REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

ISSN: 2447-3359

v. 10, nº 1 (2024)

https://doi.org/10.21680/2447-3359.2024v10n1ID35406

Influence of Land Use on Meso and Edaphic Macrofauna: A Study in the Northwest Region of Rio Grande do Sul

Influência do Uso do Solo na Meso e Macrofauna Edáfica: Um Estudo na Região Noroeste do Rio Grande do Sul

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Abstract: Soil fauna is a valuable indicator of environmental quality for assessing the impact of production systems, owing to its involvement in soil and plant nutrient decomposition and cycling. The northwest region of Rio Grande do Sul relies predominantly on agriculture as its primary economic activity, employing pesticides and fertilizers for crop cultivation and management, potentially leading to contamination and a decline in edaphic diversity. To assess the influence of human activities on soil-dwelling fauna, we conducted a study across four areas with varying land uses during the winter and spring seasons. In these areas, traps were set up to capture organisms, which were then quantified and identified. Our results indicate a higher prevalence of mesofauna compared to macrofauna, with the Coleoptera and Collembola groups showing the highest abundance, respectively. Moreover, notable differences in individual abundance were observed depending on soil type and seasonality. Based on this assessment, we tentatively conclude that areas with lower anthropogenic impact, managed under no-tillage practices resulting in reduced soil disturbance and litter deposition, provide favorable habitats for soil-dwelling organisms.

Keywords: Soil fauna, Soil biodiversity, Environmental indicator.

Resumo: A fauna do solo é um indicador de qualidade ambiental útil para identificar a influência dos sistemas de produção pela sua associação com a decomposição e ciclagem de nutrientes do solo e das plantas. A região noroeste do estado do Rio Grande do Sul tem como principal atividade econômica a agricultura e utiliza defensivos agrícolas e fertilizantes para o plantio e manejo dos cultivos, o que pode causar contaminação e redução da diversidade edáfica. Com o objetivo de avaliar o impacto da influência humana sobre a endofauna, foram analisadas quatro áreas com diferentes usos do solo durante inverno e primavera. Nestas áreas foram instaladas armadilhas para captura de organismos, os quais foram posteriormente quantificados e identificados. Os resultados indicam maior presença de mesofauna em relação à macrofauna, sendo os grupos Coleoptera e Collembola os com maior prevalência, respectivamente, além de diferenças na abundância de indivíduos dependendo do tipo de solo e da estação do ano. A partir dessa avaliação, foi possível reconhecer de forma pré-limiária que áreas com menor influência antrópica e cultivadas por plantio direto com menor revolvimento do solo e deposição de serrapilheira propiciam um habitat favorável aos organismos edáficos.

Palavras-chave: Fauna edáfica, Biodiversidade do solo, Indicador ambiental.

Received: 25/02/2024; Accepted: 02/05/2024; Published: 23/05/2024.

1. Introduction

Soil quality refers to the soil's capacity to enhance plant growth, maintain watershed integrity by regulating water infiltration and distribution of precipitation, and mitigate water and air pollution by neutralizing potential contaminants such as agricultural chemicals, organic waste, and industrial pollutants (NATIONAL RESEARCH COUNCIL, 1993). Soil quality indicators encompass various physical parameters such as texture, density, infiltration rate, moisture content, and temperature. Chemically, indicators include pH levels, total organic carbon, labile carbon fractions, as well as total and extractable content of nitrogen, phosphorus, and potassium, among others. From a biological perspective, indicators such as microbial biomass carbon, soil respiration, and enzymatic activity, among others, are commonly employed (JORDÁN VIDAL, 2023). Soil fauna represents a component of biodiversity that warrants further investigation for comprehensive understanding. Nevertheless, it is important in ecosystem functioning and conservation, contributing significantly to plant growth and primary production (MAHARNING et al., 2009; FUSCO et al., 2023).

The term utilized to describe invertebrates, that inhabit the soil either entirely or partially, is edaphic fauna (BARETTA et al., 2011). Various approaches exist for categorizing soil organisms, with size often serving as the primary criterion, alongside factors such as mobility, dietary habits, and specific roles fulfilled (BERUDE et al., 2015; REICHERT et al., 2009). Lavelle et al. (1994) introduced a classification system to facilitate the identification of soil organisms, including microfauna, mesofauna, and macrofauna. Mesofauna encompasses organisms with body diameters ranging from 0.2 to 4.0 mm, including mites, springtails, nematodes, gastrotrics, and others, and macrofauna consists of organisms with body diameters exceeding 4.0 mm, such as earthworms, beetles, ants, snake lice, and centipedes.

The organisms dwelling in the soil have a profound influence on soil quality characteristics. (CORREIA & OLIVEIRA, 2000). Indeed, research has demonstrated a positive statistical correlation between soil chemical and physical properties and macrofauna communities (CHÁVEZ-SUÁREZ et al., 2023). Furthermore, soil macrofauna plays a crucial role in litter decomposition and the maintenance of soil quality (PANT & KUMAR, 2017). Factors such as climate, soil type, organic matter content, and soil management practices can influence the diversity and density of these organisms (REICHERT et al., 2009; GARCÍA-PALACIOS et al., 2013). Hence, soil fauna serves as a bioindicator of environmental quality (DÁVILA & DE LEÓN, 2022; JORDÁN VIDAL, 2023), owing to its heightened sensitivity to ecosystem fluctuations and its capacity to evaluate the functionality of cultivation systems. This is underscored by its crucial functions in nutrient cycling and the decomposition of organic matter (CORREIA & OLIVEIRA, 2000; FUSCO et al., 2023).

In this sense, arthropods (edaphofauna) reflect the conditions of the vegetation and the state of soil functioning. Therefore, its study is useful as a tool to assess the sustainability of cultivated soils (ARMENDANO et al., 2018). In Chile, for example, mites (68.5%) and springtails (28.1%) were among the most abundant groups in agricultural areas (CASTRO-HUERTA et al., 2018). In Hungary, Tóth et al. (2023) assessed soil biological quality in urban green spaces of woody and non-woody nature along a disturbance intensity gradient, using community metrics and soil arthropod-based indicators. They measured basic soil properties along with total and bioavailable concentrations of the main heavy metals (Cd, Co, Hg, Ni, Zn). The results revealed that the biological quality and structure of the soil arthropod community were significantly influenced by both the soil C/N ratio and heavy metal contamination. In the northern region of Colombia, 200 agricultural production units were evaluated using the Berlesse-Tullgren method, to determine the composition of the macrofauna (1330 individuals) and mesofauna (1171), with a greater diversity for the macrofauna. The findings indicated that soil biological diversity is sensitive to changes in the soil environment (CHAMORRO-MARTÍNEZ et al., 2022).

A better understanding of the connections between soil-dwelling communities and degradation processes has highlighted the importance of incorporating higher levels of the soil trophic network to assess soil quality (UNITED STATES ENVIRONMENTAL PROTECTION AGENCY - USEPA, 1998). Despite the ecological and economic significance of soil mesofauna in agricultural and livestock contexts, it is often overlooked, and the efforts for its preservation are limited (SOCARRÁS-RIVERO, 2018).

The northwest of the State of Rio Grande do Sul has abundant biodiversity, its main activity is agriculture, involving several crops such as the cultivation of rice, soybeans, wheat, and corn, among others, with different soil management methods. In agriculture, the utilization of pesticides and fertilizers may lead to soil and water contamination, as well as biodiversity depletion (DA SILVA et al., 2013; ROSSET et al., 2014; GOMES, 2019; GALARZA SUÁREZ, 2019). The diversity of soil fauna serves as a valuable indicator of soil quality (CORRÊIA et al., 1995), demonstrating sensitivity to both management practices and anthropogenic impacts, as well as intrinsic ecosystem properties, such as climate change (SILVA et al., 2009). Furthermore, individual species within the soil fauna community exhibit varied responses to these impacts. The quantification and qualification of edaphic organisms in different areas allow us to understand the soil quality and contribute to possible plans for preventing and mitigating impacts, resulting from improper soil management practices.

This study aimed to conduct an edaphic assessment of mesofauna and macrofauna across areas characterized by diverse land use types to investigate the potential impact of anthropogenic activities on soil quality, and to examine how seasonal temperatures affect the characteristics and distribution of macro and mesofauna.

2. Methodology

The study area is located at latitude 27º 25' 43 S, longitude 53° 43' 25 W, and average altitude of 488 m, inside the Campus of the Federal University of Santa Maria, in the municipality of Frederico Westphalen, in the state of Rio Grande do Sul. Köppen (1936) classifies the climate of this region as humid subtropical, type Cfa, with the coldest month's temperature between 0 °C and 18 °C and the warmest month's temperature above 25 °C. The average annual rainfall is 2,100 mm. The dominant soils of this region are Neosols; Cambisols; Red Nitosol and Luvisols (CUNHA, et al., 2011), and the predominant vegetation is submontane Seasonal Deciduous Forest (SCIPIONI, et al., 2011).

This agricultural region hosts a variety of crops. Taking into account these diverse land uses, four specific areas were chosen for the installation of Provid traps (CONCEIÇÃO et al., 2001): (1) an *Avena strigosa* crop area managed under no-tillage practices, (2) a floodplain region, (3) a native grassland area, and (4) a native forest area. Two sample sets were collected to assess potential temporal variations between winter (June) and spring (October).

A Provid-type system consists of a two-liter PET bottle with four rectangular openings of 6 x 4 cm located 20 cm from its base, serving as a trap for capturing soil fauna (Figure 1). Three traps were strategically positioned within each study area, spaced approximately 50 meters apart (Figure 2). Each trap remained in the field for seven days, placed with the edges of the bottle openings flush with the soil surface, containing 200 mL of 70% alcohol solution and four drops of 2% formalin.

Figure 1 – Provid system used for macro and mesofauna collection.
Source: Authors (2023).

Figure 2 – Illustration of the sampling design and the trap used
Source: Authors (2023).

The collected material was transferred from the trap to a flask and stored in a 70% alcohol solution until the fauna could be counted and identified in the laboratory (RUPPERT & BARNES, 1996). Edaphic mesofauna and macrofauna identification and quantification were conducted in Petri dishes, utilizing a binocular magnifying glass and reference literature. The identification and classification of edaphic organisms were performed at the class, subclass, and order levels, and the diversity of edaphic fauna across different land uses was compared using the Margaleff Richness Index and the Shannon Diversity Index (SHANNON & WEAVER, 1949; CONTRERAS-SANTOS et al., 2023).

From the week preceding trap installation until their removal, we recorded the average daily environmental temperature and daily accumulated precipitation using the Institutional Meteorology website (https://portal.inmet.gov.br). This data collection aimed to explore potential relationships between climate conditions and the density and diversity of edaphic fauna.

Additionally, three soil samples were collected from each area (total n = 12) during the initial sampling to assess the soil's physicochemical properties, including density, moisture, and organic matter content. Density was determined using the volumetric ring method (BLAKE & HARTGE, 1986), where the ring was inserted into the soil to a depth of approximately 5 cm until fully filled. Subsequently, the soil-filled rings were transported to the Water Resources Laboratory of the Federal University of Santa Maria – Frederico Westphalen Campus for further analysis.

The moist soil was weighed and placed in a greenhouse at 105°C for 24 hours. The bulk density of the soil was determined from the dry and wet weights, along with the volume of the ring. For soil organic matter content, 100 g of soil (three replicates per area) was collected and analyzed using the Walkley & Black (1934) method. This method involves oxidation by sulfochromic solution with external heat, followed by spectrophotometric determination of Cr^{3+} (TEDESCO et al., 1995) using Nanocolor Vis equipment.

3. Results and discussion

Table 1 presents the measured values for soil density and organic matter content obtained during the initial sample collection in July, categorized by different land uses. Soil density ranged from 1.1 to 1.3 g/cm³ across all land uses. Notably, the highest density was observed in the native grassland area, while the forest soil exhibited lower density. These findings align with the observations of Islam & Weil (2000), who noted that forest soil tends to be less dense due to its higher porosity and greater aggregate stability. Conversely, the elevated density observed in the native grassland area may be attributed, as suggested by Sattler (2006), to animal trampling and insufficient rest periods for area regeneration.

On the other hand, soil organic matter contents ranged from 1.9% to 4.0%, with the following trend: Várzea < Lavoura < Campo < Mata. The highest content was detected in the forest, attributed to the continuous renewal of flora, which results in consistent deposition of plant material for decomposition. These values are comparable to those reported for soils with sugarcane cultivation, pasture, and native vegetation in Veracruz, Mexico (2.9%-3.5%) (CABRERA-MIRELES et al., 2019).

Table 1 – Values of density and organic matter for different land uses.

	Land Uses			
	Crop area	Floodplain	Grassland	Forest area
Soil density (g.cm^{-3})	1.2 ± 0.1	1.1 ± 0.1	1.3 ± 0.1	1.0 ± 0.1
Organic matter (%)	2.4 ± 0.2	1.9 ± 0.2	2.5 ± 0.3	4.0 ± 0.4

Source: Authors (2023).

The combined total of organisms collected across both assessments amounted to 19,736, spanning sixteen orders, one class, and one subclass of meso- and edaphic macrofauna. Figure 3 provides an illustrative representation of meso and macrofauna distribution within a Petri dish, aiding in the enumeration and identification of the gathered individuals. The functional groups identified were: Predator, Microphage, Social, Herbivore, and Others. The orders with the highest occurrence were Araneae, Collembola, Coleoptera, Hymenoptera, Diptera, Hemiptera, Dermaptera, and Orthoptera, in addition to the subclass Acarina. The orders, classes, and subclasses that occurred in few traps and with lower density were classified as "other" and include the orders Isoptera, Blattaria, Lepidoptera, Odonata, Pulmonata, and the class Diplopoda, as well as larvae and five types of unidentified individuals. In total, three macrofauna groups and six mesofauna groups were recovered from the various sampled areas, with a higher abundance observed in the mesofauna (Table 2).

Figure 3 – Illustrative photograph of recovered edaphic fauna.
Source: Authors (2023).

Table 2 – Edaphic fauna collected during winter and spring in areas with different land uses.

Group Functional e taxonomic	**Crop area**		**Floodplain**		**Grassland**		**Forest area**		
	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	∑
Macrofauna									
Araneae[a]	3	55	7	14	9	39	19	61	207
Coleoptera[a]	3	216	4	11	4	26	11	146	421
Orthoptera[d]	3	31	5	15	1	12	7	24	98
Total number of Individuals (macrofauna)	**9**	**302**	**16**	**40**	**14**	**77**	**37**	**231**	**726**
Mesofauna									
Collembola[b]	295	7221	127	71	8343	489	53	221	16820
Dermaptera[e]	0	9	7	0	37	10	29	8	100
Diptera[e]	28	59	33	15	66	39	32	37	309
Hymenoptera[c]	58	524	85	176	61	203	147	74	1328
Hemiptera[d]	11	40	6	2	20	6	9	30	124
Acarina (subclass)[e]	8	206	0	5	5	38	16	51	329
Total number of Individuals (mesofauna)	**400**	**8059**	**258**	**269**	**8532**	**785**	**286**	**421**	**19407**
Total number of Individuals (macro and mesofauna)	**409**	**8361**	**274**	**309**	**8546**	**862**	**323**	**652**	**19736**
Number of orders	**9**		**9**		**12**		**13**		

Source: Authors (2023).

[a] Predator, [b] Microphage, [c] Social, [d] Herbivore, [and] Others

Upon assessing the number of individuals across various land uses and seasons, a wide variation ranging from 274 to 8546 was observed, indicating significant heterogeneity in the abundance of edaphic organisms. Particularly noteworthy was the greater variability observed in mesofauna (258-8532 individuals) compared to macrofauna, which exhibited a narrower range between 9 and 302 individuals (SILVA et al., 2013). Research, such as that conducted by Brown et al. (2024), suggests that soil biodiversity plays a pivotal role in ecosystem stability and recovery from disturbances, which could account for the observed variations in soil fauna density across different land uses. When tallying the recovered organisms for each land use type across both seasons, the floodplain area recorded the lowest count (583), followed by the forest area (975), crop area (8770), and field area (9408), with the latter exhibiting the highest abundance. Additionally, it is worth noting that mesofauna were more abundant and diverse than macrofauna throughout this study. The Coleoptera emerged as the dominant macrofauna group, with 421 individuals, while the Collembola prevailed among the mesofauna, totaling 16820 individuals. These groups were particularly abundant during spring, a period marked by heightened biological activity characterized by plant emergence and increased availability of food resources. According to Cornelissen (2011), the fluctuations in species density and diversity are directly influenced by environmental conditions, as evidenced by the seasonal surge observed in the crop area. Analysis of soil density, organic matter content, and meso- and edaphic macrofauna revealed notable differences among the soil areas studied. Specifically, the floodplain area, characterized by lower organic matter content, exhibited reduced diversity and density of edaphic organisms relative to the other examined areas (VASCONCELLOS et al., 2013). In this study, diversity refers to the variety of organisms classified at the class, subclass, and order levels.

Regarding the season, there was an increase in the number of species observed during spring, particularly notable in the crop area, with an uptick of 7952 individuals. In contrast, the floodplain area experienced a more modest increase of only 35 individuals, while the forest soil saw an increase of 329 individuals. However, contrary to expectations, grassland exhibited a decrease during spring, with a reduction of -7684 individuals.

The diversity of edaphic fauna in the floodplain and forest areas can be elucidated by Lavelle and Spain (2001), who attribute this richness to the influx of organic material into the ecosystem via animal, plant, and root debris. These residues not only act as a food source but also foster favorable habitats for the growth and development of edaphic organisms.

On the other hand, the increase in most taxonomic groups in spring may be associated with the temperature rise, since the macro and mesofauna groups respond positively to this increase (SOUTO, et al., 2008). Concerning the functional groups, it was determined that microphages had the highest presence (total number of individuals: 16820), followed by social insects, specifically Hymenoptera (total number of individuals: 1328).

The prevalence of these two groups has been consistently observed in prior studies conducted by Silva et al. (2013) and Almeida et al. (2017). The notable presence of these functional groups plays a pivotal role in the decomposition of organic material within the soil. As the availability of food for soil fauna diminishes, there is a selective increase in the number of individuals within the Collembola (microphages) and Hymenoptera (social) orders, resulting in a reduction in soil fauna diversity (GATIBONI et al., 2009; SILVA et al., 2013).

Figure 4 depicts the results of the calculated diversity indexes, revealing higher diversity values under forest conditions compared to other land uses. The Margalef index exhibited a trend in winter of forest area > grassland > floodplain > crop area, resembling what was observed in spring. Additionally, the forest condition recorded the highest values of the Shannon index in both seasons analyzed. Specifically, in winter, the trend was forest area > crop area > floodplain > grassland, while in spring, it was forest area > grassland = floodplain > crop area.

Cultural practices can directly impact soil fauna populations, as they are highly sensitive to environmental changes and exhibit rapid responses to management practices (LIMA et al., 2010) and climatic fluctuations (SOUTO et al., 2008).

In the evaluation carried out in winter (1st evaluation), 48% of the edaphic individuals were quantified, and in the spring (2nd evaluation) they were 52% of the total quantified. According to Kühnelt (1961), the density of soil fauna can be influenced by the seasons, as temperature fluctuations cause migrations of soil fauna. The low density of the fauna in this season can be justified considering that the temperatures during the installation of the traps in July (winter) remained below 10 °C, with an average temperature of 12.68 °C (Figure 5), and studies carried out by Kühnelt (1961) recorded a decrease in the number of individuals in winter with an increase in summer and autumn.

During the spring the average temperature was 20.6 °C, and there was a higher total number of individuals in all areas except grassland. As for rainfall in July, there was a large accumulation in the days before the installation of the traps, which may have reduced the number of organisms captured (LUDWIG, 2012). The number of days without rain in the two seasons was similar, but there was more precipitation in October.

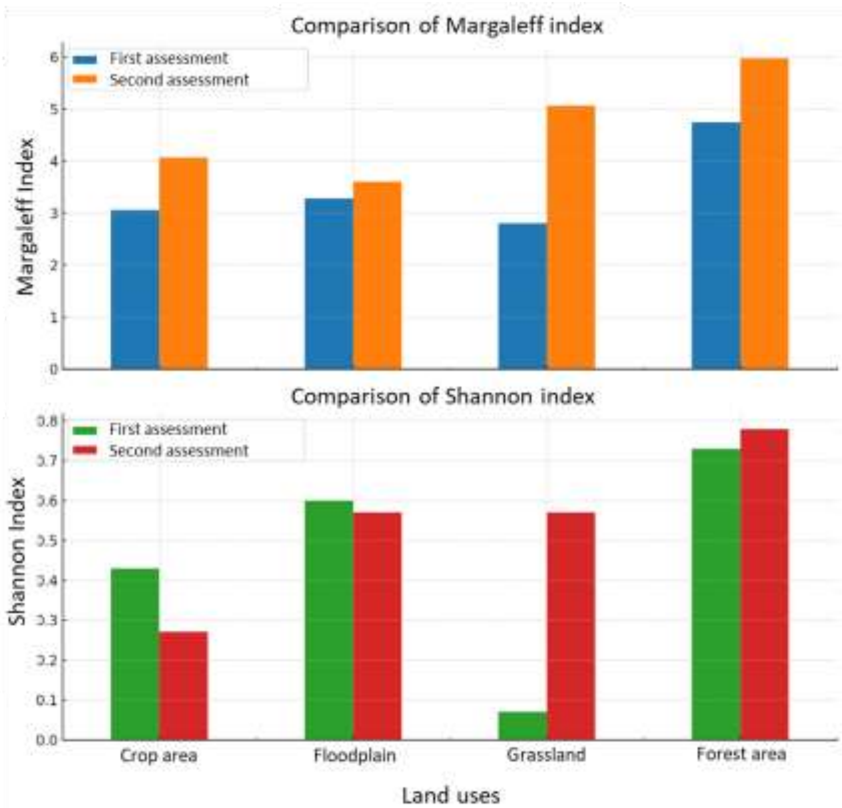

Figure 4 – Indices of Diversity of the soil fauna in each soil area in the different evaluations (1st Evaluation – Winter; 2nd Evaluation – Spring)
Source: Authors (2023)

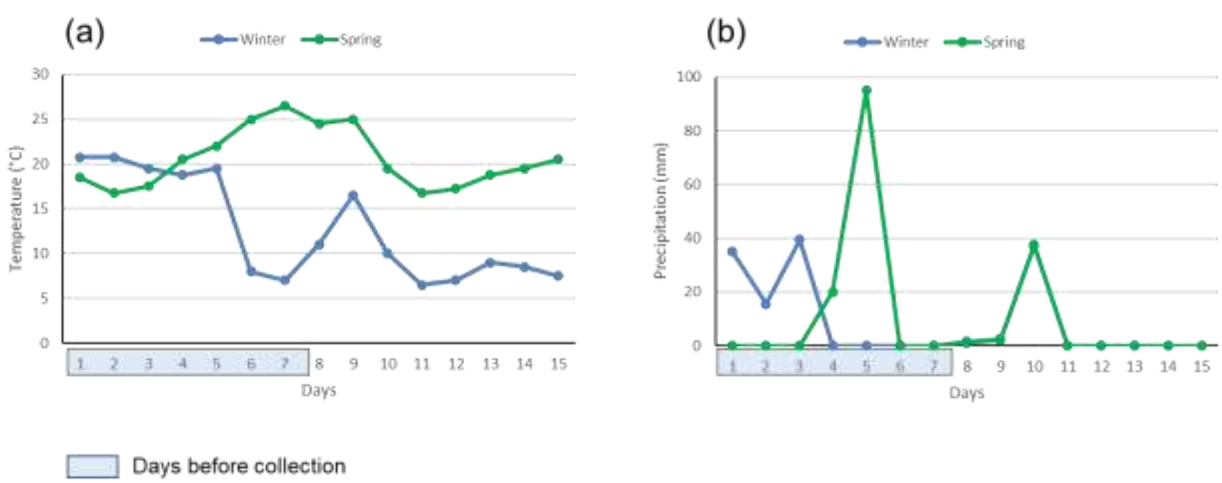

Figure 5 – Graphs of climatic conditions before and during the days of fauna collection. (a) Temperature for seven days before the implantation of the traps on the ground until the day of removal. (b) daily accumulated rainfall for seven days before the implantation of the traps in the ground until the day of removal.
Source: Authors (2023)

Comparing the graphs in Figures 4 and 5 reveals several noteworthy observations: the higher biodiversity indices observed in the forest may be linked to the more stable temperatures and increased humidity typically found within forest interiors, creating favorable conditions for soil meso- and macrofauna. According to Brown et al. (2024), environments with greater vegetation cover tend to maintain more stable microclimatic conditions, thus promoting edaphic diversity through continuous habitat and food resource provision. The greater temperature variation in winter, with lower extremes, may limit the activity of soil meso and macrofauna, which may explain the lower biodiversity recorded in the first assessment. Conversely, the consistent and elevated temperatures experienced during spring promote increased activity among these organisms, potentially leading to a rise in biodiversity, as evidenced in the subsequent assessment. Soil invertebrates have been observed to respond positively to warmer conditions, facilitating their reproduction and dispersal (CORNELISSEN, 2011). Spring precipitation peaks can elevate soil moisture levels, which are typically beneficial for meso- and macrofauna, as many of these organisms depend on moist conditions for survival and flourishing. Conversely, tillage, which exhibits the lowest biodiversity, may be adversely impacted by agricultural practices that disrupt soil moisture and structure, consequently affecting soil fauna. Vasconcellos et al. (2013) note that alterations in soil structure and the availability of organic matter due to intensive agricultural practices can substantially diminish soil biodiversity by altering habitats crucial for the survival of soil fauna.

According to Primavesi (1987), both soil temperature and moisture have a significant influence on mesofauna. Excessive heat poses a threat by drying out the protective layer surrounding these organisms, which can lead to fatal consequences. This impact may arise directly from events like fires or indirectly from thermal fluctuations resulting from the destruction of vegetation cover. Consequently, practices that modify vegetation and expose soil directly impact the viability of soil mesofauna.

4. Concluding Remarks

Soil management practices contribute to fluctuations in the abundance of edaphic organisms. Particularly, in our study an increase in abundance was observed in crop and grassland areas, with a significant spike noted during spring, especially in the crop area. Conversely, the field area exhibits a notable decrease in abundance during spring. The data analyzed over the study period revealed the presence of 16 orders, one class, and one subclass.

The native forest soil exhibited the highest diversity of edaphic fauna, in conjunction with the lowest density and the highest organic matter content. Equally, the floodplain area displayed the lowest diversity and density of edaphic fauna, besides the lowest organic matter content.

The density of the edaphic fauna was influenced by the seasons, with a decrease in winter and an increase in spring.

These interactions between soil, vegetation, management practices, and climatic conditions can determine the diversity and abundance of edaphic meso- and macrofauna in the study area.

Acknowledgments

The authors express their gratitude to the Coordination for the Improvement of Higher Education Personnel (CAPES) for the funding provided in the form of postdoctoral and Academic Solidarity scholarships (process numbers 88887.910949/2023-00 and 88887.910945/2023-00, respectively) and master's degree scholarships (process number 23081.027481/2023-48).

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