Scientific Paper

Ecological indices of the edaphic macrofauna in five grasslands of Granma province, Cuba

Licet Chávez-Suárez[1] https://orcid.org/0000-0002-7837-2168, Idalmis Rodríguez-García[2] https://orcid.org/0000-0001-5897-5431 and Alexander Álvarez-Fonseca[1] https://orcid.org/0000-0002-5218-445X

[1]*Instituto de Investigaciones Agropecuarias Jorge Dimitrov. Carretera vía Manzanillo km 16 ½, Peralejo, Bayamo, Granma, Cuba.* [2]*Instituto de Ciencia Animal, Mayabeque, Cuba. E-mail:* licet@dimitrov.cu, idalmisdoloresrodriguezgarcia@gmail.com, alexanderf@dimitrov.cu

Abstract

Objective: To determine the ecological indexes of the edaphic macrofauna in five agroecosystems of grasslands in Granma province, Cuba.

Materials and Methods: Sampling was carried out twice a year: rainy and dry season, from July, 2014 to March, 2017. The edaphic macrofauna was collected according to the methodology proposed by the Tropical Soil Biology and Fertility (TSBF) program. Ecological indices species richness, Shannon-Wiener diversity index (H'), Simpson index (λ) Berguer-Parker dominance index (d) and community coefficient were calculated.

Results: The richness of taxonomic units was variable in the evaluated periods and agroecosystems. In all agroecosystems, the order with the highest number of taxonomic units was Hymenoptera with 12 units in the Pasture Station. It was followed by El Triángulo and Ojo de agua, with 11 and 10, respectively. It was not possible to establish the pattern of abundance of edaphic macrofauna in either climate period, except in the Ojo de agua and Pasture Station pastures, where this variable was higher in the dry season than in the rainy season. In the dry period of the second year, there was greater macrofaunal diversity than in the rainy period in all pastures. The highest similarity was recorded in the Ojo de agua and El Progreso pastures (0,63) and with the Pasture Station (0,60).

Conclusions: In the studied grassland agroecosystems, the ecological indices of edaphic macrofauna showed heterogeneous performance in the rainy and dry seasons.

Keywords: biodiversity, soil, rangeland management

Introduction

Edaphic macrofauna communities are considered bioindicators of soil quality, as they are sensitive to environmental changes that can cause variation in their abundance and composition (Machado-Cuellar *et al*., 2021). This is the most studied group of soil fauna, especially the effect of different land uses on the communities. However, few publications characterize the interaction and evolution of the macrofauna in time and space, depending on system design and management (Marsden *et al*., 2020).

In the case of grasslands, the absence of the tree stratum leads to the simplification of the vegetation structure, which causes the homogenization of the leaf litter and alterations in temperature and organic matter content, all of which brings about a decrease in ecological niches and, therefore, in macrofauna populations (Cabrera-Dávila *et al*., 2021). Grazing also has an impact depending on the stocking rate and intensity, since the trampling of animals causes the mechanical destruction of microhabitats.

Ecological indices summarize a lot of information in a single value and allow rapid comparisons between the diversity of different habitats or the diversity of the same habitat over time (Moreno, 2001). In addition, they are used to evaluate the condition of ecosystems, to quantify the influence of environmental factors on different species and to plan conservation measures (Xu *et al*., 2020). They are related to the total number of existing species (richness) and how the population is distributed across species (equity). Among the ecological indices most commonly used to assess species diversity in ecology are the Shanon-Wiener index and Simpson's index (Omayio and Mzungu, 2019; Gao and Wu, 2020; Roswell *et al*., 2021; Kunakh *et al*., 2023).

The objective of this research was to determine the ecological indices of edaphic macrofauna in grasslands of Granma province, Cuba.

Materials and Methods

Location. The research was developed in five grassland agroecosystems in three municipalities

Received: March 25, 2024
Accepted: September 07, 2024

How to cite a paper: Chávez-Suárez, Licet; Rodríguez-García, Idalmis & Álvarez-Fonseca, Alexander. Ecological indices of the edaphic macrofauna in five grasslands of Granma province, Cuba. *Pastures and Forages.* 47:e16, 2024.

of Granma province (figure 1), located in the south-western portion of the eastern region of the island of Cuba, between coordinates 20°23′00″N and 76°39′09″W.

Table 1 shows the main characteristics of the agroecosystems. Sampling was conducted twice a year, once in the rainy period (RS) and once in the dry season (DS), from July, 2014, to March, 2017.

Sampling and identification of edaphic macrofauna. The method recommended by the Tropical Soil Biology and Fertility program (Anderson and Ingram, 1993) was used.

The leaf litter was previously cleaned and all types of alien bodies, such as stones and plant residues, were removed. In the diagonal of the sampling area, 5 monoliths per ha, 25 x 25 x 20 cm, were extracted at 20 m distance. Macrofaunal individuals were collected and counted manually *in situ*. The earthworms were preserved in 4 % formaldehyde and the remaining invertebrates in 70 % ethanol.

For the identification of the preserved specimens, the works of Hickman *et al*. (2001) and Brusca and Brusca (2003) were consulted. The entomological collection belonging to the provincial laboratory of Plant Health in Granma was also consulted. The minimum level at which identification was possible was called taxonomic unit (TU). Ecological indices were calculated with the number of individuals belonging to each TU: Shannon-Wiener diversity index (H'), Berguer-Parker dominance index (d), Simpson dominance index (λ) according to Moreno (2001). The statistical package INFOSTAT version 2012 was used.

The Community Coefficient (CC, equivalent to Sorensen's Index of Similarity) was calculated by the equation S= 2C/(A+B), where A and B are the number of species in each sample and C the number of common species between both samples (Feinsinger and Ventosa-Rodríguez, 2014).

Results and Discussion

The number of species is the most commonly used measure for biodiversity analyses (Hernández-Chavez *et al*., 2020). The richness of taxonomic units was variable in the evaluated seasons and agroecosystems. It was not possible to establish the pattern of abundance of the edaphic macrofauna in one or another climate period; that is, there was no constant relationship between the time and the number of observed taxonomic units. In all the evaluations carried out in the Ojo de agua Pasture Station pastures, this variable was higher in the dry season than in the rainy period (table 2).

Cabrera-Dávila (2019) recommends the rainy season for sampling edaphic macrofauna, since it is in this period that the greatest abundance of individuals is recorded. However, the results

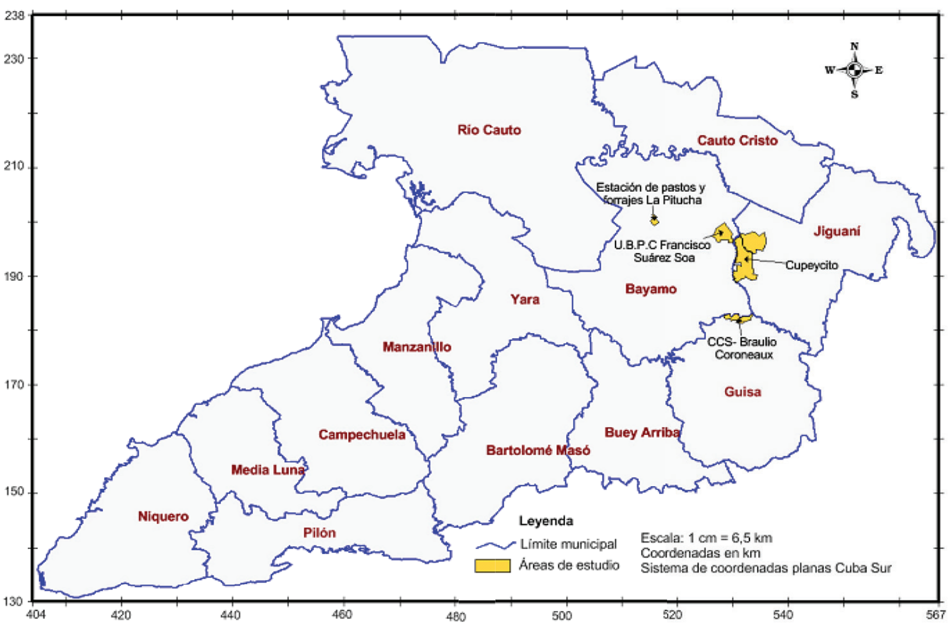


Figure 1. Geographical location of the studied agroecosystems.

Table 1. Main characteristics of the studied agroecosystems.

Agroecosystem	El Triángulo and El Progreso	Cupeycito	Ojo de agua	Pasture Station
Affiliation	UBPC Francisco Suárez Soa	Genetic Enterprise Manuel Fajardo	Rafael Almaguer's farm, CCS Braulio Coroneaux	IIA Jorge Dimitrov
Soil type	Pellic Vertisol	Loose Brown with carbonates	Loose Brown with carbonates	Fluvisol
Grazing method	Continuous	Rotational	Continuous	Rotational
Sampling area, ha Total area, % it represents	T: 2 11 % P: 2 10 %	1,8 13 %	1,2 18 %	0,8 100 %
Prevailing pasture type	*Dichantium caricosum* L. A. Camus and *Cynodon nlemfuensis* Vanderyst.)	*Megathyrsus maximus* (Jacqs.) B.K. Simon & S.W.L. Jacobs	*D. caricosum*	Silvopastoral system of *M. maximus* and *Leucaena leucocephala* (Lam) de Wit
33Time of exploitation	20 years	10 years	7 years	10 years
Breed and stocking rate (LAU ha^{-1})	Siboney crossbred 1,5	Creole 1,7	Crossbred 2,2	Siboney crossbred 1
General conditions	Completely deforested grazing area, without paddocks, it is flooded in the rainy season	Good shade level by trees and pasture enclosing, high rockiness. Tree species: coconut (*Cocos nucifera* L.); West Indian elm (*Guazuma ulmifolia* Lam); poplar (*Populus* sp.)	Good shade level by trees, without paddocks, relief with slope (10 %). Susceptibility to erosion. Tree species: *L. leucocephala*; rain tree [*Samanea saman* (Jacq.) Merr.]; mahogany [*Swietenia mahagoni* (L.) Jacq.]; Spanish cedar (*Cedrela odorata* L.)	Good shade level, zone of intense drought

T: El Triángulo P: El Progreso

Table 2. Richness of taxonomic units of the edaphic macrofauna in five grassland agroecosystems.

Agroecosystem	Year 1		Year 2		Year 3	
	RS	DS	RS	DS	RS	DS
El Triángulo	5	1	8	28	6	0
El Progreso	10	10	5	12	8	3
Cupeycito	11	8	10	16	7	12
Ojo de agua	9	11	3	17	12	17
Pasture Station	10	17	19	28	10	22

RS: rainy season; DS: dry season

presented suggest the need for soil macrofauna sampling in both climate periods, especially considering the current climate variability (Montecelos-Zamora *et al*., 2018).

It is acknowledged that the distribution of soil macrofauna depends on several factors: among them rainfall or climate seasonality, which in turn define temperature and soil humidity (Cabrera-Dávila, 2019). All these factors are of wide variability in the climate regions where the studied agroecosystems are located (Montecelos-Zamora *et al*., 2018), which could have influenced the variable performance of the macrofauna. A very important part of the interannual variability of climate elements in Cuba is explained by the presence of the El Niño/Southern Oscillation (ENSO), which tends to favor higher rainfall in the dry season. This phenomenon had an intense manifestation between 2015 and 2016 (Galván *et al*., 2017), the period included in this research.

These results coincide with those reported for grasslands in different regions of the planet. Sabatté *et al*. (2021) reported species richness of 11 in temperate grasslands in Argentina, although this result is much lower than that reported in other plant systems such as agroforests and forests (Morán-Centeno and Jiménez-Martínez, 2024).

In all agroecosystems, the order with the highest number of taxonomic units was Hymenoptera, with the highest number (12) at the Pasture Station, followed by El Triángulo and Ojo de agua with 11 and 10 TUs, respectively (figure 2). The order

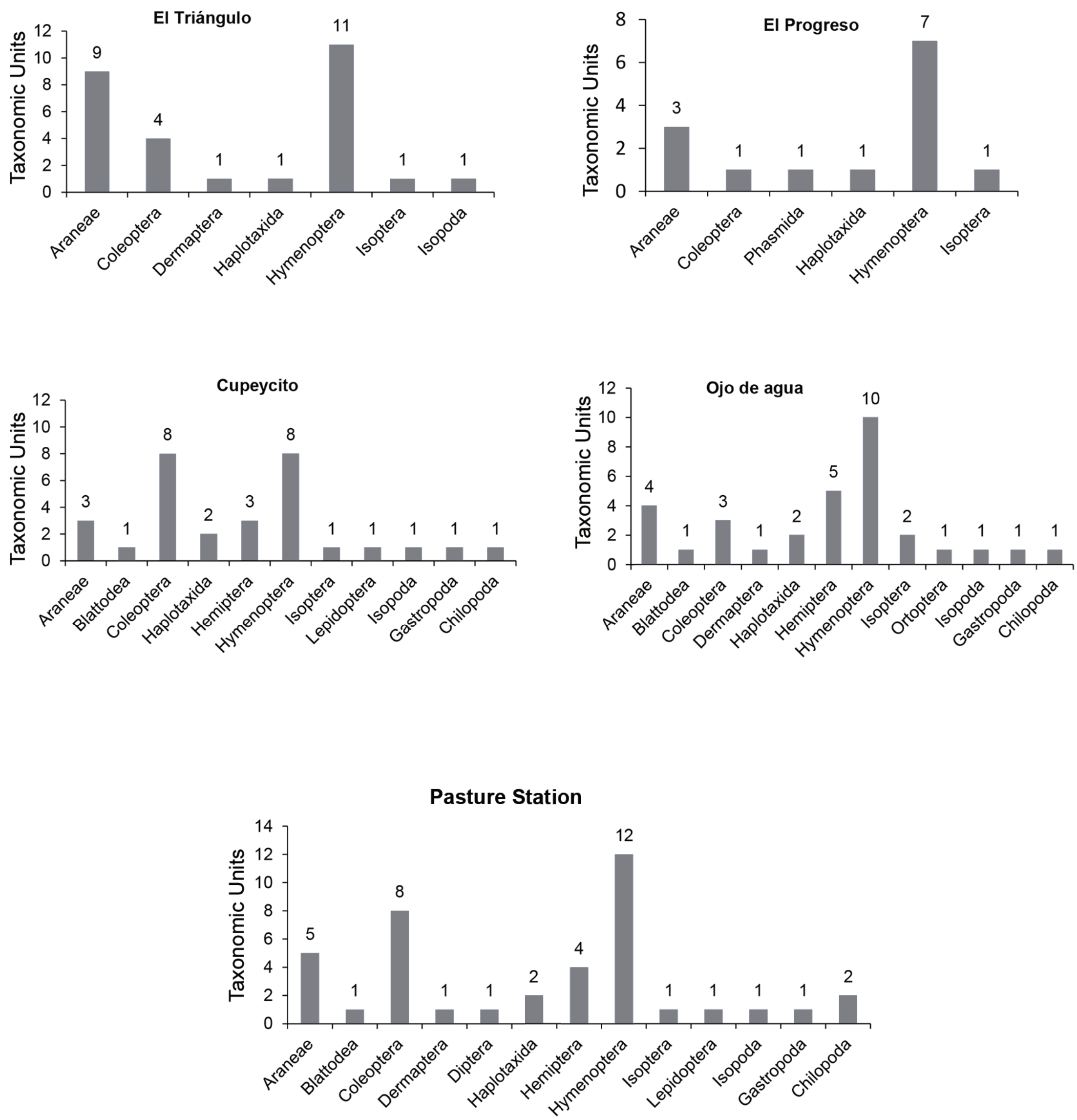


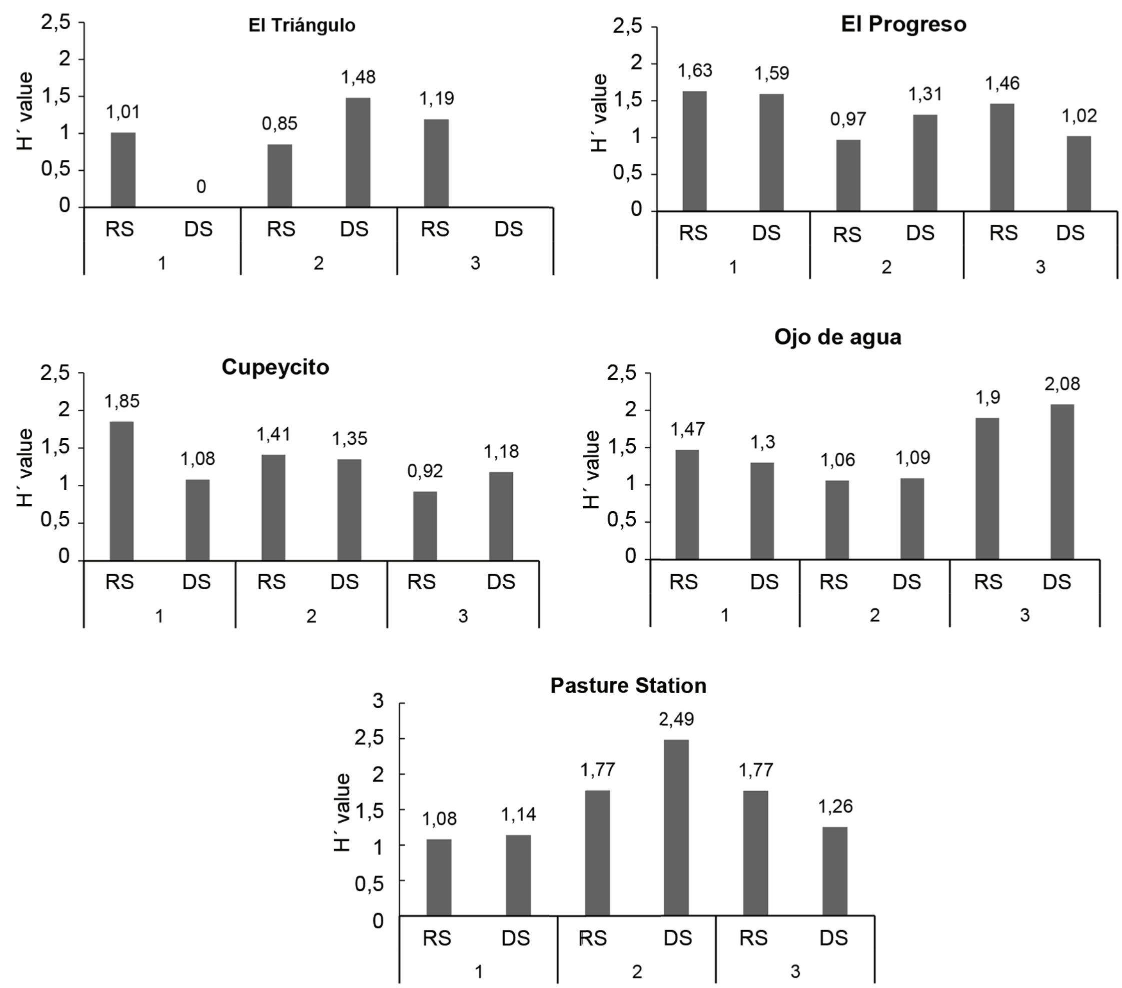
Figure 2. Taxonomic units of the edaphic macrofauna in five grassland agroecosystems.

Araneae was best represented in El Triángulo; while Cupeycito and Pasture Station exhibited the highest number of Coleoptera taxonomic units, with eight.

Taxonomic units belonging to Formicidae contributed significantly to the prevalence of the order Hymenoptera. Numerous authors report their dominance in grasslands (Cabrera-Dávila, 2019; Vazquez *et al*., 2020; Silva *et al*., 2023). Ants are considered as ecosystem engineers, since through their maintenance activities and in nest construction, they can influence the physical-chemical properties of the soil, thus modifying the microhabitat. In addition, as predators they act directly or indirectly on the abundance and diversity of other organisms in the ecosystem (De Almeida *et al*., 2020).

The distinction of ants as disturbance indicators is due to their high diversity, abundance and generalist habits, which makes them occupy a great variety of niches and have a wide range of resources, from seeds and organic material incorporated into the soil to small slow-moving organisms (insect eggs and some adult arthropods), which at the same time allows them to compete and survive very successfully against other soil organisms (Cabrera-Dávila *et al*., 2021).

Likewise, no constant pattern was observed in the Shanon-Wiener diversity index (H') in relation to the studied climate periods, nor a defined trend in the agroecosystems of increase or decrease (figure 3). This is one of the most common measures of species diversity, and depends not only on the number of species present in an ecosystem, but also on their relative abundance. Its use is preferred due to the ease of its calculation and interpretation (Omayio



RS: rainy season; DS: dry season

Figure 3. Shanon-Wiener index of edaphic macrofauna in five grassland agroecosystems.

and Mzungu, 2019). Depending on its value, it is usually between 1,5 and 3,5.

In this study, the minimum value of this index was zero, since no organism was recorded in the last dry season in El Triángulo (table 2); while its maximum value was reached at Pasture Station (2,49), in the dry season of the second year. This value is close to that reported by other authors in more conserved sites, such as forests and agroforestry systems (Castillo-Pérez and Ñique-Álvarez, 2019, Morales-Rojas *et al*., 2021). This fact emphasizes the positive influence of silvopastoral systems on the diversity of edaphic macrofauna and is associated with the combination of the herbaceous stratum with leucaena trees, which improves soil conditions, due to the quality and quantity of leaf litter that is incorporated. The leaf litter layer maintains soil moisture and temperature, which favors the development of edaphic macrofauna (Cabrera-Dávila, 2019). Other authors have also reported greater diversity of edaphic macrofauna in silvopastoral systems relative to grass monoculture pastures (Ramírez-Barajas *et al*., 2019, Gutiérrez-Bermúdez *et al*., 2020).

Hernández-Chavez *et al*. (2020) obtained similar results by reporting an H' value of 1,84 and 1,94 in natural pasture and silvopastoral system, respectively, in Sancti Spíritus, Cuba. Caicedo-Rosero *et al*. (2018) found lower values of this index, between 0,9 and 1,2; in silvopastoral systems dedicated to milk production in Carchi province, Ecuador. Rodríguez-Suárez *et al*. (2018), in *Urochloa* sp. pasture and silvopastoral system, obtained values of this index close to one in the Colombian Amazon. Sabatté *et al*. (2021) in temperate grasslands of Argentina found values close to 1,5 in this index. Meanwhile, in Ethiopia, Bufebo *et al*. (2021) reported an H' of 0,17 in extensive grazing areas.

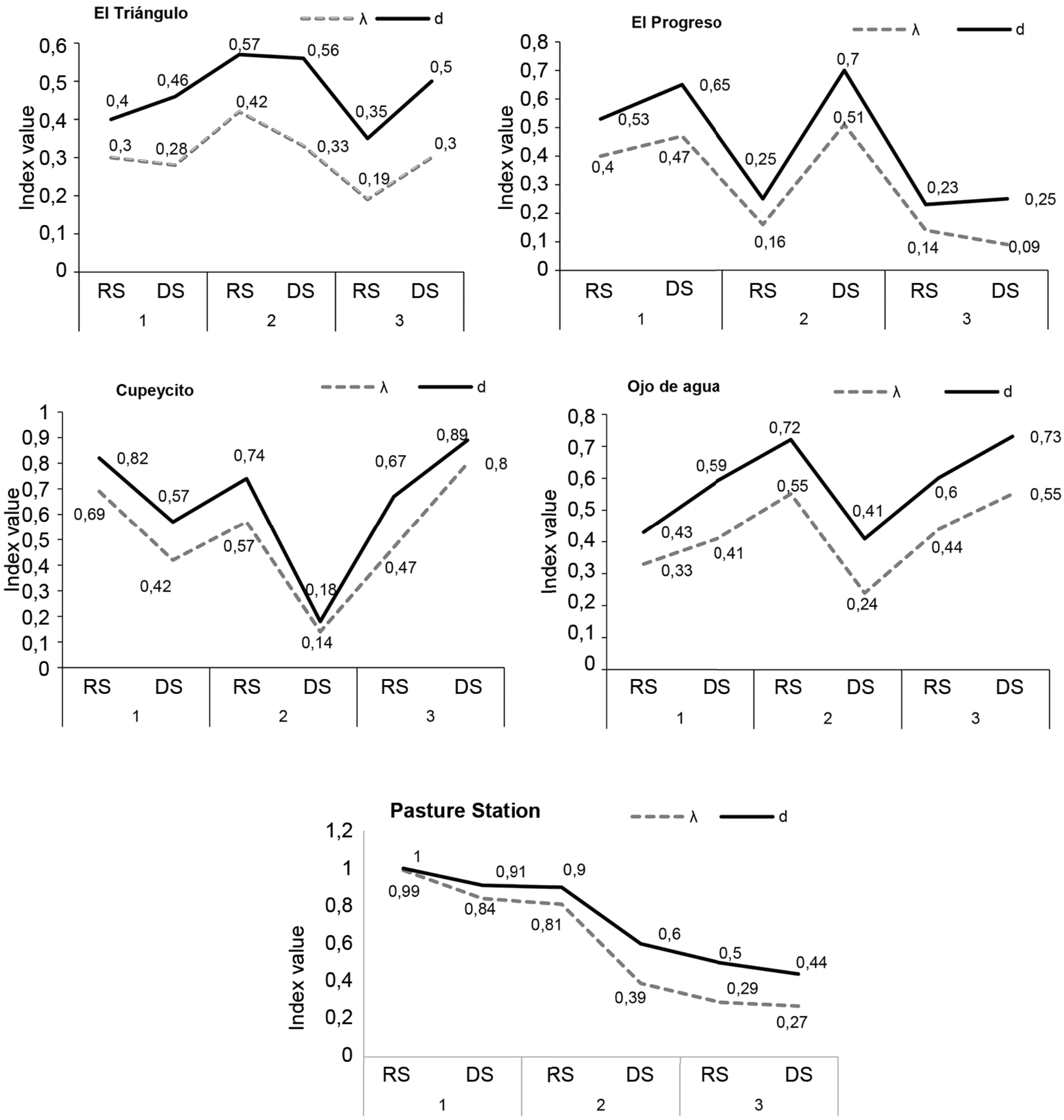
Ramírez-Barajas *et al*. (2019) refer that H' values showed higher macroinvertebrate diversity in *L. leucocephala* silvopastoral systems with *M. maximus* cv. Mombaza and *Cynodon plectostachyus* (K.Schum.) Pilg.(H'= 1,58 and H'= 1,44; respectively). They noted that the abundance of macroinvertebrate species is positively related to plant complexity, which determines a greater number of microhabitats and available resources. Birhanu *et al*. (2018) recorded higher Shanon-Wiener index in natural forest (2,04), followed by grassland (1,83) and finally cultivation (1,03). Other authors report higher values of H' in other land uses, such as agroforestry systems and forests at different latitudes (Coelho *et al*., 2021, Chamorro-Martínez *et al*., 2022, Ferreira *et al*., 2024, Morán-Centeno and Jiménez-Martínez, 2024).

The Berguer- Parker index (d) measures the dominance of the most abundant species; while the Simpson index (λ), which is also a dominance index, allows to estimate the probability that two randomly chosen individuals in one community come from different species (Moreno, 2001). In general, the Berguer-Parker index values were high in most of the performed evaluations, especially in the agroecosystems Ojo de agua and Pasture Station , where the values were higher than 0,4 in all the samplings (figure 4). The Simpson index (λ) had lower values than the Berguer-Parker index. This is translated into the fact that a small number of species dominate the edaphic macrofauna community in these agroecosystems and complements the low previously reported H` values.

All agroecosystems showed different trends in dominance indices. In the Pasture Station, a sustained decreasing trend was observed. In Ojo de Agua and Cupeycito, the lowest dominance values were observed in the dry season of the second year. However, in El Progreso, the highest values were observed in that period.

Similar results were obtained by other researchers such as Caicedo-Rosero *et al*. (2018), who reported dominance values of the main species higher than 0,66 %, in three silvopastoral systems. However, Zhou *et al*. (2022) in a study that included several vegetation ground covers reported a Simpson's index of 0,14 in grassland. Similarly, the other studied systems showed values of this index lower than 0,25. Bufebo *et al*. (2021), on the other hand, found a value of 0,37 in extensively managed rangelands in south-central Ethiopia.

The community coefficient showed a wide range of values, from 0,25 to 0,63, even though all the studied agroecosystems are considered in the landscape matrix as grasslands, with a greater or lesser presence of trees (table 3). The greatest similarity existed in the Ojo de agua and El Progreso grasslands (0,63) and with the Pasture Station (0,60). This similarity between Ojo de agua and El Progreso is striking considering the differences between these pastures in terms of geographic location, relief, soil type and cover. The similar factor between these grasslands is the method of continuous cattle grazing, which, apparently, in this case determines the presence of common



λ: Simpson index
d: Berguer-Parker index
RS: rainy season; DS: dry season

Figure 4. Dominance indices of edaphic macrofauna in five grassland agroecosystems.

Table 3. Community coefficient of the edaphic macrofauna in five grassland agroecosystems.

Agroecosystem	El Triángulo	El Progreso	Cupeycito	Ojo de agua
El Triángulo	-	-	-	-
El Progreso	0,48	-	-	-
Cupeycito	0,25	0,35	-	-
Ojo de agua	0,41	0,63	0,55	-
Pasture Station	0,35	0,54	0,56	0,60

taxonomic units in both agroecosystems. Another significant fact is the community coefficient of less than 0,5 between El Triángulo and El Progreso pastures. Due to the spatial proximity and similar edaphic characteristics of these grasslands, it would be expected that they would share a higher number of species. It seems that it is in El Triángulo where the conditions for the development of exclusive taxa exist, since it expressed the lowest similarity with the other grasslands.

Conclusions

In the studied grassland agroecosystems, the ecological indices of the edaphic macrofauna showed heterogeneous performance in the rainy and dry seasons. The specific diversity (H') of species showed mean values from 0,8 to 2,06 in the different ecosystems, independently from the evaluated climate period.

Acknowledgments

The authors thank the managers and work groups of the units where the research was carried out and the national project P131_LH002_016 Rehabilitation of pastoral systems in fragile and degraded ecosystems in the eastern region of Cuba for funding the research.

Conflicts of interests

There is no conflict of interests among the authors.

Authors' contribution

- Licet Chávez-Suárez. Research design, direction of field work, analysis and interpretation of results and writing.
- Idalmis Rodríguez-García. Research design, analysis and interpretation of the results and writing of the paper.
- Alexander Alvarez-Fonseca. Collaboration in research design, field sampling and taxonomic identification.

Bibliographic references

Anderson, J. M. & Ingram, J. S. I. *Tropical soil biology and fertility: A handbook of methods*. 2nd ed. Wallingford, United Kingdom: CAB International, 1993.

Birhanu, G.; Gorems, W.; Girmay, Z.; Yimer, F. & Demie, G. Soil macrofaunal diversity and biomass across different land use systems in Wondo Genet, Ethiopia. *Adv. Life Sci. Technol.* 67:17-23. https://core.ac.uk/reader/234687750, 2018.

Brusca, R. C. & Brusca, G. J. *Invertebrados*. España: McGraw-Hill Interamericana de España, 2003.

Bufebo, B.; Elias, E. & Getu, E. Abundance and diversity of soil invertebrate macro-fauna in different land uses at Shenkolla watershed, South Central Ethiopia. *JoBAZ*. 82:11, 2021. DOI: https://doi.org/10.1186/s41936-021-00206-1.

Cabrera-Dávila, Grisel de la C. *Evaluación de la macrofauna edáfica como bioindicador del impacto del uso y calidad del suelo en el occidente de Cuba*. España: Departamento de Ecología, Universidad de Alicante, Instituto de Ecología y Sistemática. http://hdl.handle.net/10045/88889, 2019.

Cabrera-Dávila, Grisel de la C.; Sánchez-Rendón, J. A. & Ponce-de-León-Lima, D. Macrofauna edáfica: composición, variación y utilización como bioindicador según el impacto del uso y calidad del suelo. *Acta Bot. Cub.* 221. https://revistasgeotech.com/index.php/abc/article/view/404, 2021.

Caicedo-Rosero, D. M.; Benavides-Rosales, H. R.; Carvajal-Pérez, L. A. & Ortega-Hernández, Jessica P. Población de macrofauna en sistemas silvopastoriles dedicados a la producción lechera:análisis preliminar *La Granja*. 27 (1):77-88, 2018. DOI: https://doi.org/10.17163/lgr.n27.2018.06.

Castillo-Pérez, Shirley O. & Ñique-Álvarez, M. Macrofauna del suelo como indicador biológico del estado de conservación en sistemas agroforestales del sector el Choclino en San Martín-Perú *TAYACAJA*. 2 (2):46-62, 2019. DOI: https://doi.org/10.46908/rict.v2i2.49.

Chamorro-Martínez, Yiseth; Torregroza-Espinosa, Ana C.; Moreno-Pallares, María I.; Pinto-Osorio, Diana; Corrales-Paternina, Amaira & Echeverría-González, Ana. Soil macrofauna, mesofauna and microfauna and their relationship with soil quality in agricultural areas in northern Colombia: ecological implications. *Rev. Bras. Ciênc. Solo*. 46:e0210132, 2022. DOI: https://doi.org/10.36783/18069657rbcs20210132.

Coelho, Virgínia O.; Neto, A. R.; Anhê, Ana C. B. M.; Lima, Sandra S. de; Vieira, Dinamar M. da S.; Loss, A. *et al.* Soil macrofauna as bioindicator of soil quality in different management systems. *Res., Soc. Develop.* 10 (6):e54210616118, 2021. DOI: https://doi.org/10.33448/rsd-v10i6.16118.

De Almeida, T.; Mesléard, F.; Santonja, M.; Gros, R.; Dutoit, T. & Blight, O. Above- and below-ground effects of an ecosystem engineer ant in Mediterranean dry. *Proc. R. Soc. B*. 287:20201840, 2020. DOI: https://doi.org/10.1098/rspb.2020.1840

Feinsinger, P. & Ventosa-Rodríguez, Ilarys. *El diseño de estudios de campo para la conservación de la biodiversidad*. Santa Cruz de la Sierra, Bolivia: Editorial FAN. https://edisciplinas.usp.br/pluginfile.php/2615742/mod_resource/content/3/Feinsinger%20%20Ventosa%20Rodrigues_2014.pdf, 2014.

Ferreira, Cyndi dos S.; Lima, Sandra S. de; Ramos, Aurea P. dos; Coelho, Irene da S. & Pereira, M. G. Invertebrate macrofauna in litter of mountain environments in the state of Rio de Janeiro. *Res., Soc. Dev.* 13 (7):e2813746255, 2024. DOI: https://doi.org/10.33448/rsd-v13i7.46255.

Galván, Romina; Carbonetti, Micaela; Gende, M. & Brunini, C. Impacto del evento extremo Enos 2015-2016 sobre la geometría de la superficie terrestre en la región ecuatorial de Sudamérica. *Geoacta.* 42 (2):23-44. https://www.scielo.org.ar/scielo.php?script=sci_arttext&pid=S1852-77442017000200003&lng=es&tlng=es, 2017.

Gao, B. & Wu, D. H. The effects of returning farmlands to forests or pastures on soil animal diversity and its regional differentiation characteristics in China: a meta-analysis. *Appl. Ecol. Environ. Res.* 18 (5):6335-6353, 2020. DOI: http://dx.doi.org/10.15666/aeer/1805_63356353.

Gutiérrez-Bermúdez, C del C.; Mendieta-Araica, B. G. & Noguera-Talavera, A. J. Trophic composition of edaphic macrofauna in animal husbandry systems in the Dry Corridor of Nicaragua. *Pastos y Forrajes.* 43 (1):32-40. http://scielo.sld.cu/pdf/pyf/v43n1/en_2078-8452-pyf-43-01-32.pdf, 2020.

Hernández-Chavez, Marta B.; Ramírez-Suárez, Wendy M.; Zurita-Rodríguez, A. A. & Navarro-Boulandier, Marlen. Biodiversidad y abundancia de la macrofauna edáfica en dos sistemas ganaderos en Sancti Spíritus, Cuba. *Pastos y Forrajes.* 43 (1):18-25. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0864-03942020000100018, 2020.

Hickman, C. P.; Roberts, L. S. & Larson, A. I. *Integrated principles of zoology.* 11th ed. New York: McGraw-Hill. https://bayanbox.ir/view/8110887935878997036/PART-II-Hickmanx-Robertsx-Larson-Integrated-Principles-of-Zoology.pdf, 2001.

Kunakh, O. M.; Volkova, A. M.; Tutova, G. F. & Zhukov, O. V. Diversity of diversity indices: Which diversity measure is better? *Biosyst. Divers.* 31 (2):131-146, 2023. DOI: https://doi.org/10.15421/012314.

Machado-Cuellar, Leidy; Rodríguez-Suárez, L.; Murcia-Torrejano, V.; Orduz-Tovar, S. A.; Ordoñez-Espinosa, Claudia M. & Suárez, J. C. Soil macrofauna and edaphoclimatic conditions in an altitude gradient of coffee growing regions, Huila, Colombia. *Rev. Biol. Trop.* 69 (1):102-112, 2021. DOI: https://doi.org/10.15517/rbt.v69i1.42955.

Marsden, Claire; Martin-Chave, Ambroise; Cortet, J.; Hedde, M. & Capowiez, Y. How agroforestry systems influence soil fauna and their functions-a review. *Plant Soil.* 453:29-44, 2020. DOI: https://doi.org/10.1007/s11104-019-04322-4.

Montecelos-Zamora, Yalina; Cavazos, Tereza; Kretzschmar, T.; Vivoni, E. R.; Corzo, G. & Molina-Navarro, E. Hydrological modeling of climate-change impacts in a tropical river basin. A case study of the Cauto River, Cuba. *Water.* 10 (9):1135, 2018. DOI: https://doi.org/10.3390/w10091135.

Morales-Rojas, E.; Chávez-Quintana, S.; Chichipe-Vela, E.; Oliva, M. & Quiñones-Huatangari, L. Edaphic macrofauna and soil physicochemical properties, in smallholder coffee farms. *Rev. Fac. Agron. (LUZ).* 38 (4):934-950. https://produccioncientificaluz.org/index.php/agronomia/article/view/36803, 2021.

Morán-Centeno, J. C. & Jiménez-Martínez, E. Soil macrofauna in agroecosystems of *Coffea arabica* L., in Tepec-Xomolth, Nicaragua. *Agron. Mesoam.* 35:57626, 2024. DOI: https://doi.org/10.15517/am.2024.57626.

Moreno, Claudia E. *Métodos para medir la biodiversidad.* M&T–Manuales y Tesis SEA, vol. 1. Zaragoza, España: CYTED, ORCYT/UNESCO & SEA. http://entomologia.rediris.es/sea/manytes/metodos.pdf, 2001.

Omayio, D. & Mzungu, E. Modification of Shannon-Wiener diversity index towards quantitative estimation of environmental wellness and biodiversity levels under a non-comparative scenario. *J. Environ. Earth Sci.* 9 (9):46, 2019. DOI: https://doi.org/10.7176/JEES.

Ramírez-Barajas, P. J.; Santos-Chable, Bella E.; Casanova-Lugo, F.; Lara-Pérez, L. A.; Tucuch-Haas, J. I.; Escobedo-Cabrera, A. *et al.* Diversidad de macro-invertebrados en sistemas silvopastoriles del sur de Quintana Roo, México. *Rev. biol. trop.* 67 (6):1383-1393, 2019. http://dx.doi.org/10.15517/rbt.v67i6.36944.

Rodríguez-Suárez, L.; Paladines-Josa, Yuli T.; Astudillo-Samboni, Erika J.; Lopez-Cifuentes, Karla D.; Durán-Bautista, E. H. & Suárez-Salazar, J. C. Soil macrofauna under different land uses in the Colombian Amazon. *Pesq. agropec. bras.* 53 (12):1383-1391, 2018. DOI: https://doi.org/10.1590/S0100-204X2018001200011.

Roswell, M.; Dushoff, J. & Winfree, Rachael. A conceptual guide to measuring species diversity. *Oikos.* 130 (3):321-338. 2021. DOI: https://doi.org/10.1111/oik.07202.

Sabatté, María L.; Massobrio, M. J.; Cassani, M. T. & Momo, F. R. Macro and mesofauna soil food webs in two temperate grasslands: responses to forestation with *Eucalyptus*. *Heliyon.* 7 (1):e05869. 2021 DOI: https://doi.org/10.1016/j.heliyon.2020.e05869.

Silva, Bianca C. da; Trevisan, Adriana C. D.; Elguy, L. G. P.; Benamú, M. A. & Silva, V. L. da. Análise da macrofauna edáfica em pomar caseiro: subsídios para implantação dequintais agroflorestais no bioma Pampa. *Rev. Bras. Agroecol.* 18 (1):44-60, 2023. DOI: https://doi.org/10.33240/rba.v18i1.23637.

Vazquez, E.; Teutscherova, N.; Lojka, B.; Arango, J. & Pulleman, Miriam. Pasture diversification affects soil macrofauna and soil biophysical properties in tropical (silvo)pastoral systems. *Agric. Ecosyst. Environ.* 302:107083, 2020. DOI: https://doi.org/10.1016/j.agee.2020.107083.

Xu, S.; Böttcher, L. & Chou, T. Diversity in biology: definitions, quantification and models. *Phys Biol.* 17 (3):031001, 2020. DOI: https://doi.org/10.1088/1478-3975/ab6754.

Zhou, Y.; Liu, C.; Ai, Ning; Xianghui, T.; Zhiyong, Z.; Gao, R. *et al.* Characteristics of soil macrofauna and Its coupling relationship with environmental factors in the loess area of Northern Shaanxi. *Sustainability.* 14 (5):2484, 2022. DOI: https://doi.org/10.3390/su14052484.