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Edaphic macrofauna associated with the cultivation of maize (*Zea maiz*)
Macrofauna edáfica asociada al cultivo de maíz (*Zea maíz*)

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Abstract

Macrofauna is a biological indicator of soils, in this sense, the objective of this research was to determine the edaphic macrofauna community and its physicochemical properties of the soil, by means of its abundance and richness of groups during the growing season and post-harvest of corn. Three monoliths 25 x 25 cm wide by 30 cm deep were established. Soil samples were taken in each plot, then the organic matter (OM) content, hydrogen potential (pH), electrical conductivity (EC) and nitrogen (N) content were determined. The results show differences between atmospheric temperatures during the development period (25 °C) and the post-harvest period (41.4 °C). Physicochemical parameters such as pH ranged between 8.5 and 8.3. The maximum Shannon index was 0.48 (growing season) and 0.13 (post-harvest season). The greatest number of individuals was ants (111) and was identified during the post-harvest period. In this sense, the biological diversity was lower in the growing season of corn, and during the post-harvest period a greater number of ant organisms was determined, which was associated with the resistance to high temperatures.

Resumen

La macrofauna es un indicador biológico de suelos, en este sentido el objetivo de esta investigación fue determinar la comunidad de macrofauna edáfica y sus propiedades fisicoquímicas del suelo, por medio de su abundancia y riqueza de grupos durante la época de crecimiento y post cosecha del maíz. Se establecieron tres monolitos 25 x 25 cm de ancho por 30 cm de profundidad. Se tomaron muestras de suelo en cada parcela, luego se determinó el contenido de materia orgánica (MO), potencial de hidrógeno (pH), conductividad eléctrica (CE) y contenido de nitrógeno (N). Los resultados muestran diferencias entre las temperaturas atmosféricas, durante la época de desarrollo (25 °C) y la época de post cosecha (41.4 °C). Los parámetros fisicoquímicos como el pH oscilo en 8.5 y 8.3. El índice de Shannon máximo fue de 0.48 (época de post cosecha) y de 0.13 (época de desarrollo). La mayor cantidad de individuos fue de hormigas (111) y se identificó durante la época de post cosecha. En tal sentido la diversidad biológica fue menor en la época de crecimiento del maíz, y durante la post cosecha hubo mayor cantidad de organismos de hormigas el cual estuvo asociado a la resistencia de las altas temperaturas

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Palabras clave:

Maíz,
altitud,
abundancia,
desarrollo,
post cosecha.

Introduction

Soil fauna can be considered a very effective means of helping microorganisms to dominate and expand into soil horizons, improving their fertility, equilibrium, and vegetation development[1,2]. Edaphic macrofauna (EM) is one of the indicators of soil quality, and is widely distributed in all soil types, but is very sensitive to different human interventions[3]. EM is used as a bioindicator, due to its simplicity, low cost[4], contributes to the control of soil structure, altering its aggregation and porosity, improving infiltration, changing water retention patterns, contributing to the mineralization of organic matter (OM), with the decomposition of leaf litter[5-7].

Macroinvertebrates in the soil alter microbial activity in the processes of OM mineralization and humification, thus influencing the availability of assimilable nutrients for plants[8], in addition, these organisms contribute to the vertical mobility of assimilable nutrients, which is of great benefit to plant root systems[9].

The abundance and diversity of EM are important factors for the sustainability of primary production in ecosystems with different land covers[10], and their richness reflects the state of soil degradation[11].

EM can be affected by climatic periods[12], likewise, the population of organisms can be observed in greater quantity during the rainy season[13,14], some crops have detrimental effects on EM, especially earthworms[15].

Very little is known about the distribution of EM under conditions of elevated temperatures and low OM content[16]. Studies relate the probability of physical degradation and soil compaction to the population of EM[17]. Other studies have reported that soil invertebrates are highly correlated with the surrounding vegetation[18,19], and highlight the importance of soil biota in the recovery of degraded areas[20-22].

The factors that can cause the reduced density of edaphic biota in corn crops may possibly be the loss of OM[23]. In these crops during the growing season, populations of species that are mostly pests, such as Melolonthidae ("blind hen")[24] are usually observed.

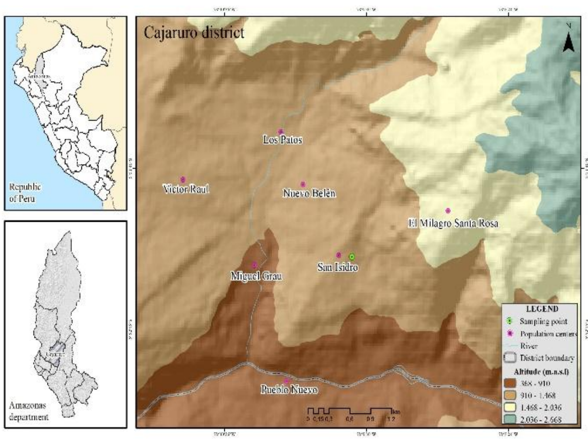
There is scarce information on EM in corn crops. Based on the above, the objective of this research was to determine the edaphic macrofauna and physicochemical properties of the soil dedicated to corn cultivation.

Materials and methods

Location. Sampling was carried out in January and October 2020, in the hamlet of San Isidro, district of

Cajaruro, province of Utcubamba, Amazonas Region-Peru, Figure 1. San Isidro is located at an altitude of 990 meters above sea level. With coordinates 149950 east and 9350074 west. The coordinates were measured with the GPS model GPSMAP 66i-GARMIN. The plot is located on the right bank of the Utcubamba River and is characterized by being an agricultural sector, its main crop is hard yellow corn[25]. The average production per hectare is 4000 kg (80 qq/ha)[26].

Figure 1 Location of the study area-San Isidro hamlet



The predominant soils are vertisols[27]. The climate is warm, varying according to the altitudinal levels of the zone, from 10 to 40 ºC. Rainfall varies from 200 to 1000 mm per year, with more intense rainfall from January to March, and from June to September is the dry season[28].

Methodology. Two periods were taken into account: a) corn development period when it was one month into its growth b) post-harvest period (two months after harvest), a corn plot of one ha (10000 m²) was selected, the plot was 15 years old. For the sampling, three monoliths of 25 x 25 cm wide by 30 cm deep were extracted, according to the methodology "Tropical Soil Biology and Fertility" or TSBF[29]. The selection of the EM was carried out in situ, and manually with the help of a white blanket. It consisted of removing foreign bodies such as stones and plant debris. The extracted organisms were stored in flasks with 70% ethyl alcohol for subsequent identification and visual counting in the agro-industrial engineering laboratory of the Universidad Nacional Toribio Rodríguez de Mendoza (UNTRM). The richness of the samples and diversity were then calculated using Shannon's (H') and Simpson's (DSi)[30] index. Soil samples were taken to analyze pH, EC, with the EPA 9045/Soil-Water Ratio 1:1[31] method. The organic carbon (C) and nitrogen (N) content of the soil was determined from the soil OM, using the method proposed by Walkley & Black[32]. The analyses were carried out at the Soil and Water Research Laboratory of the Research Institute for Sustainable Development of Ceja de Selva (INDES-CES) of the UNTRM. Atmospheric temperature and relative humidity were taken with a Thermohygrometer Model: VA-EDT-1-55 and soil temperature was taken with a 13 cm needle digital thermometer, code 111TMP14.

For data processing, Minitab 17[33] was used to determine averages and their standard deviation in the temperatures (development and post-harvest period of corn).

Results

Table 1 shows the results of soil temperature and atmospheric temperature in the San Isidro farmhouse, in the post-harvest stage, the atmospheric temperature was higher, compared to the soil temperature, with a variation of only 0.9 °C.

Table 1 Temperature during the two sampling periods

Development phase (February)			Post-harvest phase (October)		
ST	AT	RH %	ST	AT	RH %
23.3±1.4	25.5±1.4	71.5±6.5	24.2±1.3	31.4±1.6	49.9±2.2

ST= Soil temperature, AT= Atmospheric temperature, RH= Relative humidity

Physicochemical parameters. Figure 2 shows the behavior of the physicochemical parameters for the February period (development phase), October period (post-harvest period). The MO for the post-harvest period decreased from 5.67 to 3.37 %. Soil nitrogen was also reduced for the post-harvest period (0.28-0.17 %).

Edaphic macrofauna in the developmental stage of maize. Thirteen ME families were identified at the crop development stage and the individuals that stood out were caterpillars (Table 2).

Figure 2 Behavior of the physicochemical parameters of soil

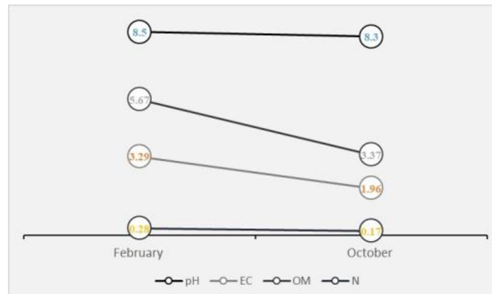


Table 2 Edaphic macrofauna for the maize development period in an area of 0.625 m^2

Época	orders	families	Common name	N° Individuals
Development	Lepidoptera	Scarabaeidae	Cucaracha	1
	Hymenoptera	Formicidae	Hormiga	4
	Hemípteros	Cydnidae	Chinche	4
	Araneae	Lycosidae	Araña	3
	Haplotaxida	Lumbricidae	Lombriz	3
	Dermaptera	Forficulidae	Tijeras	1
	Isoptera	Termitidae	comejen	1
	Diptera	Muscidae	Mosca	2
	Coleoptera Linnaeus	Bostrichidae	Escarabajo	1
	Lepidoptera	Noctuidae	Oruga	11
	Coleópteros	Elateridae	Gusano	5
	Diptera	Culicidae	Zancudo	3
	Blattodea	Termitidae	Cochinilla	1
Total				**40**

During the post-harvest period, 12 families were identified, distributed in 12 orders. The maximum number is 86 individuals of Formicidae and occurred in the post-harvest stage (Table 3).

Table 3. Edaphic macrofauna for the post-harvest period of maize in an area of 0.625 m^2.

Shannon and Simpsom index. In the development stage, the Shannon index yielded a value of 0.13, while in the post-harvest stage the Shannon index was 0.48. The Simpsom index confirms the faunal richness, showing the same behavior with values of 2.09 during the corn development stage and 7.69 for the post-harvest stage (Figure 3).

Discussion

ME individuals could be influenced by atmospheric and soil temperature, it was observed that the increase in temperature during the post-harvest period is directly related to the number of individuals and their abundance. Just as the elimination of vegetation can reduce the protection of the soil against climatic variations, causing high insolation, high temperatures, and low humidity, it makes the soil environment of some individuals less favorable for their survival[34]. Humidity can be a limiting factor for plants; however, some species of soil fauna have developed mechanisms to tolerate extreme drought conditions[35].

Figure 3 Behavior of faunal diversity

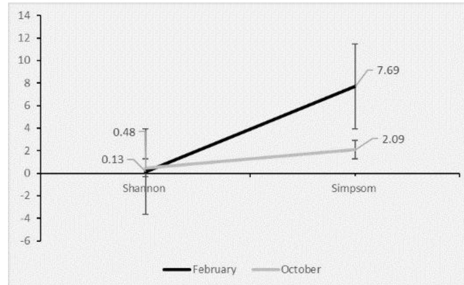


Table 3. Edaphic macrofauna for the post-harvest period of maize in an area of 0.625 m^2

Epoca	orders	families	Common name	N° Individuals
Total, post-harvest	Lepidoptera	Scarabaeidae	Cucaracha	6
	Scolopendrida	Scolopendridae	Ciempies	4
	Hymenoptera	Formicidae	Hormiga	86
	Hemipteros	Cydnidae	Chinche	4
	Araneae	Lycosidae	Araña	5
	Haplotaxida	Lumbricidae	Lombriz	1
	Isoptera	Termitidae	comejen	3
	Lepidoptera	Noctuidae	Oruga	8
	Coleópteros	Elateridae	Gusano	4
	Diptera	Culicidae	Zancudo	1
	Blattodea	Termitidae	Cochinilla	3
	Ortópteros	Grylloidea	Grillo	1
Total				**126**

During the corn development period, a greater abundance of caterpillars could be observed; their presence is intuited because they feed on corn leaves[36], the presence of earthworms in small quantities in both periods is attributed to the fact that they tend to prevail in humid, non-compacted edaphic environments with high MO content[37]. However, the greatest quantity of earthworms was during the development of corn, the results are related to the development of these plants since earthworms tend to leave deep soils in search of favorable environments[38].

In the post-harvest stage, the greatest number of individuals, ants, characteristics of the summer season, and the remains of the corn stover, the tillage systems can influence the abundance of predatory groups[39]. Ants are important bioindicators, since they adapt to different disturbance regimes, such as an increase in the number of invasive plants, inhibition of decomposition, and contamination levels, generally due to agrochemicals[40]. The number of families of soil macrofauna in corn crops is similar to that of native vegetation[41], leaving open the possibility of studying it in neighboring native plots. Ants and termites are classified as "ecosystem engineers "[42], present in low altitude soils[43]. Ants were observed to be prevalent in abundance and resistance in systems that had some level of anthropic intervention[44]. The richness and abundance of the macrofauna were those that coincided in the post-harvest, summer season. The dominant family in most of the land-use systems was Formicidae (ants)[45], land-use change may be one of the greatest threats to soil biodiversity[46].

When results of lower macrofauna density during the dry season are observed, this does not agree with the results of Jiménez et al.[47], however, the existence of a greater presence of the order Araneae (Arachnida) is valid.

Variables such as MO, affect the distribution of the edaphic groups of fauna[48], pH values close to 7, the number of individuals may decrease, however, this is in accordance with the type of soil use[49]. In this study, the pH was between 8.5 and 8.3 for the post-harvest period. Temperature and humidity are factors that regulate the OM[50,51], earthworms were associated with OM and pH, and it was found that when OM and pH showed high values, there were more earthworms.

Shannon's index, as well as Simpson's index, indicate a similar behavior indicating the abundance of the EM, with greater abundance being observed in the post-harvest period. In agreement with the study conducted by Reis-Ferreira et al.[52], the abundance and total richness in maize soils were generally higher in the dry season. The specific richness of the ME of this site is low, possibly reflecting the state of soil degradation[53]. The Shannon index usually has higher values in times of maximum rainfall[54]. MO is important for diversifying soil OM communities[55].

The highest abundance was observed during the post-harvest period, when the greatest number of individuals represented by ants, characteristic of dry soils at low altitudes, and was associated with physicochemical parameters. The temperature and the remains of corn stover during the post-harvest period may have influenced the number of individuals (ants). OM and N are characteristic of humid soils where it is affirmed by obtaining high values in the corn development period, unlike the post-harvest period, which yielded low values.

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Conflicts of interest

The authors declare that this research does not generate conflicts of interest.

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Ethical considerations

Approval of the research by the Ethics Committee of the Research Institute for Sustainable Development of Ceja de Selva (INDES-CES), National University Toribio Rodriguez de Mendoza of Amazonas (UNTRM).

Authors' contributions

Eli Morales Rojas, the main author of the project, design, and execution. As well as the accompaniment in the interpretation of the data related to the edaphic macrofauna, elaboration, and preparation of the research report. *Segundo Chavez Quintana*, the establishment of tests and systematization of the information and revision of the manuscript. *Roxana Hurtado Burga*, has participated in the design of the research, systematization of the information obtained, and preparation of the scientific manuscript. *Manuel Milla Pino*, participated in the research design, systematization of the information obtained, and preparation of the scientific manuscript. *Tito Sanchez Santillan*, participated in the research design, systematization of the information obtained, and preparation of the scientific manuscript. *Erik Martos Collazos Silva*, participated in the research design, systematization of the information obtained, and preparation of the scientific manuscript.

Cited Literature

1. Feng Y, Balkcom KS. Nutrient cycling and soil biology in row crop systems under Intensive tillage. In: Al-Kaisi MM, Lowery B, editors. Soil health and intensification of agroecosytems. Ney York: Academic Press; 2017. p. 231-55. DOI: https://doi.org/10.1016/B978-0-12-8053171.0001 1-7
2. Kamau S, Barrios E, Karanja NK, Ayuke FO, Lehmann J. Soil macrofauna abundance under dominant tree species increases along a soil degradation gradient. Soil Biol Biochem 2017;112:35-46. DOI: https://doi.org/10.1016/j.soilbio.2017.04.016
3. Lavelle P, Dolédec S, Arnauld de Sartre X, Decaëns T. Gond V, Grimaldi M. Unsustainable landscapes of deforested Amazonia: An analysis of the relationships among landscapes and the social, economic and environmental profiles of farms at different ages following deforestation. Glob Environ Change 2016;40: 137-55. DOI: https://doi.org/10.1016/j.gloenvc ha.2016.04.009
4. Velasquez E, Lavelle P. Soil macrofauna as an indicator for evaluating soil based ecosystem services in agricultural landscapes. Acta Oecol 2019;100:103446. DOI: https://doi.org/10.1016/j-actao.2019.103446
5. Frouz J, Roubíčková A, Heděnec P, Tajovský K. Do soil fauna really hasten litter decomposition? A meta-analysis of enclosure studies. Eur J Soil Biol 2015;68:18-24. DOI: https://doi.org/10.1016 /j.ejsobi.2015.03.002
6. Sofo A, Mininni AN, Ricciuti P. Soil macrofauna: A key factor for increasing soil fertility and promoting sustainable soil use in fruit orchard agrosystems. Agronomy 2020;10(4): 456. DOI: https://doi.org/10.3390/agronomy100 40456
7. Machaco Siqueira G, França Silva ÊD, Matos Moreira M, Araújo Santos A, Alves Silva R. Diversity of soil macrofauna under sugarcane monoculture and two different natural vegetation types. Afr J Agric Res 2016;11(30):2669-77. DOI: https://doi.org/10.5897/ajar2016.11083
8. Decaëns T, Bureau F, Margerie P. Earthworm communities in a wet agricultural landscape of the Seine Valley (Upper Normandy, France) The 7th international symposium on earthworm ecology Cardiff Wales 2002. Pedobiologia 2003;47(5–6):479-89. DOI: https://doi.org/10. 1078/0031-4056-00217
9. Lavelle P, Brussaard L, Hendrix P. Earthworm Management in Tropical Agroecosystems [Internet]. Wallingford: CABI Publishing is a division of CAB International; 1999 [citado 22-de octubre de 2021]. 314 p. Recuperado a partir de: https://core.ac.uk/download/pdf/39848561.pdf#page=99
10. Ferrera Cerrato R, Alarcón A. The microbial activity in the agroecosystem. Cienc Ergo Sum 2001;8(2):175-83.
11. Mancilla-Brindis RF, Rangel Ruiz LJ, Falcón-Brindis A, Gamboa Aguilar J, Valdez Leal JDD. Riqueza y abundancia de la macrofauna epigea en

cuatro sistemas tropicales del estado de Chiapas, México. Acta Zool Mex 2017;33(3):464-71. DOI: https://doi.org/10.21829/azm.2017.3331147

12. Medina MG, García DE, Moratinos P, Clavero T, Iglesias JM. Macrofauna edáfica en sistemas silvopastoriles con Morus alba, *Leucaena leucophala* y pastos. Zootecnia Trop 2011;29(3):301-12.

13. Gamboa JA, Suárez JC, Chaves JA. Macroinvertebrados edáficos asociados a rastrojos en paisaje de lomerío de la Amazonia colombiana. En: Orjuela Chávez JA, Suárez Salazar JC, editores. Valoración de rastrojos para la formación de sistemas silvopastoriles en la Amazonia colombiana. Florencia: Edith'ores, Florencia; 2011. p.116-128.

14. Zamudio-Chavero A, Guzmán-Mendoza R, Salas-Araiza MD. Abundancia y diversidad de insectos edáficos en huertas de nogal pecanero. Jóvenes en la ciencia 2018;4(1):439-43.

15. Pashanasi-Amasifuen B. Estudio cuantitativo de la macrofauna del suelo en diferentes sistemas de uso de la tierra en la Amazonia Peruana. Folia Amazónica 2001;12(1-2):75-97. DOI: https://doi.org/10.24841/fa.v12i1-2.126

16. Amat G, Soto L. Efectos del uso actual del suelo sobre la macrofauna edáfica en la región del Guejar, Reserva Natural Integral La Macarena. Meta 1988;2(6-7):43-67.

17. Pankhurst CE, Doube BM, Gupta VVSR, Grace PR. Soil biota: management in sustainable farming systems. Melbourne: CSIRO Publications; 1994. 262 p.

18. Burger JC, Redak RA, Allen EB, Rotenberry JT, Allen MF. Restoring arthropod communities in coastal sage scrub. Conserv Biol 2002;17(2):460-7. DOI: https://doi.org/10.1046/j.1523-1739.2003.01325.x

19. Hidalgo G, Toledo W, Granados-Barba A. Diversidad y distinción taxonómica de la macrofauna en fondos blandos de la plataforma norte y suroccidental cubana. Lat Am J Aquat Res 2015;43(5):845-55. DOI: https://doi.org/10.3856 /vol43-issue5-fulltext-5

20. Barros E, Neves A, Fernandes ECM, Wandelli E, Lavelle P. Soil macrofauna community of Amazonian agroforestry systems. In: Jiménes F, Beer J, editors. International symposium: Multi-strata agroforestry systems with perennial crops: 22-27 February 1999. Tropical Agricultural Research and Training Center [Internet]. Turrialba: CATIE; 1999 [citado 3 de agosto de 2020]. p. 166-70. Recuperado a partir de: https://www.researchgate.net/publication/278597651_Multistrata_agroforestry_systems_with_perennial_crops

21. Araujo-Vergara YM. Oligoquetos sob adição de liteira e sua relação com a disponibilidade de nitrogênio em solos de capoeira na Amazônia Central [tesis mestrado]. [Manaus]: Universidade do Amazonas; 2000 [citado 26 de octubre de 2020]. Recuperado a partir de: https://bdtd.inpa.gov.br/handle/tede/3139

22. Castilho as Silva G. Efeito da qualidade do substrato na biomassa microbiana do solo de uma capoeira da Amazônia Central [tesis mestrado]. [Manaus]: Universidade do Amazonas; 2000 [citado 26 de octubre de 2020]. Recuperado a partir de: https://bdtd.inpa.gov.br/handle/tede/3137

23. Villalobos FJ, Ortiz-Pulido R, Moreno C, Pavón-Hernández NP, Hernández-Trejo H, Bello J, et al. Patrones de la macrofauna edafica en un cultivo de *Zea maiz* durante la fase postcosecha en "la mancha", Veracruz, México. Acta Zool Mex 2000;(80):167-83.

24. Pérez-Agis E, Vázquez García M, González Eguiarte D, Pimienta Barrios E, Nájera Rincón MB, Torres Morán P. Sistemas de producción de maíz y población de macrofauna edáfica. Terra Latinoam 2004;22(3);335-41.

25. Bustamante Sánchez G. Plan Estratégico Concertado de Desarrollo-Provincia Utcubamba [Internet]. Chiclayo: Centro de Investigación Capacitación Asesoría Y Promoción; 2004 [citado 22-de

octubre de 2020]. 193 p. Recuperado a partir de: https://www.peru.gob.pe/docs/PLANES/11823/PLAN_11823_Plan_Estrat%C3%A9gico_Concertado_de_Desarrollo_%E2%80%93_Provincia_Utcubamba_2011.pdf

26. Chávez Santa Cruz G, Sevilla Panizo R, Vásquez Núñez L, Ramos Delgado HF, Fernández Vásquez EJ, Vásquez Arca LP, et al. Servicio de prospección, colección, elaboración de mapas de distribución y estudio socioeconómico y de conocimientos tradicionales asociados al cultivo de las razas de maíz [Internet]. Lima: Ministerio de Medio Ambiente; 2015 [citado 22-de octubre de 2020]. 179 p. Recuperado a partir de: https://bioseguridad.minam.gob.pe/wp-content/uploads/2017/02/maiz_13regiones_2015.pdf
27. Montanarella L, Pennock D, Neil McKenzie N. Estado mundial del recurso del suelo [Internet]. Roma: Organizacion de las Naciones Unidas para la Alimentacion y agricultura; 2016 [citado 12-de noviembre de 2020]. 34 p. Recuperado a partir de: http://www.fao.org/3/i5126s/i5126s.pdf
28. Campos Baca L, Rodríguez Achung F, Guzmán Castillo W, Florián Huayán C, Reátegui Reátegui F, Escobedo Torres R. Zonificación ecológica y económica del departamento de amazonas [Internet]. Lima: Instituto de Investigaciones de la Amazonia Peruana; 2010 [citado 2-de octubre de 2020]. 199 p. Recuperado a partir de: https://sinia.minam.gob.pe/documentos/propuesta-zonificacion-ecologica-economica-departamento-amazonas
29. Anderson JM, Ingram JSI. Tropical soil biology and fertility a handbook of methods. [Internet]. WaHingford: CAB International; 1993. [citado 22-de octubre de 2020]. 237 p. DOI: https://doi.org/10.2307/2261129
30. Medrano Meraz MJ, Hernández FJ, Corral Rivas S, Nájera Luna JA. Diversidad arbórea a diferentes niveles de altitud en la región de El Salto, Durango. Rev Mex Cienc Forestales 2017;8(40):57-68. DOI: https://doi.org/10.29298/rmcf.v8i40.36
31. Estrada-Herrera IR, Hidalgo-Moreno C, Guzmán-Plazola R, Almaraz Suárez JJ, Navarro-Garza H, Etchevers-Barra JD. Soil quality indicators to evaluate soil fertility. Agrociencia 2017;51(8): 813-31.
32. Walkley A, Black IA. An examination of Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 1934;37(1):29-38. DOI: https://doi.org/10.1097/00010694-193401000-00003
33. Reyes Dixson Y, Nuñez Maturel L. El análisis estadístico aplicado a la gestión de la enseñanza para la toma de decisiones. Rev Cuba Cienc Informát 2015;9(3):113-27.
34. Matos PS, Barreto-Garcia PAB, Scoriza RN. Effect of different forest management practices on the soil macrofauna in the arboreal caatinga. Rev Caatinga 2019;32(3):741-50. DOI: https://doi.org/10.1590/1983-21252019v32n318rc
35. Villalobos FJ, Ortiz-Pulido R, Moreno C, Pavón-Hernández NP, Hernández-Trejo H, Bello J, et al. Patrones de la macrofauna edáfica en un cultivo de Zea maiz durante la fase postcosecha en" La Mancha", Veracruz, México. Acta Zool Mex 2000;(80):167-83.
36. Hall D, Meagher RR. Nagoshi R Irey M. Monitoring populations of adult fall armyworm, *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae), in Florida sugarcane using pheromone traps, with special reference to genetic strains of the pest. Proc ISSCT [Internet]. 2005 [citado 5 de octubre de 2020]; 25: 784-7. Recuperado a partir de: https://www.ars.usda.gov/ARSUserFiles/22401/MONITORING%20POPULATIONS.pdf
37. Chocobar Guerra EA. Edafofauna como indicador de la calidad en un suelo Cumulic Phaozem some-

tido a diferentes sistemas de manejo en un experimento de larga duración [tesis maestría]. [Montecillo]: Instituto de Enseñanza e investigación en Ciencias Agrícolas; 2010 [citado 26 de octubre de 2020]. Recuperado a partir de: https://es.scribd.com/document/340836339/Chocobar-Guerra-EA-MC-Edafologia-2010-pdf

38. Baizán S, Vicente F, Martínez-Fernández A. Management influence on the quality of an agricultural soil destined for forage production and evaluated by physico-chemical and biological indicators. Sustainability 2021;13(9):5159. DOI: https://doi.org/10.3390/su13095159

39. Maria de Aquino A, da Ferreira da Silva RF, Mercante FM, Fernandes Correia ME, Guimarães MDF, Lavelle P. Invertebrate soil macrofauna under different ground cover plants in the no-till system in the Cerrado. Eur J Soil Biol 2008;44(2):191-7. DOI: https://doi.org/10.1016/j.ejsobi.2007.05.001

40. Wink C, Carus Guedes JV, Kurzmann Fagundes C, Rovedder AP. Soilborne insects as indicators of environmental quality. Rev Ciênc Agrovet 2005;4(1):60-71.

41. Santos DP, Schossler TR, Lima dos Santos I, Batista Melo N, Guimarães Santos G. Soil macrofauna in a Cerrado/Caatinga ecotone under different crops in Southwestern Piauí State, Brazil. Ciênc Rural 2017;47(10):e20160937. DOI: https://doi.org/10.1590/0103-8478cr20160937

42. Lavelle P, Decaëns T, Aubert M, Barot S, Blouin M, Bureau F, et al. Soil invertebrates and ecosystem services. Eur J Soil Biol 2006;42(Suppl 1):S3-15. DOI: https://doi.org/10.1016/j.ejsobi.2006.10.002

43. Velasquez E, Lavelle P. Soil macrofauna as an indicator for evaluating soil based ecosystem services in agricultural landscapes. Acta Oecol 2019;100:103446. DOI: https://doi.org/10.1016/j.actao.2019.103446

44. Cabrera G. La macrofauna edáfica como indicador biológico del estado de conservación/perturbación del suelo. Resultados obtenidos en Cuba. Pastos y Forrajes 2012;35(4):349-64.

45. Cabrera Dávila GDLC, Sánchez Rendón J (dir), López Iborra G (dir). Evaluación de la macrofauna edáfica como bioindicador del impacto del uso y calidad del suelo en el occidente de Cuba [tesis doctoral]. [Alicante]: Universidad de Alicante; 2019 [citado 26 de octubre de 2020]. Recuperado a partir de: http://rua.ua.es/dspace/handle/10045/88889

46. Nielsen UN, Wall DH, Six J. Soil biodiversity and the environment. Annu Rev Environ Resour 2015;40:63-90. DOI: https://doi.org/10.1146/annurev-environ-102014-021257

47. Jiménez JJ, Moreno AG, Decaëns T, Lavelle P, Fisher MJ, Thomas RJ. Las comunidades de lombrices en las sabanas nativas y en los pastizales introducidos de los Llanos Orientales de Macrofauna edáfica asociada con sistemas agroforestales en la Amazonía colombiana 220 Colombia. En: Jiménez JJ, Thomas RJ, editores. El arado natural: Las comunidades de macroinvertebrados del suelo en las sabanas neotropicales de Colombia [Internet]. Cali: Centro Internacional de Agricultura Tropical; 2003. p. 57-75. Recuperado a partir de: http://ciat-library.ciat.cgiar.org/articulos_ciat/arado_natural.pdf

48. Kraft E, Oliveira Filho LCID, Carneiro MC, Klauberg-Filho O, Baretta CRDM, Baretta D. Edaphic fauna affects soybean productivity under no-till system. Sci Agric 2021;78(2):e20190137. DOI: https://doi.org/10.1590/1678-992x-2019-0137

49. Huerta Lwanga E, Rodríguez-Olán J, Evia-Castillo I, Montejo-Meneses E, de la Cruz-Mondragón M, García-Hernández R. Relación entre la fertilidad del suelo y su población de macroinvertebrados. Terra Latinoam 2008;26(2):171-81.

50. Rojas P. El papel de las hormigas (Hymenoptera: Formicidae) en la dinámica edáfica. In: Alvarez-

Sánchez J, Naranjo-GarcíaE, editores. Ecología del suelo en la selva tropical húmeda de México. Xalapa: Instituto de Biologia y Facultad de Ciencias UNAM; 2003. p. 197-216.
51. McCallum HM, Wilson JD, Beaumont D, Sheldon R, O'Brien MG, Park KJ. A role for liming as a conservation intervention? Earthworm abundance is associated with higher soil pH and foraging activity of a threatened shorebird in upland grasslands. Agric Ecosyst Environ 2016;223:182-9. DOI: https://doi.org/10.1016/j.agee.2016.03.005
52. Reis Ferreira C, Nascimento Guedes J, Sérgio Rosset J, Anjos LHC, Pereira MG. Diversity of the edaphic macrofauna in areas managed under no-tillage for different periods. Semin Cienc Agrar 2019;40(2):599-610. DOI: https://doi.org/10.5433/1679-0359.2019v40n2p599
53. Lavelle P, Pashanasi B. Soil macrofauna and land management in Peruvian Amazonia (Yurimaguas, Loreto). Pedobiologia 1989;33:283-91.
54. Suarez Salazar JC, Duran Bautista EH, Rosas Patiño G. Macrofauna edáfica asociada con sistemas agroforestales en la Amazonía Colombiana. Acta Agron 2015;64(3):214-20. DOI: https://doi.org/10.15446/acag.v64n3.38033
55. De la Rosa IN, Negrete-Yankelevich S. Distribución espacial de la macrofauna edáfica en bosque mesófilo, bosque secundario y pastizal en la reserva La Cortadura, Coatepec, Veracruz, México. Rev Mex Biodiv 2012;83(1):201-15. DOI: https://doi.org/10.22201/ib.20078706e.2012.1.788