SHORT ARTICLE

Influence of land use on the diversity and composition of edaphic arthropods in the Granja Tunguavita

Influencia del uso del suelo en la diversidad y composición de artrópodos edáficos en la Granja Tunguavita

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ABSTRACT

The modification of the landscape, the intense exploitation of natural resources through intensive agriculture and the advance of the agricultural frontier result in the homogenization of the landscape and alteration of soil physicochemical conditions. These soil alterations cause changes in the composition and diversity of edaphic arthropod communities that can be used as biomonitoring and diagnostic tools in local areas. The objective of the study was to evaluate the diversity of edaphic arthropods and their association to different physicochemical parameters (i.e., pH, real density, bulk density, %OC, %OM and gravimetric and volumetric humidity) in three soil uses (permanent crop, rotational crop and pasture) in the experimental farm Tunguavita Paipa - Boyacá. The plot sampling technique was used to obtain data on biological and physicochemical variables. Samples were taken in three soil uses, permanent crop, rotational crop and cattle ranch. The edaphic arthropods and physicochemical variables were determined in the soil laboratory of the Universidad Pedagógica y Tecnológica de Colombia. The highest diversity of edaphic arthropods (309 individuals) was recorded in the permanent crop plot, followed by the rotational crop plot, both with high average values of %OM (1.82 - 1.90) and %OC (1.05 - 1.10). The Oligochaeta, Diplopoda and Araneae group were the major contributors to the biological differentiation between land uses. The changes in the abundance of edaphic arthropods were related to % gravimetric humidity, %volumetric humidity, pH, %OM and %OC, while the values of real density and bulk density did not correlate to a great extent with the changes in abundance. These variations allow the differentiation of land uses in an intervention gradient.

RESUMEN

La modificación del paisaje, la intensa explotación de recursos naturales mediante agricultura intensiva y el avance de la frontera agrícola da resultado la homogeneización del paisaje y alteración de condiciones fisicoquímicas del suelo. Estas alteraciones en el suelo provocan cambios en la composición y diversidad de las comunidades de artrópodos edáficos que pueden ser utilizados como herramientas de biomonitoreo y diagnostico en zonas locales. El objetivo del estudio fue evaluar la diversidad de artrópodos edáficos y su asociación a diferentes parámetros fisicoquímicos (i.e., pH, densidad real, densidad aparente, CO, MO y humedad gravimétrica y volumétrica) en tres usos del suelo (cultivo permanente, cultivo rotativo y pastoreo) en la granja experimental Tunguavita Paipa – Boyacá. Para obtener los datos de las variables biológicas y fisicoquímicas se usó la técnica de muestreo por parcela. Las muestras fueron tomadas en tres usos de suelo, cultivo permanente, cultivo rotativo y lote de ganadería. Los artrópodos edáficos y se determinó las variables fisicoquímicas en el laboratorio de suelos de la Universidad Pedagógica y Tecnológica de Colombia. La mayor diversidad de artrópodos edáficos (309 individuos), se registró en el lote de cultivo permanente, seguido del cultivo rotativo ambos con valores promedio altos de %MO (1.82 – 1.90) y %CO (1.05 – 1.10). El grupo de Oligochaeta, Diplopoda y Araneae fueron los que contribuyeron en mayor proporción a la diferenciación biológica entre usos de suelo. Los cambios en la abundancia de artrópodos edáficos, se relacionaron con % Humedad gravimétrica, %Humedad volumétrica, pH, %MO y %CO, mientras que los valores de densidad real y densidad aparente, no se correlacionaron en gran medida con los cambios de abundancia. Estas variaciones permiten la diferenciación de usos de suelo en un gradiente de intervención.

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INTRODUCTION

The loss of biological diversity is one of the main consequences of the climate change that humanity has experienced, becoming a global issue of interest (Arribas *et al.*, 2012). The modification of the landscape, the loss of animal and plant species, the intense exploitation of natural resources through intensive agriculture, and the advance of the agricultural frontier result in the homogenization of the landscape, as well as the alteration of the microclimate and of the biogeochemical cycles (i.e., water, carbon, and nitrogen) (Paruelo *et al.*, 2005). These anthropogenic modifications leave out of the original habitats, affecting the richness, diversity, and composition of mainly arthropod communities in the soil (Dornelas, 2010). The arthropods, especially the soil macro-arthropods, are an essential component of natural ecosystems and agroecosystems due to their participation in regulating fragmentation and decomposition of organic matter, nutrient recycling (Iannacone and Alvariño, 2006; Coleman *et al.*, 2017). For this reason, the conservation of these organisms is essential due to the multiple services they provide for agroecosystems, which is why they are considered a valuable tool to evaluate the effectiveness of ecosystem management and conservation strategies (Arribas *et al.*, 2012).

Soil arthropods are an essential component of natural and artificial ecosystems due to their adaptability and diversity of species (González-Montaña *et al.*, 2017). They also play an important role in the organic matter decomposition, nutrient recycling, and regulation of biotic communities inside or outside the soil (Wardle, 2006; Brussaard, 2012). Therefore, edaphic arthropods are considered indicators of soil quality and health of any ecosystem (i.e., crops) (Lavelle *et al.*, 2006; Gergócs and Hufnagel, 2009). One of the characteristics that is considered for soil quality is studies of species diversity, mainly

explained by the soil spatial heterogeneity that favors the distribution of resources and the coexistence and interaction between species (Wardle, 2006). Also, other studies have revised the relationship between biotic and abiotic components (i.e., physicochemical variables) on soil arthropod diversity (Wardle, 2006; Donoso *et al.*, 2010). For this reason, the generation of information on the direct and indirect effects that agricultural activity can produce on the arthropod communities diversity is vital for the design and improvement of management plans and biological conservation in crops.

Soil physicochemical variables are an essential component for crop development and control; this is because these will depend on soil use (i.e., Permanent crops, Rotation crops, or Pasture). Therefore, the association of soil's physical and chemical properties can be used with the soil composition and abundance of arthropods to develop monitoring and diagnostic tools in local areas (Domínguez *et al.*, 2010). Different studies show that soil factors such as humidity, organic matter content, compaction, agricultural intensification or class of vegetation significantly affect the composition and abundance of edaphic arthropod communities (de Aquino *et al.*, 2008; Diekötter *et al.*, 2010; Feijoo-Martínez *et al.*, 2010; Falco and Momo, 2010).

At present, the municipality of Paipa contributes with 12.1% of the production of peach (*Prunus pérsica* L) (Espinal *et al.,* 2005), being the experimental farm Tunguavita of the Universidad Pedagógica y Tecnológica de Colombia, one of the leading centers of production of deciduous fruit trees (pears, apples, peaches) in the region. For this reason, this research evaluated the diversity of edaphic arthropods and their association with three soil uses (Permanent crop, Rotation crop, or Pasture) in Tunguavita farm Paipa-Boyacá and to established relationships for the diagnosis of soil quality through biological parameters.

MATERIALS AND METHODS

Area of study. The Tunguavita farm of the Universidad Pedagógica y Tecnológica de Colombia, located in the municipality of Paipa at an altitude of 2470 m above sea level, with 5º45' N - 73º06' W, average annual temperature of 14.1 ºC and average relative humidity of 74.9 %. The area has a bimodal rainfall regime with an average precipitation of 966 mm, being the sampling near the beginning of the first rainy season (Ideam Station No. 2403517). The farm has 134 ha of which three plots corresponding to three different land uses were selected. The first plot corresponds to the permanent cultivation of peach (*Prunus pérsica* L), Rubidoux variety. The second plot is for rotational use between peach and pear crops between each season. The third plot corresponds to a pasture area for cattle and sheep. The plots have less anthropic influence in terms of soil use, making these plots the most stable areas in terms of physicochemical and biological conditions throughout the year.

Field phase. For each land use, sampling was carried out in April 2018. Samples were taken in a previously selected grid within each plot of 100 x 100 m (1 ha). Within each quadrant, a zigzag path was made, thus choosing a total of seven sampling points randomly. At each sampling point, soil samples were taken for physicochemical and biological analysis using a 50 x 50 cm grid and a depth of 10 cm. For the physicochemical analysis, the soil samples consisted of 3 subsamples in order to obtain a quantity of 200 g of soil. This soil sample was stored in black bags to avoid any type of degradation due to light and was sent to the soil laboratory of the Universidad Pedagógica y Tecnológica de Colombia for subsequent physicochemical analysis (IGAC, 2006).

The procedure used for the collection of biological material (edaphic arthropods) was as follows. The sampling points previously selected for the physicochemical variables

were taken as a starting point. For each point, with the help of a sieve of 1 mm pore size and 50 cm in diameter, soil material was taken to saturation in order to complete a total of 3 sieving per sampling point. Each individual was collected and separated with entomological forceps and placed in plastic containers to ensure adequate survival conditions during transfer to the laboratory. According to their visible characteristics, the individuals collected per replicate and location in the laboratory were counted and then grouped into morphospecies. Once the counting was done, one specimen per associated group was selected to be preserved in 70% alcohol for subsequent taxonomic identification by stereoscopy and taxonomic keys (Vargas *et al.,* 2014; Choate, 2010; Amat-García, 2009).

Laboratory phase. Soil samples were taken from the plots for subsequent analysis. Direct and indirect variables were taken into account in order to have a broader view of the physicochemical variations of the soil. The analysis of the physicochemical variables was carried out in the laboratory of the Universidad Pedagógica y Tecnológica de Colombia, with the methods proposed by the Instituto Geográfico Agustín Codazzi (IGAC, 2006) where the following were analyzed: pH ratio 1:1, %OC Walkey – Black method, %OM = %OC * 1.724, real density was calculated using the pycnometer method, bulk density was calculated using the ring of known volume or cylinder, gravimetric humidity percentage (GH) at 105°C for 24 h and volumetric humidity (VH) is the product of the gravimetric humidity by the value of the bulk density (Forero, 2021)

Statistical analysis. In order to quantify the diversity patterns of edaphic arthropods and the influence of physicochemical variables, the following statistical analyses were performed for the three sampled plots. The abundance of individuals was determined for each of the plots, and the abundance and diversity were

related to the three land uses to be visualized by means of a Ternary graph (Smith, 2017). To determine if significant differences exist within sampling sites for each land use and among the three land uses evaluated, the ANOSIM (Analysis of Similarities) test was used with a permutation of 999 and a significance level of P < 0.05 (Zubcoff, 2012). Relationships between edaphic arthropods and soil physicochemical variables were evaluated using a Canonical Correspondence Analysis (CCA) (Ter Braak, 1987). Finally, to evaluate which taxa are mainly responsible for the differences between the three land uses, the SIMPER test was performed with a permutation of 999 and a significance level of P < 0.05 (Clarke, 1993). All statistical analyses and tests were performed using the Vegan library of the Rstudio program (Team R, 2015).

RESULTS AND DISCUSSION

The results showed that organic matter and organic carbon contents were higher in the Permanent crop and Rotation crop, showing significant differences with the Pasture (P < 0.05). The apparent and real density was higher in the cattle lot but did not differ significantly from the peach crop lots (Permanent crop and Rotation crop). Also, gravimetric humidity and volumetric humidity showed significant differences between the Rotation crop and the other lots. At the same time, the pH levels were higher in the permanent cultivation of peach (Table 1).

A total of 714 individuals were found in the three land uses, being (Permanent crop 309, Rotation crop 261, and Pasture 144) distributed

Table 1. Average physicochemical variables for each land use and pairwise test comparing groups; R values and significance levels.

Land uses	(Mean ± SD)						(Pairwise)		
	%GH[1]	Bulk density (g/cc)	Real density (g/cc)	pH	%OC[2]	%OM[3]	Pc[4]	Rc[5]	Pa[6]
(Pc[4])	23.11 ± 2.22	1.62 ± 0.17	2.58 ± 0.08	6.48 ± 0.48	1.05 ± 0.88	1.82 ± 1.52	--	--	--
(Rc[5])	31.33 ± 2.14	1.65 ± 0.08	2.60 ± 0.07	5.57 ± 0.18	1.10 ± 0.66	1.90 ± 1.14	(R= 0.75;	--	--
(Pa[6])	21.34 ± 2.97	1.67 ± 0.15	2.63 ± 0.08	5.69 ± 0.28	0.67 ± 0.33	1.16 ± 0.57	(R= 0.13; P<0.05)	(R= 0.37; P<0.050)	--

[1]Gravimetric Humidity; [2]Organic carbon; [3]Organic matter; [4]Permanent crop; [5]Rotation crop; [6]Pasture.

in 8 orders, nine families, and 13 genera (Table 2). The most abundant in Permanent crop and Rotation crop groups were Haplotaxida, Spirobolida, and Coleoptera, compared to Pasture. In contrast, Aranae, Hymenoptera, and Isopoda were the most abundant only in Pasture (Figure 1). According to the arthropod group abundance values, greater diversity in land use was observed in Permanent crop and Rotation crop than in Pasture (T-test; P < 0.05). Previous studies have shown that several

arthropod groups are related to soil organic matter contents, suggesting that resource contribution mainly mediates a better ecosystem status. Thus, the organic matter content is one of the fundamental axes in the environment nutrient cycle (Causarano *et al.*, 2007; Coleman and Wall, 2007; Coleman *et al.*, 2017). Furthermore, soil physical-chemical characteristics such as pH, texture, compaction, and soil density play an essential role in the preference of the environment for arthropods.

They may even be more relevant than the type of crop or soil use (Galantini and Suñer, 2008). In particular, we find forz all three land uses a very high organic matter input; this can be mainly due to vegetation and fertilization plans, generating an increased availability of energy resources that edaphic invertebrates can rapidly exploit.

Table 2. Taxonomic classification of the edaphic arthropods presents for each of the three land uses.

| Phylum	Class	Order	Family	Genus	Permanent crop	Rotation crop	Pasture
Arthropoda	Insecta	Coleoptera	Gyrinidae	*Gyrinus*	14	20	5
			Elmidae	*Heterelmis*	17	24	5
				Austrolimnius	27	22	4
				Microcylloepus	30	24	7
				Macrelmis	32	29	5
	Chilopoda	Scolopendromorpha	Cryptopidae	*Cryptops*	23	16	5
	Diplopoda	Spirobolida	Rhinocricidae	*Rhinocricus*	39	29	2
		Polydesmida	Chelodesmidae	*Eucampsella*	22	30	2
	Arachnida	Araneae	Salticidae	*Amphidraus*	13	4	31
	Insecta	Hymenoptera	Formicidae	*Solenopsis*	9	3	21
	Malacostraca	Isopoda	Oniscidae	*Porcellio*	11	17	23
				Armadillidium	11	19	22
Annelida	Oligochaeta	Haplotaxida	Lumbricidae	*Lumbricus*	61	24	12
				Total	**309**	**261**	**144**
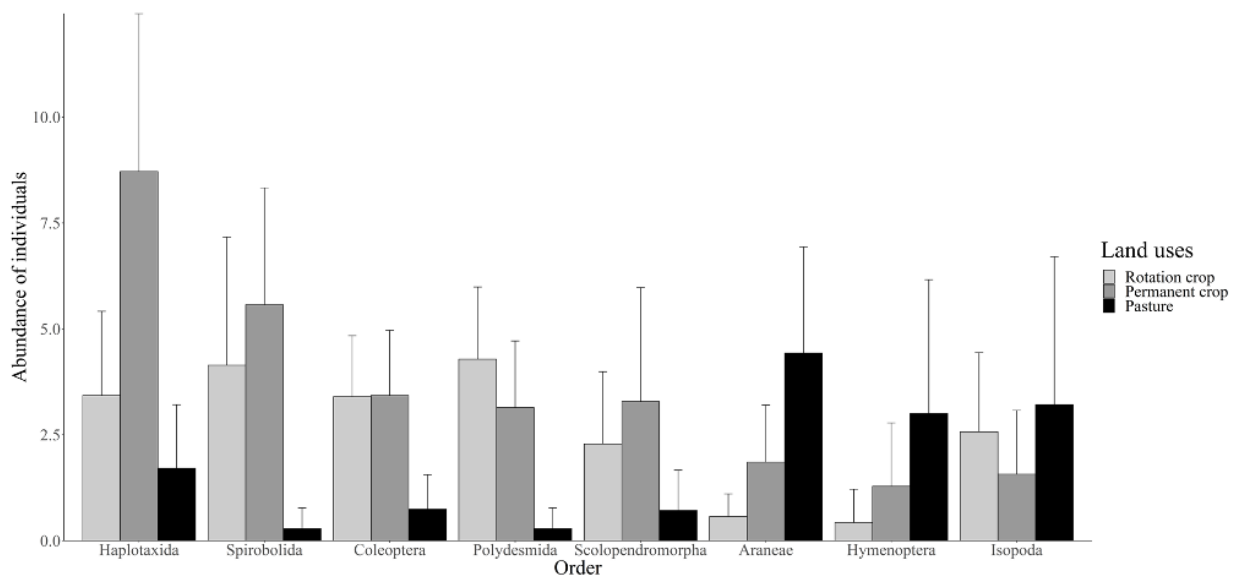
Figure 1. Average abundance of individuals belonging to each Order found at the sampling sites for each of the three land uses.

The results of Anosim for the biological variables and the physicochemical variables within each of the sampled sub-quadrants were consistent within each of the lands uses used (Anosim: R = 0.19, P = 0.001). Among the land uses it was observed that the biological variables (i.e., arthropod composition) showed significant differences in at least one of the three land uses evaluated (Anosim: R = 0.79, P = 0.001), with the Pastureland use being the most different from the others (Figure 2). This could indicate that the composition and abundance of arthropods would be related not only to intrinsic crop conditions (plant cover), but also to extrinsic factors (i.e., crop management and rotation). Also, the results of Anosim on the physicochemical variables showed significant differences among the three land uses with evidence that the variations found in soil arthropods may correspond to the variations present in each of the land uses evaluated (Anosim: R = 0.58, P = 0.001). In other words, the heterogeneity of the environments in their physicochemical variables and the management plans with different concentrations of chemical or organic fertilizers could impact the nutritional conditions of the soil, which would affect the abundance of soil arthropods present in each land use.
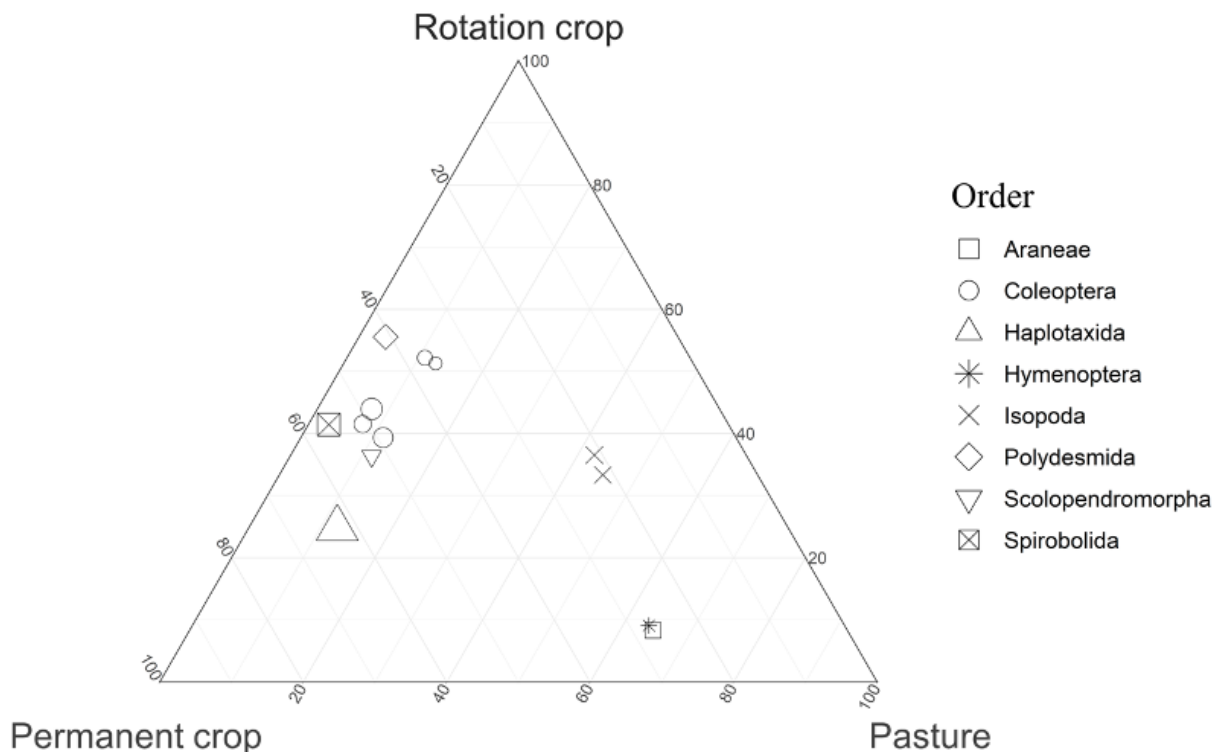

Figure 2. Ternary plot of the groupings of arthropod orders in relation to the three land uses.

The total organic matter content showed significant differences between the permanent crop and rotation crop uses with pasture, which is positively related to a greater abundance of edaphic arthropods, this is because they use available organic matter as their primary energy resource (Coleman and Wall, 2007; Coleman *et al.*, 2017). The type and quality of soil organic matter also condition the availability of nutrients for crops. Factors such as apparent and actual density in Pastureland use resulting from trampling affect the availability of resources and affect mobility under the topsoil (Almada, 2014; Gomez Pamies *et al.*, 2016). While gravimetric,

volumetric, and pH levels may indirectly affect edaphic arthropod communities, these variables depend on the type of vegetation that exists and the management, fertilization, and planning for each land use (Cuesta Segura, 2016; Diaz, 2020).

The results showed that the type of land use affects the abundance of several groups of edaphic arthropods. For example, Formicidae was found in greater abundance in the cattle lot, while Chilopoda was only found in the Permanent crop and Rotation crop. The Oligochaeta group was found in greater abundance in the crop lots of the cattle lot. In contrast, the Diplopoda, Oniscidea, and Araneae groups have very variable abundance values among the lots, which can be explained by the intrinsic factors of each lot (Diekötter *et al.*, 2010; Díaz Porres *et al.*, 2014) or anthropic variables such as insecticides management other chemical compounds. We can explain these results based on two factors: the use of organic matter and soil compaction by cattle as physical-chemical barriers; on the other hand, the influence of present vegetation, lower and less dense, which allows greater ease of movement for walking groups, such as biological barriers. In addition, the application of agricultural inputs such as agrochemicals eliminates other functional groups that live in the soil cover and regulates the edaphic arthropod community (González-Montaña *et al.*, 2017; de Carvalho *et al.*, 2019). This, in turn, contributes to ecological balance because it modifies the ideal conditions of humidity, aeration, temperature, pH, and food resources (i.e., organic matter) in the top layer of the soil. Therefore, these variations contribute to an environment conducive to the development and adaptation of specialized or highly resilient soil organisms (Bedano *et al.,* 2016).

The canonical correlation analysis showed an association between physicochemical soil variables and the diversity of taxonomic groups.

The factors structure showed that the ratio of %gravimetric humidity, volumetric humidity, and pH levels are the soil variables that best explain the edaphic arthropods distribution. Correspondence analysis showed a negative association between walking arthropod groups (Araneae and Hymenoptera) with the gravimetric and volumetric soil moisture. While groups of arthropods with elongated bodies (Coleoptera, Haplotaxida, Scolopendromorpha, Spirobolida, and Polydesmida) were associated with real and apparent soil density values. The Isopoda (Oniscidae) group was associated with extreme values of soil physicochemical variables, which show that the possible relations between soil physicochemical and biological variables are a causality of the evaluated plots' intrinsic characteristics.

In addition, the results of the SIMPER test showed the different genera of arthropods contributions in comparison within each of the land uses (Table 3). In the comparison of Permanent crop and Rotative crop, it is observed that the genera *Lumbricus* (Lumbricidae) and *Rhinocrius* (Rhinocricidae) have a significant contribution (< 0.1%) concerning other genera belonging to groups that may be abundant, such as *Cryptops* (Cryptopidae). When comparing the land uses of Permanent crop and Pasture, the same pattern is observed in the genera *Lumbricus* (Lumbricidae) and *Rhinocrius* (Rhinocricidae) contribution. While comparing Rotative crop and Pasture, we observed that the differences between the two land uses are mainly due to the genus Eucampsella (Chelodesmidae). In general, the results of the SIMPER test showed that the arthropod genera of Permanent crop and Rotation crop contributions are more similar to each other than to the Pasture contributions, showing a possible influence on the joint relationship of physicochemical variables and land use in not only the composition but also in the abundance of large groups of arthropods.

Table 3. SIMPER test results show the contribution and cumulative percentage of Arthropod Genera that have a greater incidence in the differences observed between the three land uses.

Permanent crop vs Rotation crop		
Genus	**Contribution %**	**Cumulative %**
Lumbricus	0.1967	0.1967
Rhinocricus	0.1239	0.3206
Cryptops	0.0775	0.3981
Armadillidium	0.0757	0.4738
Porcellio	0.0738	0.5476
Eucampsella	0.0705	0.6181
Heterelmis	0.0663	0.6844
Microcylloepus	0.0583	0.7427
Macrelmis	0.053	0.7957
Gyrinus	0.0524	0.8481
Amphidraus	0.0522	0.9003
Austrolimnius	0.0518	0.9521
Solenopsis	0.0479	1.000
Permanent crop vs Pasture		
Lumbricus	0.1652	0.1652
Rhinocricus	0.1228	0.2880
Macrelmis	0.0933	0.3813
Microcylloepus	0.0799	0.4612
Austrolimnius	0.0776	0.5388
Eucampsella	0.0675	0.6063
Amphidraus.	0.0653	0.6716
Armadillidium	0.0646	0.7362
Porcellio	0.0639	0.8001
Solenopsis	0.0595	0.8596
Cryptops	0.0586	0.9182
Heterelmis	0.044	0.9622
Gyrinus	0.0378	1.000

Continued Table 3. SIMPER test results show the contribution and cumulative percentage of Arthropod Genera that have a greater incidence in the differences observed between the three land uses.

Rotative crop vs Pasture		
Eucampsella	0.1063	0.1063
Rhinocricus	0.0983	0.2046
Amphidraus.	0.0972	0.3018
Macrelmis	0.0966	0.3984
Porcellio	0.0788	0.4772
Armadillidium	0.0747	0.5519
Austrolimnius	0.0747	0.6266
Heterelmis	0.0738	0.7004
Solenopsis	0.0675	0.7679
Lumbricus	0.0641	0.8320
Microcylloepus	0.0639	0.8959
Gyrinus	0.0566	0.9525
Cryptops	0.0475	1.000

The relationship between the presence and abundance of different soil arthropods with similar designs to the one made here has been studied, and the results are not univocal (Bedano *et al.*, 2016). Previous work in edaphic mesofauna, mainly in soil mites, showed that the intensity and changes in soil use have an adverse effect on the density of certain groups (i.e., Oribatide and Mesostigmata) (Domínguez *et al.*, 2010; Bedano *et al.*, 2016). Although a typical pattern of diversity is to observe higher abundances in land uses with permanent or rotational crops, in some cases, the highest abundances are found in livestock fields in groups belonging to Araneae or Formicidae as those reported from elsewhere (Domínguez *et al.*, 2010). The use of techniques such as "zero tillage" has been shown to cause a significant decrease in spiders, beetles, and diplopods concerning the lands that are used for Pasture (Díaz Porres *et al.,* 2014). In our case, the combination of factors, such as changes in

pH, organic matter, compaction, and use of agrochemicals, seems to have a direct effect on the composition and abundance of arthropods and annelids in the soil, despite not being a recurrent effect in some studies (Moço *et al.*, 2010). These synergistic effects of physicochemical conditions, soil use on species diversity (not abundances), can be mediated mainly by pH, organic matter and organic carbon contents, amount of clays, sum of bases, and apparent and real density.

Therefore, the environmental heterogeneity hypothesis establishes that the greater the heterogeneity, the greater the number of niches could coexist, resulting in a more significant number of species but with variable abundances (Allouche *et al.*, 2012). In this context, and taking into account the soil arthropods diversity presents in the three land uses, it was observed that the communities were influenced by the changes generated in the habitat (land uses), showing that the greatest abundances occur in environments with the most homogeneous physicochemical conditions. This condition was demonstrated in the permanent crop instead of pasture lot, which presents fewer environmental modifications.

CONCLUSIONS

The composition and abundance of the taxa allow to quickly evaluate the state of conservation of the soil in the different soil uses, even more, when there is the presence of sensitive organisms (i.e., Oligocheta and Araneae) to the physicochemical or biological barriers.
pH, organic matter and organic carbon contents, amount of clays, the sum of bases, and apparent and real density, seem to be linked not only to the characteristics of each land use but also to the levels of abundance of arthropods that may be found.

The three land uses evaluated in the Tunguavita experimental farm showed different degrees of heterogeneity in the physicochemical variables, which resulted in changes in the soil arthropod community by modifying its diversity in response to the environmental characteristics present; this provides evidence that the soil physicochemical barriers affect the edaphic arthropods composition and diversity present.

Conflict of Interest

The manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts at risk the validity of the presented results.

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