by Durán & Suarez (2013) for the agroforestry arrangements evaluated indicated that the development of a leaf litter layer in the season of minimum precipitation resulted in a higher density of fauna, showing the importance of this layer to maintain a favorable microclimatic condition.

Richness. The linear mixed effects analysis indicated that depth affected morphospecies richness (F=3.77, P=0.0418), with depth 1 (0-10cm) having the highest values in treatments T2, T3 (3.67) and T1 (3.33), while depth (20-30cm) had the lowest values

(1.0) in treatments T4 and T1, respectively. In general, it can be observed that as soil depth increases, the richness of morphospecies decreases. There was no effect of treatments or interaction treatment x depth.

T2 and T1 comprise the seventh and sixth taxonomic groups, respectively, in which Haplotaxida, Coleoptera and Milacidae stand out; treatments T3 and T4 with fifth taxa are mostly represented by Haplotaxida and Hemiptera (T3) and by Haplotaxida and Coleoptera in T4.

The richness of families in the study was higher in the treatments with presence of the arboreal and agricultural stratum and lower in the degraded pasture treatment (T4), coinciding with that reported in other investigations where higher values of family richness were found in polyculture areas and pastures associated with leguminous tree cover, compared to a monoculture of grasses of 30, 26, and 22 families, respectively (Cabrera-Dávila *et al.*, 2017). Tree and/or shrub cover in ecosystem management is of utmost importance as it guarantees the continuous and abundant input of organic plant material and a more favorable microenvironment for the establishment of soil macroinvertebrates (Rodríguez *et al.*, 2002).

The presence of *P. clandestinum* as an invasive arvense in T4 could have caused the low presence of morphospecies compared to the establishment stage of the agroforestry system. Suárez *et al.* (2015) reported low values of taxonomic richness of edaphic macrofauna (±3.81 p<0.0001 for the 0-10cm stratum and ±3.87 p<0.0001) due to the presence of monoculture of *Dichanthium caricosum* L., in addition to the loss of tree cover, which limits the contribution of good quality leaf litter, and the lack of shade on the soil.

Functional groups. The morphospecies of the families identified correspond to different functional groups (Table 4), which are classified according to their impact on the soil and feeding habit: Soil engineers, which constituted the most abundant group in this study, were the Lumbricidae family as the most representative in T3.

Table 4. Functional group composition of macrofauna in the agroforestry arrangement of *M. pubescens* and *S. sonchifolius* and control at Botana Experimental Farm.

Taxonomic Group	Family	Treatment				Functional group			
		T1	T2	T3	T4 (control)	Det	Her	Dep	IdS
		i/m²	i/m²	i/m²	i/m²				
	Amphizoidae			16		X	X	X	
	Carabidae	32	80	32		X	X	X	
	UF		16			X	X	X	
	Curculionidae		32		16	X	X	X	
	Chrysomelidae	16			16	X		X	
Coleoptera	Elateridae			16	32		X		
	Heteroceridae			16		X	X	X	
	Ptilodactylidae	32			32	X	X	X	
	Scarabaeidae	112	16		16	X	X	X	
	Staphylinidae	96	16	16		X	X	X	
	Tenebrionidae	32				X	X	X	
	Bibionidae			1.680		X		X	
Diptera	Cecidomyiidae	16				X		X	
	UF	16		16		X	X	X	
	Tipulidae		32	16		X		X	
Haplotaxida	Lumbricidae	1.296	896	1.312	144				X
Hemiptera	UF	16						X	
Hirudinea	UF		16	16	16			X	
Stylommatophora	Milacidae	64	80	32	32			X	
Polydesmida	UF		16			X			
Scolopendromorpha	Scolopendridae	32	16		48				X
	Total	1.760	1.216	3.168	352				

Functional group: Det: Detritivorans, Dep: Predators, Her: Herbivorans, IdS: Soil engineers, U.F = unidentified family.

Soil engineers stand out as the most abundant group in forests and agroforestry systems in environments with greater vegetation cover, richness of exudates, and shade, conditions that benefit these organisms (Morán & Alfaro, 2015). This functional group has a specific impact on the soil interior from the transformation of physical properties, which favor aggregates and structure, movement and water retention, as well as gas exchange (Lavelle *et al.*, 2006).

According to Cabrera-Dávila *et al.* (2017), the detritivores are responsible for the shredding of plant remains that make up the litter, intervening in the decomposition of organic matter and the recycling of nutrients. Brévault et al. (2007) affirm that the

abundance and diversity of this group are associated with the abundance of tree species, greater vegetation cover, high availability, and quality of organic matter, coinciding with the results of this study, where a greater density was found in the silvo-agricultural system treatments compared to the control.

The detritivores were represented by the Bibionidae family in the immature stage, most of which were found in T3 (planting distance of 0.50m) due to a higher density of available plant material. According to Ibáñez (2006), the individuals of this family behave as decomposers, feeding on abundant plant matter and sometimes on the root, as in the case of this study, where the individuals found were mainly in roots of *S. sonchifolius*, which has fibrous and reservoir roots as a source of food for its exudates and decomposition (Seminario *et al.*, 2003).

Predators were found in all treatments and were represented by the families Carabeidae and Scarabeidae. This group indicates the existence of complex trophic networks (Gullan & Cranston, 2000; Urbano *et al.,* 2019), which are responsible for controlling the availability of habitat resources (FAO, 2019). A high abundance of detritivores, or earthworms, may represent systems with little or no disturbance and a favorable state of fertility. An inverse result evidences more intense conditions of soil disturbance and degradation (Cabrera-Dávila *et al.*, 2017).

Diversity. Linear mixed effects analysis for Shannon's evenness index and Simpson's dominance index showed no significant differences between treatments ($p < 0.05$).

According to the results, there was a low diversity of morphospecies in the different treatments, including the control, a situation that may be associated with the soil and climatic conditions of the plot, characterized by a clayey texture, low organic matter input from the tree component for the establishment stage and high rainfall during the evaluation period.

This is in agreement with Machado-Cuellar *et al.* (2020), who state that the composition of soil macrofauna depends on climatic factors, plant species, and soil properties. The organic matter content and the carbon/nitrogen ratio contained in the soil are the conditions that most influence the diversity and functionality of edaphic macrofauna groups (Díaz-Porres *et al.,* 2014). The vegetation community influences the macroinvertebrate community, which may be influenced by specific species that enhance macroinvertebrate diversity (Lavelle *et al.,* 2006).

Different authors affirm that inadequate management practices how logging, intensive tillage, use of agrochemicals, and change of cover and inadequate soil use affect the diversity and density of soil macrofauna communities since they cause abrupt variations in microhabitat conditions (Mathieu *et al.,* 2005).

CONCLUSIONS

The density and richness of edaphic macrofauna in the study were higher in the treatments of the agroforestry arrangement evaluated in the productive phase of *S. sonchifolius* intercropped with *M. pubescens* than in the control degraded pasture of *Cenchrus clandestinum*.

The treatments, depth, and the interaction treatment x depth affected the density of individuals, being higher in the agroforestry arrangement with a higher density of *S. sonchifolius* in the 0-10cm stratum represented by the taxonomic groups Diptera immatures and Haplotaxida adults.

Depth affected morphospecies richness, with stratum 1 (0-10cm) having the highest values for a number of morphospecies in treatments T1 and T3, while depth (20-30cm) had the lowest values in treatments T4 and T1.

The treatments, depth and their interaction did not significantly affect the diversity of morphospecies, considering a low diversity in both the agroforestry arrangement and the control.

ACKNOWLEDGMENTS

Conflict of interest: The authors declare that there is no conflict of interest.

BIBLIOGRAPHIC REFERENCES

Anderson, J.; Ingram, J. (1993). *Tropical soil biology and fertility. A handbook of methods*. Wallingford, UK: Editorial CABI Publishing.

Brévault, T.; Bikay, S.; Maldes, J.; Naudin, K. (2007). Impact of a no-till with mulch soil management strategy on soil macrofauna communities in a cotton cropping system. *Soil & Tillage Research.* 97: 140-149. https://doi.org/10.1016/j.still.2007.09.006

Cabrera-Dávila, G.; Socarrás-Rivero, A.; Hernández-Vigoa, G.; Ponce de León-Lima, D.; Menéndez-Rivero., D.; Sánchez-Rendón, J. (2017). Evaluación de la macrofauna como indicador del estado de salud en siete sistemas de uso de la tierra, en Cuba. *Pastos y Forrajes.* 40(2): 118-126.

Cabrera, G.; Robaina, N; Ponce De León, D. (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.

Castro, H.; Burbano, H.; Bonilla, C. (2007). Abundancia y biomasa de organismos edáficos en tres unos de terreno en el altiplano de Pasto, Colombia. *Acta Agronómica.* 56(3): 127-130.

Cherubin, M.R.; Chavarro-Bermeo, J.P.; Silva-Olaya, A. M. (2019). Agroforestry systems improve soil physical quality in northwestern Colombian Amazon. *Agroforestry Systems.* 93(5): 1741-1753.

Cole, R. J.; Holl, K.D.; Zahawi, R.A.; Wickey, P.; Townsend, A.R. (2016). Leaf litter arthropod responses to tropical forest Restoration. *Ecology and Evolution.* 6(15): 5158-5168*.* https://doi.org/10.1002/ece3.2220

Díaz-Porres, M.; Rionda, M. H.; Duhour, A. E.; Momo, F. R. (2014). Artrópodos del suelo: Relaciones entre la composición faunística y la intensificación agropecuaria. *Ecología Austral.* 24(3): 327-334. https://doi.org/10.25260/EA.14.24.3.0.10

Doreste, E.; (1984). *Acarología.* N°11. San José, Costa Rica: Instituto Interamericano de Cooperación para la Agricultura. 410p.

Durán-Bautista, E.H.; Angel-Sanchez, Y.K.; Bermúdez, M.F. (2023). Agroforestry systems generate changes in soil macrofauna and soil physical quality relationship in the northwestern Colombian Amazon. *Agroforest Syst.* 97: 927–938. https://doi.org/10.1007/s10457-023-00838-y

Durán, B.E.H.; Rodríguez, S.L.; Suárez, S.J.C. (2018). Relación entre macroinvertebrados y propiedades del suelo bajo diferentes arreglos agroforestales en la Amazonia-Andina. *Acta Agronómica.* 67(3): 395-401. https://doi.org/10.15446/acag.v67n3.67266.

Durán, B.E.H.; Suárez, S.J.C. (2013). Fauna del suelo y hojarasca en arreglos agroforestales de la Amazonía Colombiana. *Momentos de Ciencia.* 10(1): 59-66.

FAO - Organización de las Naciones Unidas para la Alimentación y la Agricultura. (2019). Propiedades biológicas. http://www.fao.org/soils-portal/soil-survey/propiedades-del-suelo/propiedades-biologicas/es/

Fauchald, K. (1977). The polychaete worms. Definitions and keys to the orders, families and genera. *Natural History Museum of Los Angeles County, Science Series. Science serries.* 28: 1-198.

Granados, A.; Barrera, J. (2007). Efecto de la aplicación de biosólidos sobre el repoblamiento de la macrofauna edáfica en la cantera Soratama, Bogotá, D.C. *Universitas Scientiarum.* 12(2): 77-84.

Gullan, P.; Cranston, P. (2000). The Insects: An Outline of Entomology. http://ibimm.org.br/wp-ontent/uploads/2017/05/The-Insects-An-Outline-of-Entomology.pdf

Hartshorn, J. A. (2021). Review of Forest Management Effects on Terrestrial Leaf Litter Inhabiting Arthropods. *Forests.* 12(1): 23. https://dx.doi.org/10.3390/f12010023

Ibáñez, S. (2006). Catálogo de autoridad taxonómica orden díptera (Insecta) en México. Parte 1. Suborden Nematocera. http://www.conabio.gob.mx/institucion/proyectos/resultados/InfCS004%201.pdf

IDEAM - Instituto de Hidrología y Meteorología y Estudios Ambientales. (2010). *Reporte Técnico Estación Meteorológica Botana.* Pasto, Nariño: IDEAM. 1p.

IGAC - Instituto Geográfico Agustín Codazzi. (2004). *Estudio general de los suelos y zonificación de tierras del departamento de Nariño*. Bogotá, Colombia: IGAC. 733p.

Julca, A.; Meneses, L.; Blas, R.; Bello, S. (2006). La materia orgánica, importancia y experiencia de su uso en la agricultura. *Idesia.* 24(1): 49-61. http://dx.doi.org/10.4067/S0718-34292006000100009

Karungi, J.; Cherukut, S.; Ijala, A.R.; Tumuhairwe, J.B.; Bonabana-Wabbi, J.; Nuppenau, E.A.; Otte, A. (2018). Elevation and cropping system as drivers of microclimate and abundance of soil macrofauna in coffee farmlands in mountainous ecologies. *Applied Soil Ecology.* 132: 126-134.

Lavelle, P.; Senapati, B.; Barros, E. (2003). Soil macrofauna. En: Schroth, G.; Sinclair. F. L. (eds.). *Trees, crops and soil fertility*. pp. 303-324. Wallingford: CABI Publishing. 448p.

Lavelle, P.; Decaëns, T.; Aubert, M.; Barot, S.; Blouin, M.; Bureau, F.; Margerie, P.; Mora, P.; Rossi, J.-P. (2006). Soil invertebrates and ecosystem services. *Eur. J. Soil Biol.* 42(1): 3-15. https://doi.org/10.1016/j.ejsobi.2006.10.002

Machado-Cuellar, L.; Rodríguez-Suárez, L.; Murcia-Torrejano, V.; Orduz-Tovar, S.A.; Ordoñez-Espinosa, C.M.; Suárez, J.C. (2020). Macrofauna del suelo y condiciones edafoclimáticas en un gradiente altitudinal de zonas cafeteras, Huila, Colombia. *Revista de Biología Tropical.* 69(1): 102-112. 10.15517/rbt.v69i1.42955

Marichal, R., Grimaldi, M. ; Feijoo, A. ; Oszwald, J. ; Praxedes, C. ; Cobo, D. H. R. ; Lavelle, P. (2014). Soil macroinvertebrate communities and ecosystem services in deforested landscapes of Amazonia. *Applied Soil Ecology.* (83): 177-185. http://dx.doi.org/10.1016/j.apsoil.2014.05.006

Mathieu, J.; Rossi, J.P.; Mora, P.; Lavelle, P.; Martins, P.D.S.; Rouland, C.; Grimaldi, M. (2005). Recovery of soil macrofauna communities after forest clearance in Eastern Amazonia, Brazil. *Conservation Biology.* 19(5): 1598-1605. https://doi.org/10.1111/j.1523-1739.2005.00200.x

Molina, A.; Narváez, W.; Muñoz, J. (2000). Sistema agroforestal laurel de cera *Myrica pubescens* H.B.K, intercalado con cultivos transitorios en el municipio de Pasto (Botana). *Revista de Ciencias Agrícolas.* 17(2): 166-175.

Morales, L. (2018). Utilización de árboles fijadores de nitrógeno *Escallonia pendula* y *Alnus acuminata* para la recuperación de suelos erosionados. https://repository.unad.edu.co/bitstream/handle/10596/21708/1057586889.pdf?sequence=1&isAllowed=y

Morán, J.; Alfaro, F. (2015). *Diversidad de macrofauna edáfica en dos sistemas de manejo de Moringa oleifera Lam. (Marango) en la finca Santa Rosa, UNA.* https://repositorio.una.edu.ni/id/eprint/3203

Moreno, C. (2001). *Métodos para medir la biodiversidad.* Vol 1. Zaragoza: M&T – Manuales y Tesis SEA. 84p.

Navia, J.; Delgado-Gualmatan, W.; Lagos-Burbano, T. (2021). Macrofauna Evaluation in Two Environmental Systems of the Coffee Zone in Nariño's Department. *Revista de Ciencias Agrícolas.* 38(2): 89-98. https://doi.org/10.22267/rcia.213802.159

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

Rodríguez, I.; Crespo, G.; Rodríguez, C.; Castillo, E.; Fraga, S. (2002). Comportamiento de la macrofauna del suelo en pastizales con gramíneas naturales puras o intercaladas con leucaena para la ceba de toros. *Revista Cubana de Ciencia Agrícola.* 36(2): 181-186.

Rodríguez-León, C.H.; Peña-Venegas, C.P.; Sterling, A.; Castro, D.; Mahecha-Virguez, L.K.; Virguez-Díaz, Y.R.; Silva-Olaya, A.M. (2021). Soil quality restoration during the natural succession of abandoned cattle pastures in deforested landscapes in the Colombian Amazon. *Agronomy.* 11(12): 2484. https://doi.org/10.3390/agronomy11122484

Sánchez, S.; Milera, M. (2002). Dinámica de la macrofauna edáfica en la sucesión de un sistema de manejo de gramíneas a un sistema con árboles intercalados en el pasto. *Rev. Pastos y Forrajes.* 25(3): 189-194.

Seminario, J.; Valderrama, M.; Manrique, I. (2003). *El Yacón: Fundamentos para el aprovechamiento de un recurso promisorio.* Lima, Peru: Centro Internacional de la Papa (CIP), Universidad Nacional de Cajamarca, Agencia Suiza para el Desarrollo y la Cooperación (COSUDE). 60p.

Suárez, J.; Durán, E.; Rosas, G. (2015). Macrofauna edáfica asociada a sistemas agroforestales en la Amazonia Colombiana. *Acta Agronómica.* 64(3): 214 - 220. https://doi.org/10.15446/acag.v64n3.38033

Swift, M.J.; Bignell, D.E.; Moreira, F.M.S.; Huising, E.J. (2012). El inventario de la biodiversidad biológica del suelo: conceptos y guía general. En: Moreira, F.M.S.; Huising, E.J.; Bignell, D.E. (eds.), *Manual de Biología de Suelos Tropicales. Muestreo y caracterización de la biodiversidad bajo suelo.* pp. 29-52. México: Instituto Nacional de Ecología.

Tapia, S. C.; Pinto, C. A.; Candre, A.; Asencio, C.; Cuellar, R.; Waldez, F. (2019). Caracterización de la macrofauna del suelo en fragmentos forestales en el municipio de Leticia, Amazonía colombiana. *Revista Colombiana de Ciencia Animal.* 11(1): 4-16. https://doi.org/10.24188/recia.v11.n1.2019.690

Triplehorn, C.A.; Johnson, N.F. (2005). *Borror and DeLong's Introduction to the Study of Insects.* 7th Ed. Belmont USA: Thomson Brooks/Cole. 864p.

Urbano, M.; Pantoja, M.; Delgado, I.; Cabrera, P.; Benavides, I. (2019). The effect of green fertilizers on the ecological structure of soil invertebrate communities in an andisol of Southwestern Colombia. *Revista de Biología Tropical.* 67(6): 1394-1405. https://doi.org/10.15517/rbt.v67i6.37023

Vázquez, C.; de Goede, R. G. M.; Rutgers, M.; de Koeijer, T. J.; Creamer, R. E. (2020). Assessing multifunctionality of agricultural soils: Reducing the biodiversity trade-off. *European Journal of Soil Science.* 72(4): 1624–1639. https://doi.org/10.1111/ejss.13019

Velasquez, E.; Lavelle, P. (2019). Soil macrofauna as an indicator for evaluating soil based ecosystem services in agricultural landscapes. *Acta Oecologica.* 100: 103446.

Villalobos, F.; Ortiz, P.; Moreno, C.; Pavón, N.; Hernández, H.; Bello, J.; Montiel, S. (2000). Patrones de la macrofauna edáfica en un cultivo de *Zea maiz* durante la fase postcosecha en "La Mancha", Veracruz, México. *Acta Zoológica Mexicana.* 80: 167-183.

Wang, H.; Liu, S.; Wang, J.; Shi, Z.; Lu, L.; Zeng, J.; Yu, H. (2013). Effects of tree species mixture on soil organic carbon stocks and greenhouse gas fluxes in subtropical plantations in China. *Forest Ecology and Management.* 300: 4-13. https://doi.org/10.1016/j.foreco.2012.04.005