



## Soil fauna, litter quality and land use as decomposition factors in the Brazilian semi-arid region



David Gabriel Campos Pereira <sup>a,\*</sup> , Arley Figueiredo Portugal <sup>b</sup>, Teresinha Augusta Giustolin <sup>a</sup>, Victor Martins Maia <sup>a</sup> , Samy Pimenta <sup>a</sup>, Michele Xavier Vieira Megda <sup>a</sup>, Marcos Koiti Kondo <sup>a,1</sup>

<sup>a</sup> Universidade Estadual de Montes Claros/UNIMONTES, Av. Reinaldo Viana 2630, Janaúba, Minas Gerais CEP 39448-524, Brazil

<sup>b</sup> Embrapa Milho e Sorgo, Sete Lagoas-MG, Brazil

### ARTICLE INFO

**Keywords:**  
Agriculture  
Soil management  
Decomposition bags  
Faunal diversity

### ABSTRACT

Soil fauna mediate litter decomposition in many terrestrial ecosystems, and thus understanding how land use impacts the process has important implications. This study was conducted under semi-arid conditions in Minas Gerais, Brazil, using litterbags arranged in a randomized block design with four replications. The treatments included three land use systems (native forest, maize, and cocoa) and two mesh sizes (0.297 mm for mesofauna access and 4 mm for total soil fauna access), with decomposition assessed at seven-time intervals: 0, 30, 90, 150, 210, 270, and 330 days. Litter decomposition rates and the role of soil fauna were evaluated. Decomposition in natural vegetation was slower than in agricultural systems, despite its higher species richness and Shannon ( $H'$ ) and Simpson ( $E_s$ ) diversity indices. Agroecosystems exhibited faster decomposition, with perennial crops outperforming conventional crops under unrestricted fauna access (4 mm mesh) and showing similar rates under macrofauna-restricted conditions (0.297 mm mesh). These findings contribute to understanding the interplay between soil fauna, litter decomposition, and land use systems in semi-arid regions.

### 1. Introduction

The decomposition of litter is a fundamental process for the formation and maintenance of organic matter in the soil. Around 90 % of plant production returns as litter, serving as a pool for this fraction (Berg and McClaugherty, 2020). On a global scale, climate, substrate quality and decomposers are considered the most important factors in controlling the decomposition of plant residues (Aerts, 1997; Peng et al., 2023). However, recent research has found that fauna play a more significant role than initially assumed, notably during the early stages of the litter decomposition process (Yue et al., 2022), indicating that biotic factors can explain as much or even more variation than abiotic factors at both local and regional levels (Bradford et al., 2016, Bradford et al., 2017).

The fauna has various roles ranging from consumption to fragmentation, promoting the rate of microbial activity in the materials (García-Palacios et al., 2013; Berg and McClaugherty, 2020). Direct increases in litter input to the soil or stimulation of microbial

decomposition of litter by soil fauna can have important implications for the formation of persistent soil organic matter and its C:N balance (Cotrufo et al., 2015). For example, the presence of isopods has been shown to mobilize greater mobilisation of various nutrients and organic carbon, while the activity of Collembola increases the availability of C for the soil microbial community (Pieper; Weigmann, 2008). However, the functional roles of soil fauna in ecosystems are poorly understood (Liu et al., 2019).

Despite increasing recognition of the role of soil fauna in decomposition, most studies have focused on temperate and tropical biomes (Burtis et al., 2024; Castillo-Figueroa and Castillo-Avila, 2025). In contrast, semi-arid regions in Brazil present unique climatic and ecological characteristics that strongly influence soil biological activity and organic matter dynamics. These regions are part of the global drylands, which cover approximately 41 % of the Earth's land surface and support more than 2 billion people (Timis-Gansac et al., 2025). Semi-arid ecosystems are characterized by low and irregular rainfall,

\* Correspondence to: Universidade Federal de Viçosa, Av. Peter Henry Rolfs, s/n, Viçosa, CEP 36570-900, Minas Gerais, Brazil.

E-mail addresses: [david.campos.pereira@hotmail.com](mailto:david.campos.pereira@hotmail.com), [david.g.pereira@ufv.br](mailto:david.g.pereira@ufv.br) (D.G.C. Pereira), [arley.portugal@embrapa.br](mailto:arley.portugal@embrapa.br) (A.F. Portugal), [teresinha.giustolin@unimontes.br](mailto:teresinha.giustolin@unimontes.br) (T.A. Giustolin), [victormartinsmaia@gmail.com](mailto:victormartinsmaia@gmail.com) (V.M. Maia), [samy.pimenta@unimontes.br](mailto:samy.pimenta@unimontes.br) (S. Pimenta), [michelemegda@unimontes.br](mailto:michelemegda@unimontes.br) (M.X.V. Megda), [marcos.kondo@unimontes.br](mailto:marcos.kondo@unimontes.br) (M.K. Kondo).

<sup>1</sup> In memoriam.

high and relatively stable temperatures often exceeding 26 °C annually and strong seasonality in vegetation cover (Silva et al., 2025). Native plant species in these areas have adapted to periodic water scarcity through mechanisms such as leaf shedding during dry periods and rapid foliar recovery at the onset of rains (Riegelhaupt et al., 2010). These adaptations, combined with increasing anthropogenic pressure and land use intensification, affect litter input, soil microclimate, and faunal activity (Timis-Gansac et al., 2025; Silva et al., 2025).

In Brazilian semi-arid regions, agricultural practices have led to important changes in soil properties, with direct implications for soil quality and productivity (Corrêa et al., 2010). These effects are amplified by the region's climatic constraints and the widespread use of intensive tillage, which often results in significant alterations in the soil's physical, chemical, and biological characteristics particularly in systems with little or no ground cover. The replacement of native vegetation with monocultures can cause abrupt ecological shifts, degrading soil quality and compromising essential ecosystem services (Pragana et al., 2012).

Inadequate soil management through agricultural activities can have serious consequences over time, depleting its organic and mineral reserves, transforming soils with great production potential into soils with low fertility (Duarte et al., 2014). Several factors can influence the abundance, activity, composition and diversity of edaphic fauna, including edaphic, vegetation-related, historical, topographical and climatic factors (Machado et al., 2015). Thus, any intervention, whether anthropogenic or natural, can potentially affect the dynamics of soil fauna and, consequently, the ecological functions in which it is involved (Melo et al., 2009).

A meta-analysis has shown that soil fauna is responsible for about 37 % of the litter decomposition process in terrestrial biomes (García-Palacios et al., 2013). These effects have been extensively studied through experimental, theoretical, and meta-analytical approaches at both local and regional levels (Peng et al., 2022). The impact of litter decomposition in different land use systems (native, perennial and annual) in semi-arid conditions, especially with regard to the abundance and diversity of edaphic fauna, will allow us to know the extent of the effect of land use on soil management (Pereira et al., 2023; Adhikari et al., 2024; Mamabolo et al., 2024).

In this study, we used the decomposition bag technique to analyze the effect of soil fauna on litter decomposition in three different types of land use in semi-arid environments. We hypothesized that (i) soil fauna diversity would differ across land use types, with higher diversity expected in native vegetation and reduced diversity in intensively managed annual cropping systems; (ii) the presence of soil fauna would significantly enhance litter decomposition rates; (iii) a positive relationship would exist between soil fauna diversity and the rate of litter decomposition; and (iv) increasing agricultural management intensity would diminish the relative contribution of soil fauna to the decomposition process.

Based on these hypotheses, the specific objectives of this study were: (i) to identify variations in the diversity of soil fauna extracted from decomposition bags in different land use systems; (ii) to verify whether the presence of soil fauna affects the rate of litter decomposition; (iii) to explore the relationship between litter decomposition and soil fauna diversity metrics; and (iv) to assess the impact of agricultural management intensity on soil fauna contributions to litter decomposition.

In addition, we investigated the effects of factors related to climate and soil properties to gain a deeper understanding of the factors that can influence the dynamics of decomposition by soil fauna. Understanding how agricultural practices, soil fauna and abiotic factors interact to affect litter decomposition is crucial for soil ecology, as it helps to understand and predict ecosystem functionality (Mamabolo et al., 2024) and to maintain the health and productivity of soil ecosystems (Song et al., 2020).

## 2. Material and methods

The semi-arid region of Brazil spans approximately 970,000 km<sup>2</sup>, predominantly located in the northeastern part of the country (Supplementary material - Fig. 1). It is the most densely populated semi-arid region globally, housing around 28 million people (INSA (National Institute of the Semi-arid), 2023). The northern region of Minas Gerais constitutes 12 % of this area (Medeiros et al., 2020). This region is characterized by short rainy seasons, high evapotranspiration rates, and elevated temperatures, making it a fragile ecosystem with only 54 % of its native vegetation, known as "Caatinga," remaining intact (Althoff et al., 2018). Approximately 33.3 million hectares are utilized for agriculture. Consequently, this study focused on three soil management systems representative of current land use practices in Brazil's semi-arid region. Evaluations were conducted over time to examine litter decomposition in each setting, aiming to understand how different soil management practices influence litter decomposition dynamics and soil fauna.

### 2.1. Study area

The study was carried out in three land use systems in the state of Minas Gerais located in the Semi-Arid Region of Brazil. Two uses were located in the municipality of Nova Porteirinha (NF, CN) and one in Janaúba (CO), which are situated within a 5 km radius (Supplementary material - Fig. 1). According to the Köppen classification, the climate is characterised as Aw, i.e., savannah with a dry winter and an average air temperature of the coldest month above 24 °C. The accumulated rainfall was 39 mm and 743 mm in the dry (April-September) and rainy (October-March) seasons, respectively (data provided by the National Institute of Meteorology - INMET Brazil, weather station A563 in Nova Porteirinha) (Supplementary material - Fig. 2). The soils of the study sites were classified as Oxisol (Soil Survey Staff, 1999). Supplementary material - Table 1, shows the characterization of the study sites according to the chemical attributes of the soil in the top 0.20 m layer.

### 2.2. Characterisation of the study sites

The choice of land use systems was based on the history of the areas and the characteristics of the management adopted.

#### 2.2.1. Native forest (NF)

The area had a minimum of 50 years without any anthropogenic action, characterised as Seasonal Deciduous Forest, known as "dry forest" (Sales et al., 2017; Pereira et al., 2023).

#### 2.2.2. Perennial crop – cocoa (*Theobroma cacao*) (CO)

The cocoa trees, planted at six years of age, were initially shaded by Prata-Anã banana trees. Two years after the cocoa clones were planted, the banana trees were completely removed, and the experiment was then conducted under full sunlight. Fertilization began 90 days after the start of the experiment, with the application of 216 kg of magnesium silicate over the entire experimental area, equivalent to 1350 kg ha<sup>-1</sup>. Additionally, fertilizers were applied per plant to the soil surface without incorporation, including 500 g of single superphosphate (containing P, Ca, and S), 180 g of Fritted Trace Elements (FTE) BR-12 (a micronutrient blend with B, Cu, Mn, Mo, and Zn) in a single application, and monthly applications of 27 g of potassium chloride and 83 g of ammonium sulfate. Irrigation was managed using micro-sprinklers with a flow rate of 120 L h<sup>-1</sup>, spaced 6 × 5 m apart. Maintenance pruning was performed in November 2020, and fruit pruning occurred in April 2021, corresponding to 90 and 250 days after the beginning of the experiment, respectively.

#### 2.2.3. Conventional cultivation - corn (*Zea mays*) (CN)

In the 35 years leading up to the establishment of the experiment, the

area was used alternately for growing corn and sorghum with conventional tillage practices, interspersed with fallow periods (Sales et al., 2017). In the year immediately preceding the experiment (2019–2020), the land was planted with corn. By the time the experiment began, the corn had already been harvested, and the experiment was conducted in the absence of the crop (Pereira et al., 2023).

### 2.3. Collection of litter and sample preparation for nutrient analysis

Leaf litter was collected from the soil of each land use type using five replicates per area with  $0.5 \times 0.5$  m quadrats. For sampling, the selected materials were required to be free from decomposition or at least uniformly fragmented (Scoriza et al., 2012), focusing on recently fallen leaves (Liu et al., 2019) to avoid affecting decomposition rates and experimental outcomes. The collected samples were placed in plastic bags and transported to the laboratory, where they were air-dried in individual cardboard boxes at room temperature for 72 h (Santos, 2016). After drying and sorting, the plant materials were fragmented and weighed according to their proportions to obtain a homogeneous sample suitable for analysis: Native Forest (NF) – 25.9 % leaves, 69 % branches, 5.1 % trunk bark; Corn (CN) – 6.3 % leaves, 37.9 % stalk, 29.6 % straw, 26.1 % cob; and Cocoa (CO) – 32.9 % leaves, 45.5 % branches, 21.6 % fruit bark. Subsequently, the nutritional composition and quality of the material were analyzed (Supplementary material – Table 2).

### 2.4. Experimental design

For each land use type, the experimental area was segmented into four  $4 \text{ m}^2$  blocks, spaced 10 m apart (Supplementary material - Fig. 3). Assessments were conducted from August 2020 to June 2021, spanning a total of 330 days. The litter layer naturally deposited by the plant community in each area was preserved, ensuring that the materials on the ground remained undisturbed.

### 2.5. Decomposition of the litter

Approximately 30 g of dry material were placed in decomposition bags measuring  $0.2 \text{ m} \times 0.2 \text{ m}$  ( $0.04 \text{ m}^2$ ), using two different mesh sizes (Xie, 2020). Coarse mesh bags (4 mm) were used to allow the entry of macrofauna and mesofauna into the soil, while fine mesh bags (0.297 mm) were used to restrict macrofauna (Swart et al., 2020). The material in each bag was weighed with an analytical balance to the nearest three decimal places. At each site, 24 pairs of decomposition bags were deployed, totaling 144 bags (three land use types  $\times$  two mesh sizes  $\times$  four repetitions  $\times$  six sampling periods). A sampling grid (2 m  $\times$  2 m) was set up with four plots in each replicated field. To assess litter mass loss, the bags were sampled monthly on six occasions: 30, 90, 150, 210, 270, and 330 days. During each sampling period, one type of bag (coarse or fine mesh) was retrieved from each site, while the others were left for subsequent sampling. The recovered bags were carefully placed in plastic zip-lock bags to prevent litter loss and then transported to the laboratory. The litter from the zip-lock bags was carefully extracted and placed into Berlese-Tullgren funnels for 72 h for faunal extraction (Liu et al., 2019). The collected fauna was classified into morphospecies (Oliver and Beattie, 1996), counted, and identified to the family level using appropriate taxonomic keys (Adis et al., 2002; Rafael et al., 2012; Armstrong and Nxole, 2017). Whenever necessary, taxonomic specialists were consulted to confirm identification at the family level, especially for groups with ambiguous morphological features. Morphospecies were assigned to five feeding guilds (detritivores, omnivores, herbivores, phytophages, and predators) based on the morphological characteristics of their mouthparts and family identification (Potapov et al., 2022). The assignment to feeding guilds was primarily literature-based, but also informed by field observations of behavior and habitat, particularly for dominant morphospecies.

### 2.6. Abiotic factors

Environmental conditions were documented at each sampling event. Climate data were sourced from local weather stations within the study areas, provided by the National Institute of Meteorology (INMET Brazil), specifically weather station A563 in Nova Porteirinha (Supplementary material - Fig. 2). The data collected included average monthly temperatures (MMT) and average monthly precipitation (MMP). Geobotanical surveys were also conducted during each sampling event to assess soil and vegetation characteristics within each sampling grid, including measurements of soil organic matter and litter accumulation.

### 2.7. Data analyses

The contents of the bags were sifted to remove mineral soil particles and dust, then dried in a forced-air oven at 65 °C until they reached a constant weight. The dried litter was weighed using a precision scale (0.01 g) to calculate the mass loss ratio, with the results expressed in  $\text{Mg ha}^{-1}$ . To analyze the decomposition of the materials in each bag, the data were fitted to the exponential mathematical model described by Wider and Lang (1982):  $Q = Q_0 \exp^{(-kt)}$ ; where  $Q$  is the dry mass of the litter at time  $t$  ( $\text{kg ha}^{-1}$ );  $Q_0$  is the mass potentially released ( $\text{kg ha}^{-1}$ ); and  $k$  is the release rate ( $\text{g g}^{-1}$ ). With the value of  $k$ , the half-life time ( $T_{1/2}$  life) of the remaining crop residues was calculated, i.e. the time needed for 50 % of the material to be released. This calculation used the formula  $T_{1/2} = 0.693/k$  proposed by Paul and Clark (1989).

The effect of mesh size (ES) of the decomposition rate was calculated using  $ES = \ln(ke / keu)$ , where  $ke$  is calculated when soil fauna (macro and mesofauna) is presented in the decomposition bags, and  $keu$  when soil macrofauna is excluded. ES represents a unitless index, ranging from  $-\infty$  to  $+\infty$ , indicating the magnitude and direction of the influence (Berg and Matzner, 1997). Positive values indicate accelerated litter decomposition, while negative ES values indicate slower litter decomposition after the exclusion of soil fauna. The structure of the edaphic invertebrate community was compared at the order/family level between uses and expressed by density (individuals  $\text{m}^{-2}$ ), richness index (S), Shannon ( $H'$ ) and Simpson ( $E_s$ ).

The data was subjected to a analysis of variance of the main effects (use, assessment times and mesh size). The means of the uses were compared with each other at each sampling time using the Tukey test at 5 % probability. Regression analyses relating to mass loss were carried out using the SigmaPlot application, test version, from Systat Software Inc. and the procedure described in Snedecor and Cochran (1989) was used to compare the regression equations after linearisation. Spearman's correlation was used to correlate the variables. Correlation coefficients of  $> 0.70$  and significant correlation at 10 % were considered. The correlation matrix was performed using the psych package using the corTest function in the R software version 4.3.2. The analysis was performed using the lme4 package (Bates et al., 2014) to construct linear mixed-effects models (LMMs) for Gaussian-distributed response variables (e.g., litter mass loss) and generalized linear mixed-effects models (GLMMs) for gamma-distributed variables (e.g., abundance of individuals, Shannon index, and species richness). Mixed-effects models were chosen to account for the hierarchical structure of the experimental design, particularly the repeated measures over time and the potential variability among blocks (random effects), which could influence the response variables. Specifically, blocks were included as random intercepts in the models to control for spatial heterogeneity and avoid inflated Type I error due to pseudoreplication.

Patterns in soil fauna species composition across different land use types were analyzed using multivariate generalized linear modeling with the manyglm function from the mvabund package (Wang et al., 2012). Multivariate models were fitted with a negative binomial distribution, assuming quadratic mean variance, and estimated through the "PIT-trap" resampling approach with 1000 permutations. The results were visualized using multivariate ordinations based on both restricted

and unrestricted latent variable models, facilitated by the ecoCopula package (Popovic et al., 2021).

### 3. Results

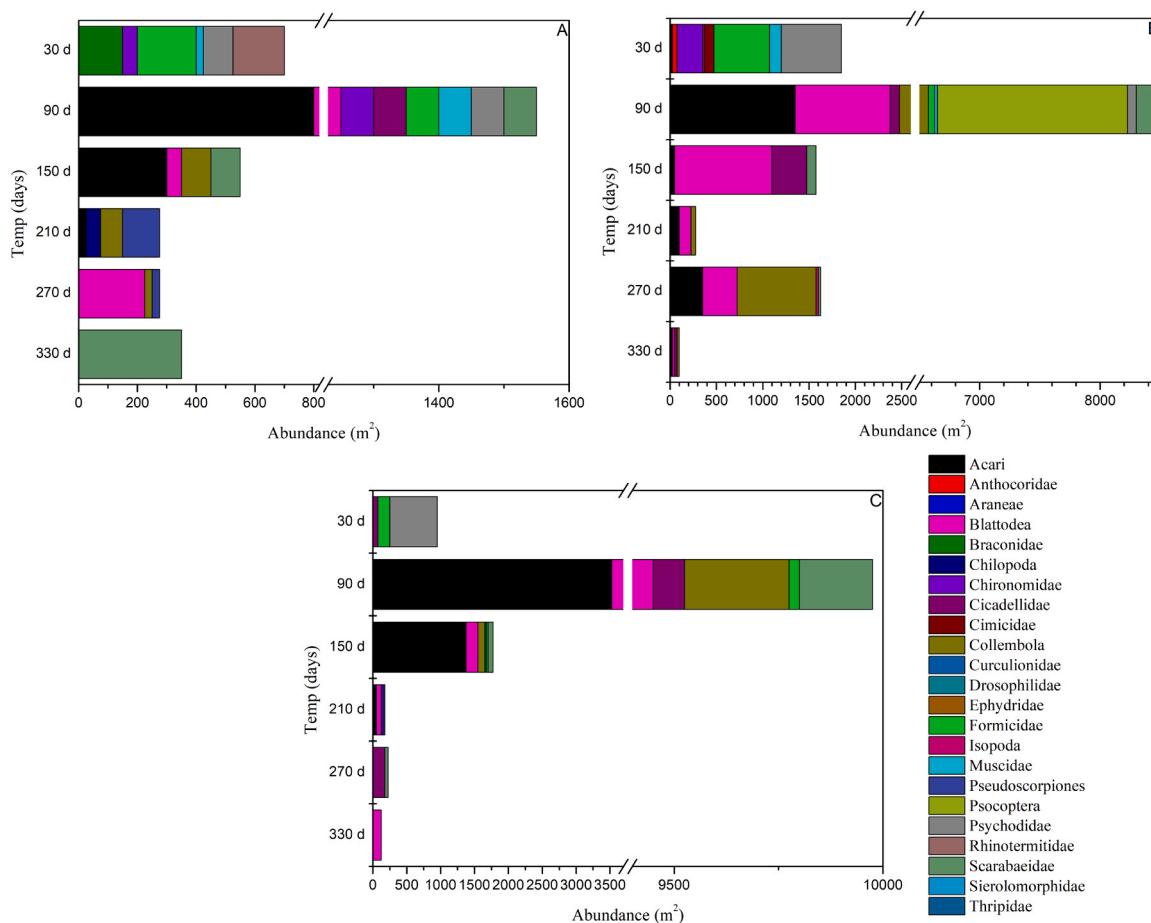
#### 3.1. Soil fauna

A total of 2973 individuals, representing 23 morphospecies and 13 taxonomic groups (class/subclass/order), were extracted from the decomposition bags (Figs. 1 and 2). These included Acari (2 spp.), Araneae (2 spp.), Blattodea (2 spp.), Chilopoda (1 spp.), Coleoptera (2 spp.), Collembola (1 spp.), Diptera (5 spp.), Hemiptera (3 spp.), Hymenoptera (3 spp.), Isopoda (1 spp.), Pseudoscorpiones (1 spp.), Psocoptera (1 spp.), and Thysanoptera (1 spp.). The morphospecies were classified into five feeding guilds: Detritivores (9 spp.), Phytophages (1 spp.), Herbivores (1 spp.), Omnivores (6 spp.), and Predators (6 spp.). Abundance was estimated per  $m^2$  and differed significantly between land use types and collection times, with the NF soil showing the lowest abundance for mesh sizes of 4 mm and 0.297 mm (8050 and 3700 individuals  $m^{-2}$ , respectively), while CO use had the highest abundance in both mesh sizes (22,125 and 13,875 individuals  $m^{-2}$ , respectively). At the beginning of the experiment, a higher abundance of species was observed. The decomposition bag with macrofauna restriction (Fig. 1) showed higher individual abundance at 90 days after installation (dai) across all land uses. However, the CN land use had lower Shannon diversity index ( $H'$ ) values compared to CO and NF (Fig. 3.A). The decomposition bag without macrofauna restriction (4 mm) (Fig. 4) showed a greater range of individuals at all collection times compared to the 0.297 mm mesh (Fig. 3). It also displayed a similar pattern, with

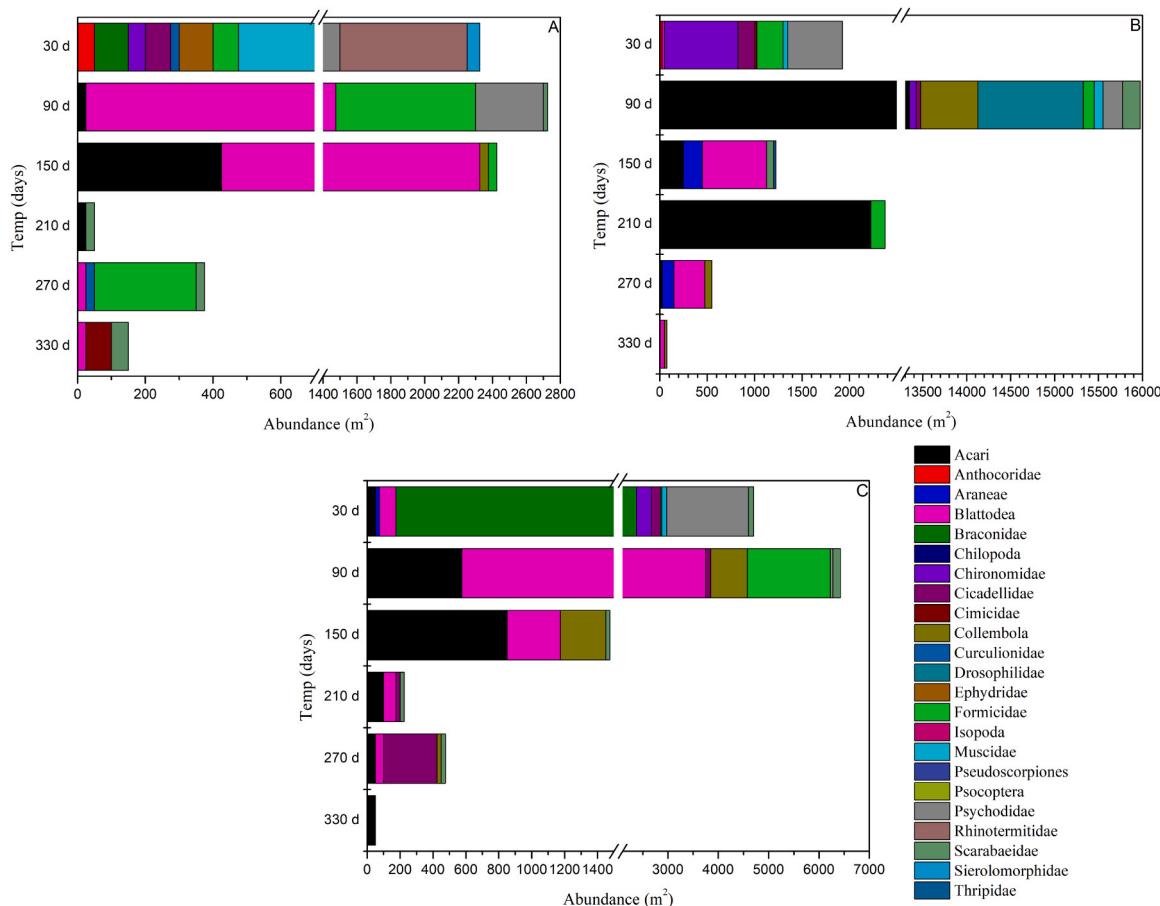
higher abundance of individuals at the beginning of the study, particularly at 90 dai, and a greater abundance of individuals in the natural system (NF) at the end of the 330-day study period, across both mesh sizes (Figs. 1 and 2).

Individuals' richness followed patterns similar to abundance, with NF and CO uses being the more taxonomically rich in soil fauna species, and CN being the lowest at 30, 90, 270, and 330 dai for the mesh with macrofauna restriction (0.297 mm) (Fig. 3.C). For the 4 mm mesh (Fig. 4.C), the CN system showed higher richness compared to CO and NF at 210 and 270 dai. At the end of the study, NF soil use had the highest individuals' richness in both mesh sizes (Fig. 3.C and 4.C). Species diversity also varied significantly between land use types, with the 0.297 mm mesh showing greater variation in results across the evaluated uses over the collection times. It was noted that in the initial period, NF and CO uses had higher Shannon ( $H'$ ) and Simpson ( $E_s$ ) diversity indices at 30, 90, and 150 dai (Fig. 3). For the 4 mm mesh, the diversity indices  $H'$  and  $E_s$  showed similar variation among uses, but with comparable values throughout most of the experimental period (Fig. 4). In the correlation analysis, only data from detritivorous morphospecies were used, revealing that litter mass loss was positively linked to all biological estimates of soil fauna in both mesh sizes (Figs. 5 and 6). A similar pattern was observed between the meshes, where increased abundance, richness, and diversity of species resulted in greater litter mass loss, although the 0.297 mm mesh (Fig. 5) had less loss compared to the 4 mm mesh (Fig. 6). All variables showed significant values for mass loss in both the macrofauna-restricted bag (Table 1) and the unrestricted bag (Table 2).

Negative effects were observed in all land use types, with the presence of soil fauna influencing the outcomes across the different systems



**Fig. 1.** Abundance of individuals according to Class/Subclass/Order in three land use systems: native forest (NF) - (A), cocoa (CO) - (B) and corn (CN) - (C) in the period from August 2020 (0 days) to July 2021 (330 days), determined by the litter bags (0.297 mm).



**Fig. 2.** Abundance of individuals according to Class/Subclass/Order in three land use systems: native forest (NF) - (A), cocoa (CO) - (B) and corn (CN) - (C) in the period from August 2020 (0 days) to July 2021 (330 days), determined by the litter bags (4 mm).

(Fig. 7). Land uses with NF, CO and CN, showed decelerated decomposition at 30 dai ( $-0.05$ ;  $-0.15$  and  $-0.08$ , respectively), 90 dai ( $-0.03$ ;  $-0.22$  and  $0.00$ , respectively), 150 dai ( $0.00$ ;  $-0.38$  and  $-0.14$ , respectively), 210 dai ( $-0.25$ ;  $-0.59$  and  $-0.16$ , respectively), 270 dai ( $-0.19$ ;  $-0.53$  and  $-0.13$ , respectively) and at 330 dai ( $-0.21$ ;  $-0.59$  and  $-0.08$ , respectively), when the soil macrofauna was excluded. The CO use showed more decelerated values compared to the other uses throughout the experimental period.

### 3.2. Decomposition of litter

Significant differences for the linearised decomposition rate of litter were found over the period evaluated (330 days), which can be explained by the effect of land use and mesh size. The interaction between the two factors (land use and mesh size) was significant. The use of macrofauna-restricted mesh (0.297 mm) showed lower decomposition rates of  $0.0011$ ,  $0.0017$  and  $0.0019 \text{ g g}^{-1}$  and a longer half-life ( $T_{1/2}$ ) of 630, 407 and 367 days, compared to the larger mesh (4 mm) with the presence of macrofauna of  $0.0018$ ,  $0.0038$  and  $0.0028 \text{ g g}^{-1}$  and 385, 162 and 247 days, for NF, CO and CN, respectively, for the period evaluated (330 days) (Table 3).

NF land use showed the lowest litter decomposition rates in both mesh sizes evaluated (Fig. 8). Land use with CO and CN did not differ from each other for the 0.297 mm mesh at any evaluation time (Fig. 8.A). The mass loss ratios were 43.2 % for CO and 44.2 % for CN, corresponding to  $3.24$  and  $3.31 \text{ Mg ha}^{-1}$  over the evaluation period, respectively. Land use with NF showed lower litter losses after 210 days, with a final litter loss of 32.9 % ( $2.46 \text{ Mg ha}^{-1}$ ). The decomposition pockets with an opening of 4 mm showed differences during the periods

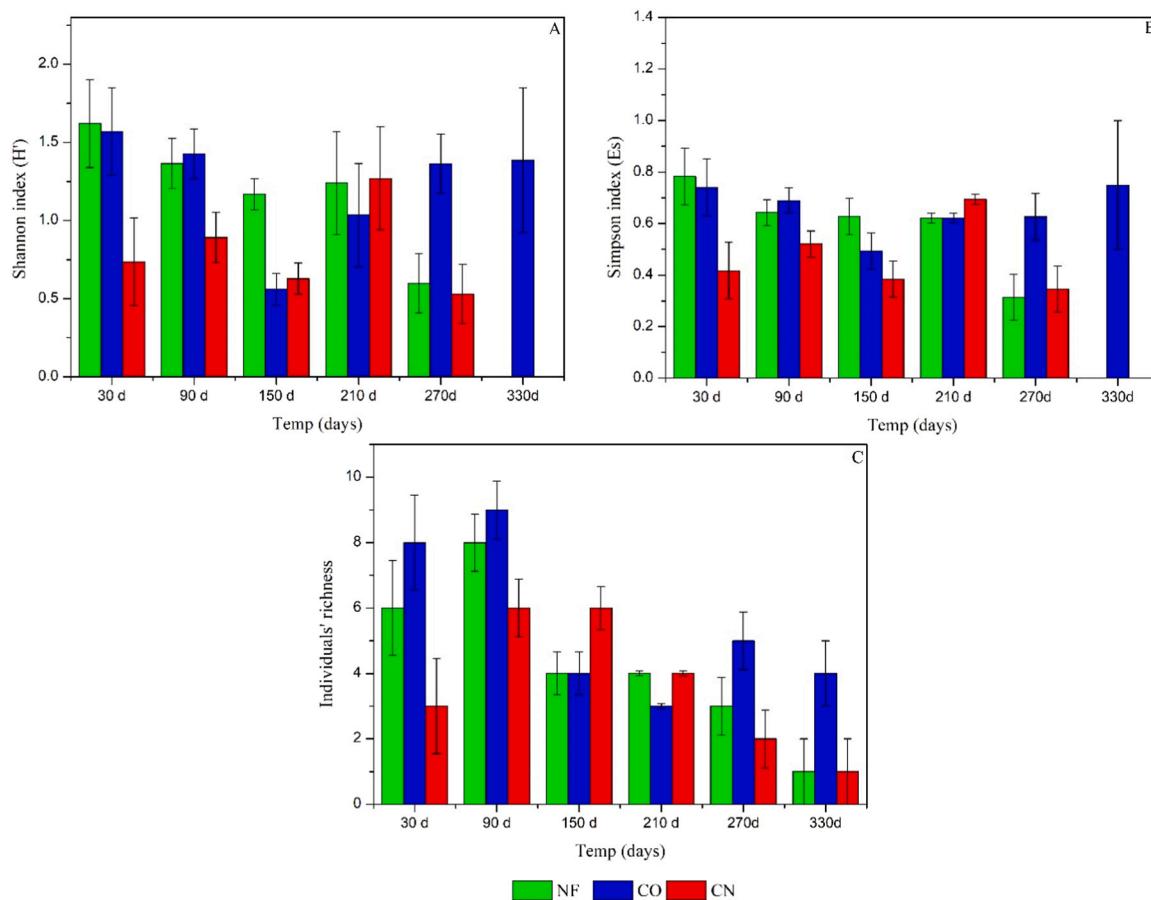
analyzed (Fig. 8.B). Land use with CO showed the lowest averages between 30 and 270 days, with a loss of  $3.31 \text{ Mg ha}^{-1}$  (44.2 %). At 330 days, there was no difference between CO and CN uses ( $2.39$  and  $2.84 \text{ Mg ha}^{-1}$ , respectively), with NF having the highest average ( $4.07 \text{ Mg ha}^{-1}$ ), showing losses of 68; 62 and 45.7 %, respectively.

Significant variations in the amount of remaining litter were noted over the 330-day evaluation period, primarily influenced by land use and time (Fig. 8). Throughout the experiment, the NF land use consistently exhibited higher levels of remaining litter compared to the other land uses, with statistically significant differences. The mesh effect for the NF use was observed from 210 days until the end of the study (330 days), where the 0.297 mm mesh showed less material loss than the 4 mm mesh (Fig. 9.A). However, the uses of the soil with agroecosystems showed different behaviour, with the CO use showing a difference throughout the experimental period (30–330 dai), the mesh with macrofauna restriction (0.297 mm) showing a lower average loss of  $1.57 \text{ Mg ha}^{-1}$  (Fig. 9.B). At the end of the study, the 0.297 mm mesh had a higher average value of  $1.86 \text{ Mg ha}^{-1}$  (330 dai).

The effect of the mesh with macrofauna restriction (0.297 mm) was observed in land use with CN from 270 days onwards, showing a higher average, with an average difference of  $0.95 \text{ Mg ha}^{-1}$  (Fig. 9.C). At 330 days, the average differences increased by around  $1.34 \text{ Mg ha}^{-1}$ .

### 3.3. Environmental factors and their impacts on soil fauna

Average fixed-effect estimates derived from the linear mixed-effects models (LMMs) and generalized linear mixed-effects models (GLMMs) indicated that temperature and litter cover significantly increased abundance (Table 4). The abundance of individuals, richness, and



**Fig. 3.** Shannon index ( $H'$ ) – (A), Simpson index ( $E_S$ ) – (B), and individuals' richness – (C) in three land use systems: native forest (NF), cocoa (CO), and corn (CN), during the period from August 2020 (0 days) to July 2021 (330 days), determined using litter bags (0.297 mm mesh). Bars represent mean values, and error bars indicate the standard error of the mean (SE). No data are shown at 330 days in panels (A) and (B) because only individuals from the same family were recovered at that sampling time, preventing the calculation of diversity indices.

diversity were positively affected by temperature, soil organic matter, and litter cover. Additionally, temperature had a positive effect on litter mass loss. Multivariate analyses showed that the composition of soil fauna was notably influenced by precipitation, temperature, and litter cover (Table 5).

#### 4. Discussion

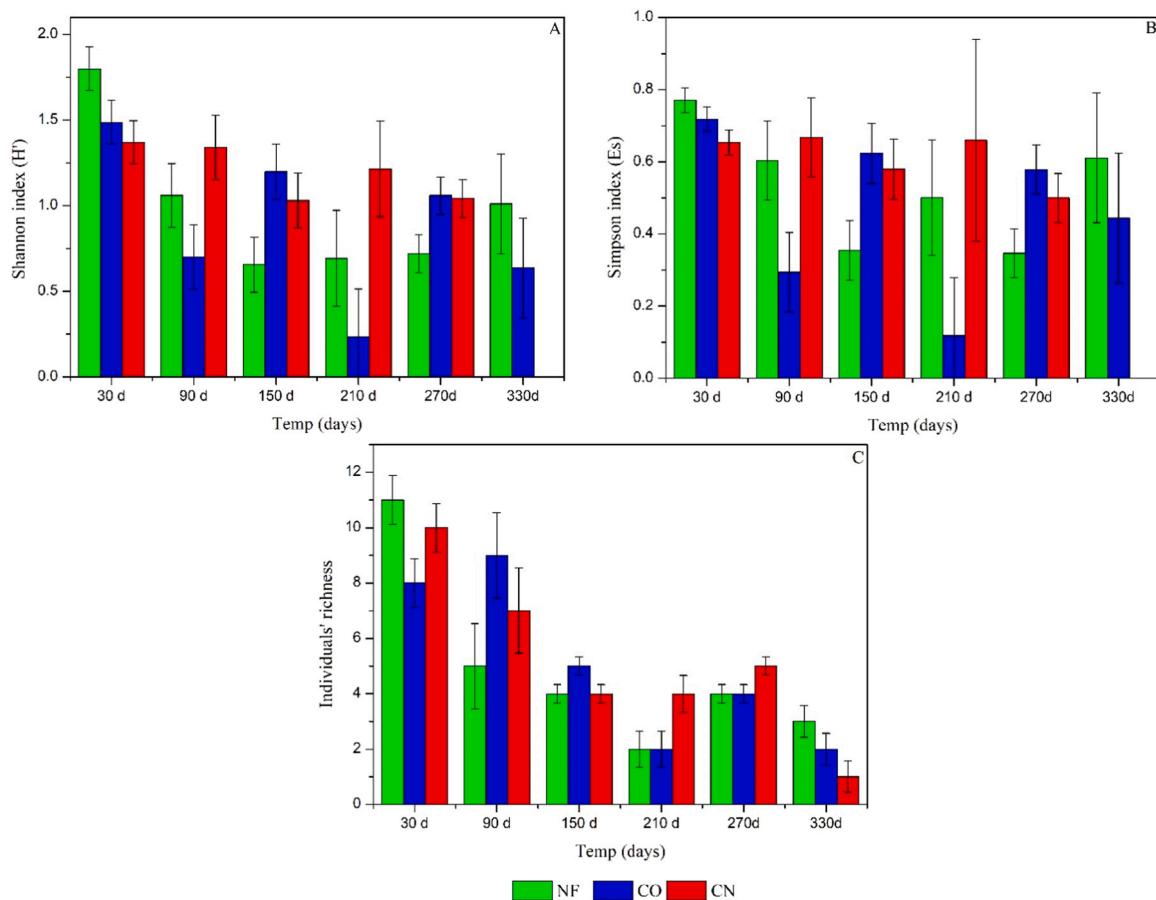
In this study, we evaluated how different land use types impact litter decomposition by soil fauna in a semi-arid region. Our findings revealed variations in soil fauna diversity, abundance, richness, and mass loss across different land uses. Perennial crop systems (CO) supported a higher abundance of species, while natural vegetation (NF) demonstrated greater species diversity, and conventional management (CN) had the lowest diversity of arthropods. These results align with the conditions associated with each land use, including the application of chemicals, reduced soil cover, monoculture practices, and high levels of soil disturbance (Mamabolo et al., 2024). We observed significant differences in abundance, richness, and diversity across the land uses and decomposition bags. Notably, both perennial and natural vegetation land uses exhibited similarly high levels of abundance and diversity, though they featured distinct individuals.

According to Gessner et al. (2010) and Mamabolo et al. (2024), litter decomposition is likely to be affected by changes or losses in soil fauna composition and diversity. In this study, lower decomposition rates were associated with significantly reduced abundance of key groups in conventional soil preparation (CN), and the mesh effect was noted, where decomposition bags with macrofauna restriction (0.297 mm) had fewer

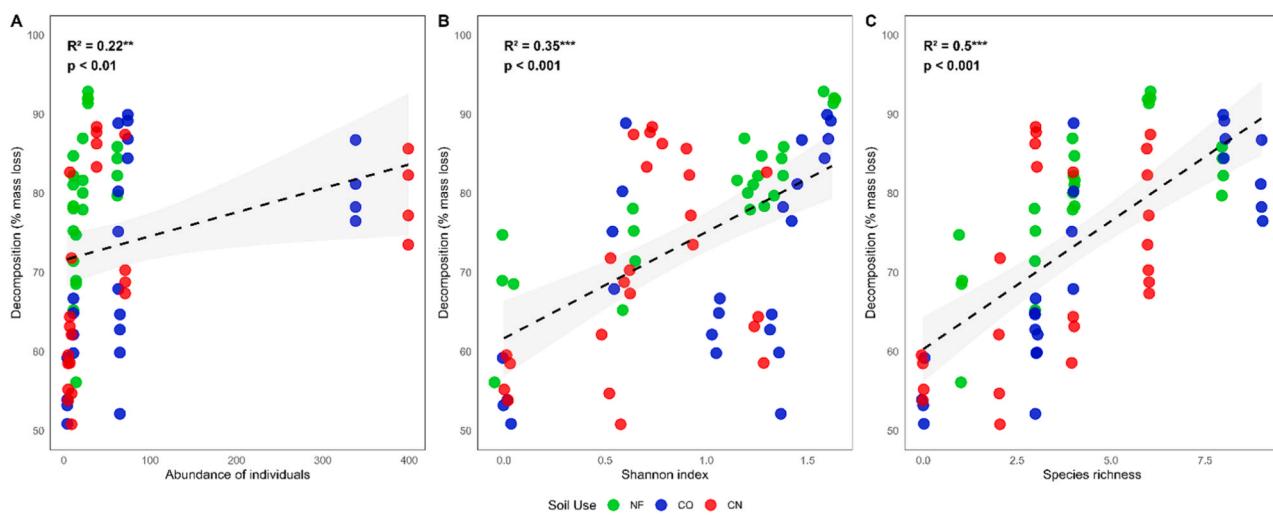
individuals and less litter mass loss across all land uses. This reaffirms the role and importance of macrofauna in the degradation and decomposition of surface materials. Conversely, the CO land use demonstrated enhanced ecosystem function, as evidenced by elevated decomposition rates. This increase is likely attributed to the presence of a well-balanced and diverse soil fauna in this type of land use. Macrofauna was found to be the primary driver of decomposition in human-intervened land systems, with the restricted mesh (Fig. 8.A) showing no effect on mass loss between uses (CO and CN), unlike the unrestricted mesh (Fig. 8.B), where CO use had the highest decomposition rate. Greater richness and higher  $H'$  and  $E_S$  indices in native forest did not result in higher decomposition rates.

This can be attributed to the conditions present in natural sites (such as moisture, temperature, soil, and habitat structure), which were likely stable and conducive to maximizing detritivore activity (Mamabolo et al., 2024). For example, moisture deficit plays a critical role in negatively affecting decomposer or detritivore activity (Manetti et al., 2010). Temperature plays a significant role in decomposition processes. Optimal temperature ranges (typically between 20–30 °C) enhance enzymatic activities and metabolic rates of decomposers, thereby accelerating litter breakdown (Prescott, 2010). In semi-arid ecosystems, substantial daily temperature fluctuations can limit the active periods of soil fauna, affecting decomposition rates.

Soil texture and structure are also critical factors. Soils with higher clay content tend to retain more moisture, which can support sustained biological activity even under limited rainfall conditions. Additionally, clay-rich soils often have a higher proportion of macroaggregates, which are associated with greater organic carbon content and provide



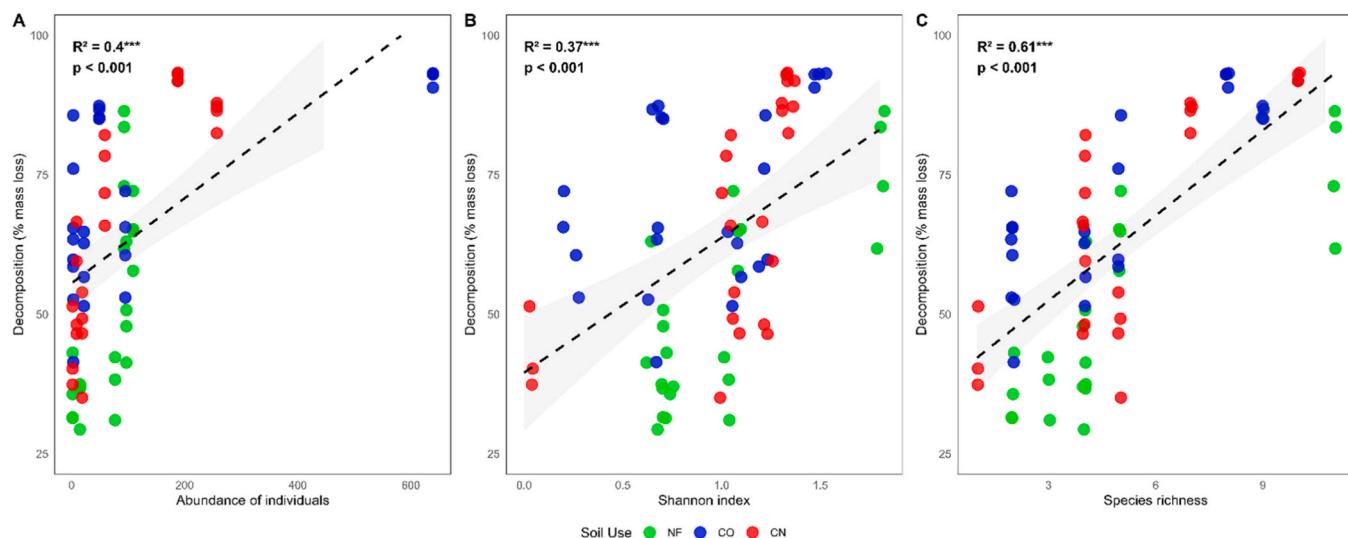
**Fig. 4.** Shannon index ( $H'$ ) – (A), Simpson index ( $Es$ ) – (B), and individuals' richness – (C) in three land use systems: native forest (NF), cocoa (CO), and corn (CN), during the period from August 2020 (0 days) to July 2021 (330 days), determined using litter bags (4 mm mesh). Bars represent mean values, and error bars indicate the standard error of the mean (SE). No data are shown at 330 days in panels (A) and (B) because only individuals from the same family were recovered at that sampling time, preventing the calculation of diversity indices.



**Fig. 5.** Estimated relationship of the model between the percentage of litter mass loss and the detritivore species in the 0.297 mm mesh: (A) abundance of individuals, (B)Shannon index and (C) Individuals' richness. The gray area shaded with a solid line represents the linear response with a 95 % confidence level. Asterisks denote significance levels: \*\*  $p < 0.01$ . \*\*\*  $p < 0.001$ .

favorable habitats for soil fauna (Six et al., 2000). Habitat structure contributes further by moderating microclimatic conditions and offering physical refuge. Increased litter layer thickness or denser vegetation cover can buffer soil temperatures and reduce desiccation, fostering

more favorable environments for detritivore communities. For instance, Bradford et al. (2002) demonstrated that the presence of macrofauna significantly increased litter decomposition rates, highlighting the importance of habitat complexity in facilitating faunal activity. In this



**Fig. 6.** Estimated relationship of the model between the percentage of litter mass loss and the detritivore species in the 4 mm mesh: (A) abundance of individuals, (B) Shannon index and (C) Individuals' richness. The gray area shaded with a solid line represents the linear response with a 95 % confidence level. Asterisks denote significance levels: \*\*  $p < 0.01$ . \*\*\*  $p < 0.001$ .

**Table 1**

Effects of an abundance and species richness of soil fauna and the Shannon index on litter mass loss at 0.297 mm mesh.

Factor (s)	Estimate	Std. Error	t-value	Pr(> t )
Species Abundance	83.417	3.411	24.433	$2.00 \times 10^{-16}^{***}$
Shannon Index	76.984	3.782	20.353	$2.00 \times 10^{-16}^{***}$
Species Richness	74.362	3.991	18.631	$2.00 \times 10^{-16}^{***}$

\*\*\*  $p < 0.001$ .

**Table 2**

Effects of an abundance and species richness of soil fauna and the Shannon index on litter mass loss at 4 mm mesh.

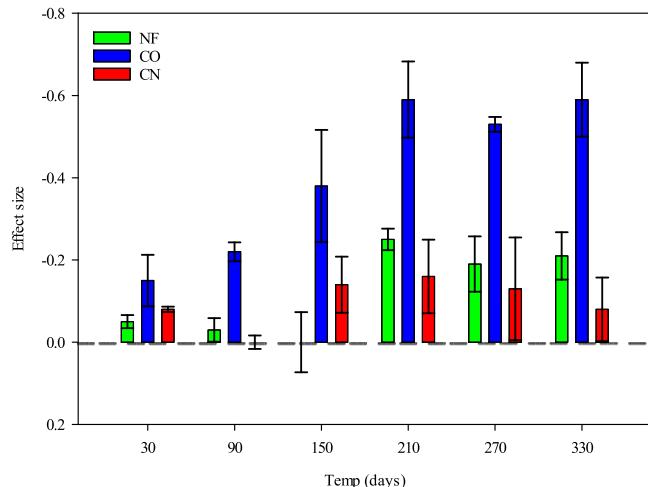
Factor (s)	Estimate	Std. Error	t-value	Pr(> t )
Species abundance	30.015	6.211	4.833	$7.85 \times 10^{-6}^{***}$
Shannon index	28.912	5.298	5.457	$7.11 \times 10^{-7}^{***}$
Species richness	27.099	4.683	5.787	$1.92 \times 10^{-7}^{***}$

\*\*\*  $p < 0.001$ .

semi-arid region, precipitation, which averaged 71 mm per month during the study (Supplementary Material – Fig. 2), is also a crucial factor in decomposition. Notably, the highest litter mass loss and species abundance coincided with the rainy season, as shown in Supplementary Figure 2. This pattern corroborates the trend observed in Fig. 8, which shows greater mass loss ratios during wetter months across all land use systems.

Studies have shown that precipitation is among the most important factors regulating litter decomposition rates in terrestrial ecosystems (Wieder et al., 2009; Taylor et al., 2017; Yu et al., 2019). According to some authors (Fierer et al., 2003; Manzoni et al., 2012), changes in soil water availability affect the abundance and community of soil microbes and fauna (Pritchard, 2011), thereby exerting considerable influence on leaf litter decomposition rates (Handa et al., 2014). Souto (2006) reports that during drought periods, food availability decreases, limiting the existence of some groups and leaving only those adapted to water scarcity and high soil temperatures (Holanda et al., 2015).

Additionally, litter decomposition is strongly influenced by its chemical composition, particularly the carbon-to-nitrogen (C/N) ratio. Although commonly associated with microbial activity, this parameter also affects the feeding behavior and efficiency of soil fauna. Lower C/N



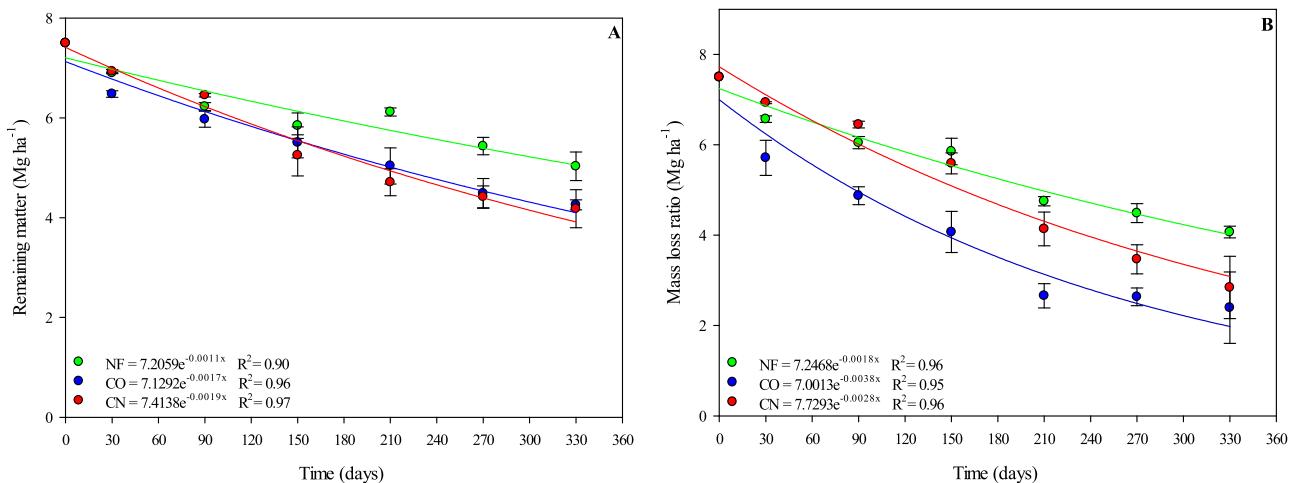
**Fig. 7.** Influence of soil fauna on litter decomposition, determined by comparing the decomposition rate ( $k$ ) between coarse (4 mm) and fine (0.297 mm) mesh litter bags in native forest (NF), cocoa (CO), and corn (CN) settings. Bars represent mean values, and error bars indicate the standard error of the mean (SE).

**Table 3**

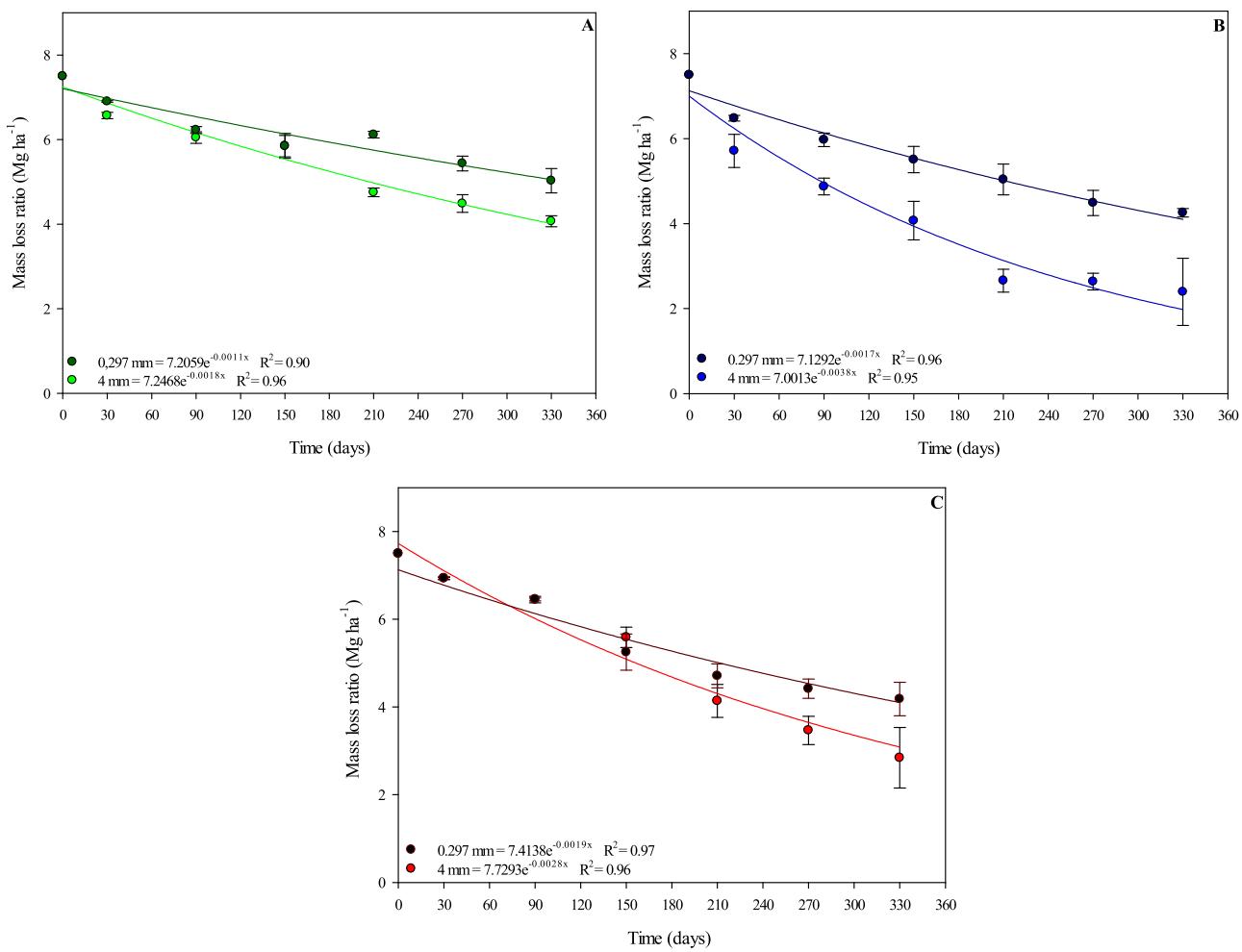
Parameters of the models fitted to the remaining dry matter values. Half-life time ( $T_{1/2}$ ) of each compartment and  $R^2$  values for each use.

Soil use	Parameters of the decomposition equation - 0.297 mm		
	$k^{(1)}$	$T_{1/2}^{(2)}$	$R^2$
NF	0.0011**	630**	0.90*
CO	0.0017**	407**	0.96*
CN	0.0019**	364**	0.97*
Parameters of the decomposition equation - 4 mm			
NF	0.0018**	385**	0.96*
CO	0.0038**	182**	0.95*
CN	0.0028**	247**	0.96*

<sup>(1)</sup> Decomposition constant; <sup>(2)</sup> Half-life time. \*  $p < 0.05$ . \*\*  $p < 0.01$ . NF: Native forest; CO: Cocoa; CN: Corn.



**Fig. 8.** Mass loss ratio of litter in three land use systems: native forest (NF), cocoa (CO) and corn (CN) in the period from August 2020 (0 days) to July 2021 (330 days), determined by the decomposition bags with mesh sizes of 0.297 mm (A) and 4 mm (B) on the soil surface of 0.297 mm (A) and 4 mm (B). Data points represent mean values, and vertical error bars indicate the standard error of the mean (SE).



**Fig. 9.** Mass loss ratio of the litter in three land use systems: native forest (NF) – (A), cocoa (CO) – (B), and corn (CN) – (C), from August 2020 (0 days) to July 2021 (330 days), determined using litter bags with mesh sizes of 0.297 mm and 4 mm placed on the soil surface. Data points represent mean values, and vertical error bars indicate the standard error of the mean (SE).

ratios tend to increase litter palatability and support greater activity and biomass of detritivores, thereby accelerating decomposition (Pereira et al., 2023). In contrast, residues with higher C/N ratios are often less

attractive or nutritionally imbalanced for many faunal groups, leading to reduced consumption and slower decomposition rates. In a study on sugarcane residues, Phukongchai et al. (2022) noted that litter with

**Table 4**

Mean model estimates of the impacts of environmental variables on soil fauna abundance, species richness, diversity, and percentage mass loss. Test statistics are shown as Spearman correlation coefficients.

Factor (s)	Abundance	Richness	Diversity	Mass loss
Temperature	0.75***	0.72***	0.60***	0.81***
Precipitation	-0.11	-0.18	-0.34	0.03
Soil organic matter	0.12	0.26*	0.32**	-0.34
pH	-0.04	0.70	-0.02	0.17
Litter cover	0.25*	0.35**	0.54***	0.031

\* p < 0.05. \*\* p < 0.01. \*\*\* p < 0.001

**Table 5**

Outcomes of multivariate generalized linear models, depicting the effects of environmental variables on the composition of soil fauna communities.

Factor (s)	Wald $\chi^2$ statistic	Pr (>Dev)
Temperature	5.343	0.047*
Precipitation	5.513	0.003**
Soil organic matter	6.154	0.701
Litter cover	8.362	0.077*

\* p < 0.1. \*\* p < 0.05. \*\*\* p < 0.01.

elevated C/N ratios not only limited microbial activity but also hindered faunal-mediated decomposition, reinforcing the role of substrate quality in modulating faunal contributions to organic matter breakdown.

These results suggest that both fauna and land use play significant roles in leaf litter decomposition rates (Pech et al., 2021). The presence or absence of macrofauna appears to be a critical factor, as evidenced in Fig. 8.A, where all land uses showed slowed decomposition during the experimental period. These results align with findings by Xu et al. (2020) and Peng et al. (2023), who observed a 30.9–37 % increase in litter decomposition with the presence of macrofauna. Cassani et al. (2021) also found similar results in naturalized pastures, where macrofauna presence accelerated.

The use of litter decomposition bags with different mesh sizes is a widely accepted method for evaluating the role of soil organisms in litter decomposition. This approach assumes that variations in mass loss between coarse and fine mesh bags are attributable to the activity of soil fauna (Wang et al., 2015). Mamabolo et al. (2024) has demonstrated that the exclusion of soil fauna from litter bags significantly impairs decomposition, with reductions exceeding 30 %. In our study, we observed significantly greater decomposition rates in coarse mesh litter bags across all land use types, particularly at the end of the 330-day period. This finding indicates a substantial contribution of soil fauna to the loss of litter mass. The abundance and diversity of soil macrofauna in natural ecosystems and agroecosystems can serve as bioindicators of land use and soil fertility (Vezzani and Mielniczuk, 2009; Araujo et al., 2019; Silva et al., 2021). Continuous monitoring makes soil macrofauna a valuable tool for assessing not only soil quality but also the functioning of a production system, as it is closely associated with decomposition and nutrient cycling processes (Bandeira, 2021).

The quality of the residue in the NF possibly contributed to the lower rate of decomposition, especially due to its composition (Supplementary Material - Table 2). Around 74 % of the material in this use is made up of tree branches and bark, which are materials that are resistant to decomposition due to the presence of polyphenols, requiring specific organisms to degrade this material. According to Silva et al. (2014), polyphenols have an astringent effect on proteins, which results in the formation of complexes that are recalcitrant to attack by soil organisms. As emphasised by Cianciaruso et al. (2006) and Pereira et al. (2023), burdocks have different compositions, resulting in different decomposition speeds. Therefore, the overall rate of decomposition is intrinsically linked to the proportion of the various components present.

In addition, the different nutrient composition of plant materials (Supplementary Material - Table 2) can modulate these effects, as

indicated by the variations in decomposition rates in the different land uses evaluated (NF, CO and CN). In a study carried out by (Pereira et al., 2023), the authors state that the quality of the litter has a strong relationship with decomposition rates, specifically due to the C/N ratio of these materials. According to the authors, a low C/N ratio tends to favour the activity of microorganisms and a high C/N ratio can harm it, directly interfering with the decomposition of the litter, giving the material lability or recalcitrance (Phukongchai et al., 2022).

Other important nutrients related to decomposition in this study are phosphorus (P) and magnesium (Mg), both of which were measured and found in higher concentrations in the CO land use (Supplementary Material – Table 3). Although several nutrients are essential for soil fauna, we focused on P and Mg because they were included in our chemical analyses. Phosphorus is a key nutrient for soil fauna, being involved in enzymatic activity (Singh et al., 2018) and positively influencing litter palatability (Rief et al., 2012), making P-rich litter more attractive to detritivores (Peng et al., 2023). Magnesium also plays an important role in decomposition, as it is vital for enzyme function and the physiological processes of soil fauna. Higher Mg concentrations in litter have been associated with increased activity and diversity of soil organisms (García-Palacios et al., 2016; Yue et al., 2018; Peng et al., 2022), supported by nutritional requirements outlined by the National Research Council (2005). These findings suggest that the CO area, due to its low disturbance, higher soil fertility, and better litter quality, favored macrofauna activity, resulting in more rapid litter consumption compared to other land uses.

The use of CN, on the other hand, showed close decomposition values between the meshes, suggesting little influence from the macrofauna in this land use. The low activity of the macrofauna may be related to the type of management adopted at the site (conventional), mainly due to soil disturbance, causing disruption to the entire soil fauna chain. Many studies (Medeiros et al., 2020; Bandeira, 2021; Pereira et al., 2023) have reported that disturbing the soil through conventional tillage affects the decomposition of litter, especially by disturbing the entire community of organisms present in the soil, interfering with the formation of soil organic matter. These alterations possibly lead to a reduction in the fauna of this use, which corroborates the data found in Figs. 1–9, in which land use with CN showed the lowest indices and diversity of species in relation to the other uses. Another fact that reaffirms the potential decline in quality in this system is that even with the presence of irrigation water and fertility correction at each cultivation, a lower diversity of individuals was observed, reinforcing the fact that conventional soil preparation leads to a reduction in fauna and consequent reduction in the decomposition of litter.

In quantitative terms, these results are in line with those found by Coelho et al. (2021), in which the natural vegetation had the highest number of individuals and the conventional system had the lowest number of individuals. According to previous studies (Sá et al., 2014; Medeiros et al., 2020), the conversion of natural ecosystems into agricultural systems especially conventional systems prevalent in the Brazilian semi-arid region can negatively impact soil structure. These changes often include a reduction in macroaggregates and an increase in microaggregates, which in turn affect the physical, chemical, and biological attributes of the soil. Supporting this, an experimental study in the central Amazon found that the conversion of forest to pasture led to a drastic decline in porosity in the 0–5 cm soil layer from 48 % in forest to just 16 % in pasture due to the formation of compacted surface crusts dominated by the earthworm *Pontoscolex corethrurus*. Remarkably, the biogenic structure of the soil was shown to be reversible within one year when forest soil blocks were transplanted into pasture and vice versa (Barros et al., 2001). These findings highlight how soil fauna-mediated structural changes can substantially affect soil functioning and faunal habitats under different land uses.

The interaction between soil fauna and ecosystem processes is complex, emphasizing the importance of understanding how soil fauna diversity influences decomposition, functional ecology, biogeochemical

cycles, and soil health (Meyer et al., 2011). The abundance, diversity, and individuals' of soil fauna significantly affect litter decomposition, with notable differences observed across various land use types. These differences are likely related to the functional diversity of soil organisms, particularly detritivores (Patoine et al., 2017). Although this study did not directly measure microbial activity and dynamics, it is plausible that the increased soil fauna diversity and decomposition rates in sites with minimal anthropogenic disturbance (such as perennial crops) are due to the interactions between microbes and detritivorous arthropods (Carrillo et al., 2011). For instance, Peguero et al. (2019) found that optimal conditions for microbial decomposition enhanced the overall contributions of soil fauna to litter mass loss.

Abiotic environmental effects have long been recognized for regulating soil fauna populations and decomposition processes (García-Palacios et al., 2013; Mamabolo et al., 2024). The study identified the primary factors affecting soil fauna and decomposition dynamics. Notably, temperature was found to be the most significant climatic variable influencing litter decomposition, while precipitation primarily impacted species diversity. Temperature also played a crucial role in determining the abundance, richness, and diversity of soil fauna, as well as litter mass loss. This effect is likely due to how favorable temperature conditions enhance the activity of decomposer organisms, thereby accelerating litter decomposition rates. (Peguero et al., 2019; Mamabolo et al., 2024). Regarding habitat variables, litter cover appeared to be a more critical factor influencing abundance, richness, and diversity of species compared to soil organic matter, which did not affect abundance of individuals. While the results might imply that litter cover is not directly related to decomposition, its significance should not be underestimated. Litter cover was closely associated with soil fauna abundance, richness, and diversity. This suggests that while litter cover may not directly influence decomposition, it plays an important indirect role by supporting essential functional soil fauna, which in turn boosts decomposition rates.

The study also reveals that climatic variables (temperature and precipitation) and habitat variables (soil organic matter and litter cover) are crucial for promoting biodiversity and, consequently, ecosystem function. Notably, temperature, soil organic matter, and litter cover positively influenced all soil fauna responses. The observation that soils under conventional use (CN) were mostly bare, while perennial use (CO) was covered with litter, underscores the importance of diverse management practices in creating suitable environmental conditions for the development and functioning of essential soil fauna groups, which ultimately benefit agricultural productivity (Stroud et al., 2016).

The findings have important implications for sustainable land management in semi-arid regions. The higher decomposition rates and greater macrofauna activity observed in perennial systems (CO), associated with reduced soil disturbance and improved litter quality, indicate that agroecosystems based on ecological principles, such as permanent soil cover, polycultures, and minimal tillage, promote key soil processes, including nutrient cycling and organic matter dynamics. In contrast, the low macrofauna activity and slower decomposition rates in conventional systems (CN) highlight the detrimental effects of intensive management practices. Therefore, the adoption of conservation-oriented practices, such as the use of organic inputs, reduced soil disturbance, and promotion of soil biodiversity, can enhance ecosystem services related to soil fertility and the resilience of agricultural systems under water-limited conditions. Integrating biodiversity-based management strategies is thus essential to reconcile productivity and sustainability in semi-arid ecosystems.

The results found in this study are promising and fill an important gap in the study of the effect of land use and management on soil fauna communities in semi-arid Brazil and their influence on litter decomposition. Based on these findings, immediate next steps could include experimental manipulations of soil fauna communities to directly assess their functional roles in decomposition processes under different land use systems. Such experiments could help clarify causal relationships

between changes in fauna composition and decomposition rates. Additionally, future studies using metagenomic and metaproteomic analyses could elucidate processes specific to each environment that interfere with the decomposition of plant material. Metagenomics has the capacity to generate information on the functional potential of soil microbial communities, allowing us to understand their behaviour in relation to environmental changes, and the importance of microbial communities in decomposition and nutrient cycling (Howe et al., 2016; Aguiar-Pulido et al., 2016; Chu et al., 2018). Metaproteomics generates information on the functionality of the communities of microorganisms present, forming a complete picture of the functional taxonomic relationships of a soil at a given time, identifying the metabolic dynamics within and between species (Tartaglia et al., 2020). Considering the difficulties in comparing results on a local scale, this study aims to stimulate additional research into decomposition dynamics within the agroecosystems of the region. It may also enhance our understanding of the essential functions of soil fauna in sustaining nutrient cycling and other ecological processes, which is crucial for the long-term sustainability of agricultural landscapes.

## 5. Conclusions

This study demonstrates that soil fauna plays a key role in regulating litter decomposition across different land-use systems in a semi-arid region of Brazil. Despite higher species diversity, natural vegetation showed slower decomposition rates, likely due to greater soil stability and lower disturbance, along with rainfall patterns characteristic of semi-arid climates. In contrast, perennial cultivation promoted faster decomposition compared to conventional systems, underscoring the functional importance of macrofauna. These findings highlight the need to integrate soil fauna dynamics into sustainable agroecosystem management strategies.

## CRediT authorship contribution statement

**Michele Xavier Vieira Megda:** Writing – review & editing, Visualization, Project administration, Formal analysis, Data curation. **Samy Pimenta:** Supervision, Formal analysis, Data curation. **Victor Martins Maia:** Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Formal analysis. **Marcos Koiti Kondo:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Teresinha Augusta Giustolin:** Visualization, Validation, Methodology. **Arley Figueiredo Portugal:** Validation, Resources, Methodology, Investigation. **David Gabriel Campos Pereira:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

We are immensely grateful to Professor Marcos Koiti Kondo (in memoriam) for his invaluable contributions and guidance. This study marks the culmination of the professional career of this esteemed soil science master. His dedication to education and passion for learning continue to inspire and guide us in our academic and professional paths. We also thank Embrapa Milho e Sorgo for providing the study areas, and the State University of Montes Claros (UNIMONTES) for its infrastructure. We acknowledge the support of FAPEMIG for the scholarship granted and thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brazil, for partial funding of this work – Finance

Code 001.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.agee.2025.109803](https://doi.org/10.1016/j.agee.2025.109803).

## Data availability

Data will be made available on request.

## References

- Adhikari, A.D., Shrestha, P., Ghimire, Rajan, Liu, Z., Pollock, D.A., Acharya, P., Aryal, D.R., 2024. Cover crop residue quality regulates litter decomposition dynamics and soil carbon mineralization kinetics in semi-arid cropping systems, 105160–105160 Appl. Soil Ecol. 193. <https://doi.org/10.1016/j.apsoil.2023.105160>.
- Adis, J., Bonaldo, A.B., Brescovit, A.D., Bertani, R., Cokendolpher, J.C., Condé, B., Woas, S., 2002. Arachnida at Reserva Ducke. Cent. Amazon. 17, 1–14 fascículo 1/2, 2002, página.
- Aerts, R., 1997. Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystems: a triangular relationship. Oikos 79, 439–449. <https://doi.org/10.2307/3546886>.
- Aguiar-Pulido, V., Huang, W., Suarez-Ulloa, V., Cickovski, T., Mathee, K., & Narasimhan, G. (2016). Metagenomics, Metatranscriptomics, and Metabolomics Approaches for Microbiome Analysis. Evolutionary Bioinformatics, 12s1, EBO.S36436. <https://doi.org/10.4137/EBO.S36436>.
- Althoff, T.D., Menezes, R.S.C., Pinto, A. de S., Pareyn, F.G.C., Carvalho, A.L. de, Martins, J.C.R., de Carvalho, E.X., Silva, A.S.A. da, Dutra, E.D., Sampaio, E.V. de S. B., 2018. Adaptation of the century model to simulate c and n dynamics of Caatinga dry forest before and after deforestation. Agric. Ecosyst. Environ. 254, 26–34. <https://doi.org/10.1016/j.agee.2017.11.016>.
- Araujo, E.C.G., Silva, T.C., Lima, T.V., de, Santos, N.A.T. dos, Borges, C.H.A., 2019. Macrofauna como bioindicadora da qualidade do solo para agricultura convencional e agrofloresta em bom Jardim-PE. Agropecuária Científica No Semiárido 14 (2), 108. <https://doi.org/10.30969/acsa.v14i2.975>.
- Armstrong, A.J., Nxele, T.C., 2017. English names of the megadrile earthworms (Oligochaeta) of KwaZulu-Natal. Afr. Invertebr. 58 (2), 11–20. <https://doi.org/10.3897/afrinvertebr.58.13226>.
- Bandeira, D.J. da C., 2021. Macrofauna e carbono orgânico total em sistemas agrícolas. Repos. ufersa. edu. Br. (<https://repositorio.ufersa.edu.br/items/5b87f47e-9db-4aa9-8fc2-a20fd46cba61>).
- Barros, E., Curni, P., Hallaire, V., Chauvel, A., Lavelle, P., 2001. The role of macrofauna in the transformation and reversibility of soil structure of an oxisol in the process of forest to pasture conversion. Geoderma 100 (1-2), 193–213. [https://doi.org/10.1016/s0016-7061\(00\)00086-0](https://doi.org/10.1016/s0016-7061(00)00086-0).
- Bates, D., Mächler, M., Bolker, B., Walker, S., 2014. Fitting Linear Mixed-Effects Models using lme4, <https://doi.org/10.48550/arxiv.1406.5823>.
- Berg, B., Matzner, E., 1997. The effect of n deposition on the mineralization of C from plant litter and humus. Environ. Rev. 5, 1–25. <https://doi.org/10.1139/a96-017>.
- Berg, B., McClaugherty, C., 2020. Plant litter. Springer International Publishing. <https://doi.org/10.1007/978-3-030-59631-6>.
- Bradford, M.A., Berg, B., Maynard, D.S., Wieder, W.R., Wood, S.A., 2016. Understanding the dominant controls on litter decomposition. J. Ecol. 104 (1), 229–238. <https://doi.org/10.1111/1365-2745.12507>.
- Bradford, M.A., Tordoff, G.M., Eggers, T., Jones, T.H., Newington, J.E., 2002. Microbiota, fauna, and mesh size interactions in litter decomposition. Oikos 99 (2), 317–323. <https://doi.org/10.1034/j.1600-0706.2002.990212.x>.
- Bradford, M.A., Veen, G.F., Bonis, A., Bradford, E.M., Classen, A.T., Cornelissen, J.H.C., Crowther, Thomas W., de Long, J.R., Freschet, G.T., Kardol, P., Manrubia-Freixa, M., Maynard, D.S., Newman, G.S., Logtestijn, R.S.P., Viketoff, M., Wardle, D.A., Wieder, W.R., Wood, S.A., van der Putten, W.H., 2017. A test of the hierarchical model of litter decomposition. Nat. Ecol. Evol. 1 (12), 1836–1845. <https://doi.org/10.1038/s41559-017-0367-4>.
- Burtis, J.C., Pipes, G.T., Yavitt, J.B., 2024. How do soil fauna mediate leaf litter decomposition in north temperate forest ecosystems?, 150975 Pedobiologia, 150975. <https://doi.org/10.1016/j.pedobi.2024.150975>.
- Carrillo, Y., Ball, B.A., Bradford, M.A., Jordan, C.F., Molina, M., 2011. Soil fauna alter the effects of litter composition on nitrogen cycling in a mineral soil. Soil Biol. Biochem. 43 (7), 1440–1449. <https://doi.org/10.1016/j.soilbio.2011.03.011>.
- Cassani, M.T., Sabatté, M.L., Riveira Rubín, M.A., Sfeir, A.J., Massobrio, M.J., 2021. Litter decomposition by soil fauna: effect of land use in agroecosystems. Heliyon 7 (10), e08127. <https://doi.org/10.1016/j.heliyon.2021.e08127>.
- Castillo-Figueroa, D., Castillo-Avila, C., 2025. Little influence of soil fauna on decomposition in successional upper andean tropical forests. Soil Ecol. Lett. 7 (2). <https://doi.org/10.1007/s42832-024-0277-8>.
- Chu, B.T.T., Petrovich, M.L., Chaudhary, A., Wright, D., Murphy, B., Wells, G., Poretsky, R., 2018. Metagenomics reveals the impact of wastewater treatment plants on the dispersal of microorganisms and genes in aquatic sediments. Appl. Environ. Microbiol. 84 (5). <https://doi.org/10.1128/AEM.02168-17>.
- Cianciaruso, M.V., Pires, J.S.R., Delitti, W.B.C., Silva, É.F.L.P. da, 2006. Produção de serapilheira e decomposição do material foliar em um cerradão na Estação Ecológica de Jataí, município de Luiz Antônio, SP, Brasil. Acta Bot. Bras. 20 (1), 49–59. <https://doi.org/10.1590/S0102-33062006000100006>.
- Coelho, V.O., Ribeiro Neto, A., Anhê, A.C.B.M., Lima, S.S. de, Vieira, D.M. da S., Loss, A., Torres, J.L.R., 2021. Macrofauna edáfica como bioindicadora da qualidade do solo em diferentes sistemas de manejo. Res. Soc. Dev. 10 (6), e54210616118. <https://doi.org/10.33448/rsd-v10i6.16118>.
- Corrêa, R.M., Freire, M.B.G. dos S., Ferreira, R.L.C., Silva, J.A.A. da, Pessoa, L.G.M., Miranda, M.A., Melo, D.V.M. de, 2010. Atributos físicos de solos sob diferentes usos com irrigação no semiárido de pernambuco. Rev. Bras. De. Eng. Agr. Ícola e Ambient. 14 (4), 358–365. <https://doi.org/10.1590/S1415-43662010000400003>.
- Cotrufo, M.F., Soong, J.L., Horton, A.J., Campbell, E.E., Haddix, M.L., Wall, D.H., Parton, W.J., 2015. Formation of soil organic matter via biochemical and physical pathways of litter mass loss. Nat. Geosci. 8 (10), 776–779. <https://doi.org/10.1038/geo2520>.
- Duarte, I.B., Gallo, A. de S., Gomes, M. da S., Guimarães, N. de F., Rocha, D.P., Silva, R.F. da, 2014. Plantas de cobertura e seus efeitos na biomassa microbiana do solo. Acta Iguaçu 3 (2), 150–165. <https://doi.org/10.48075/actaigua.v3i2.10625>.
- Fierer, N., Schimel, J.P., Holden, P.A., 2003. Influence of Drying-Rewetting frequency on soil bacterial community structure. Microb. Ecol. 45 (1), 63–71. <https://doi.org/10.1007/s00248-002-1007-2>.
- García-Palacios, P., Maestre, F.T., Kattge, J., Wall, D.H., 2013. Climate and litter quality differently modulate the effects of soil fauna on litter decomposition across biomes. Ecol. Lett. 16 (8), 1045–1053. <https://doi.org/10.1111/ele.12137>.
- García-Palacios, P., Shaw, E.A., Wall, D.H., Hättenschwiler, S., 2016. Temporal dynamics of biotic and abiotic drivers of litter decomposition. Ecol. Lett. 19 (5), 554–563. <https://doi.org/10.1111/ele.12590>.
- Gessner, M.O., Swan, C.M., Dang, C.K., McKie, B.G., Bardgett, R.D., Wall, D.H., Hättenschwiler, S., 2010. Diversity meets decomposition. Trends Ecol. Evol. 25 (6), 372–380. <https://doi.org/10.1016/j.tree.2010.01.010>.
- Handa, I.T., Aerts, R., Berendse, F., Berg, M.P., Bruder, A., Butenschoen, O., Chauvet, E., Gessner, M.O., Jabiol, J., Makkonen, M., McKie, B.G., Malmqvist, B., Peeters, E.T.H. M., Scheu, S., Schmid, B., van Ruijven, J., Vos, V.C.A., Hättenschwiler, S., 2014. Consequences of biodiversity loss for litter decomposition across biomes. Nature 509 (7499), 218–221. <https://doi.org/10.1038/nature13247>.
- Holanda, A.C., Feliciano, A.L.P., Marangon, L.C., Freire, F.J., Holanda, E.M., 2015. Decomposição da serapilheira foliar e respiração edáfica em um remanescente de Caatinga na Paraíba. Rev. Árvore 39 (2), 245–254. <https://doi.org/10.1590/0100-672202015000200004>.
- Howe, A., Yang, F., Williams, R.J., Meyer, F., Hofmockel, K.S., 2016. Identification of the core set of carbon-associated genes in a bioenergy grassland soil. PLOS ONE 11 (11), e0166578. <https://doi.org/10.1371/journal.pone.0166578>.
- Liu, Y., Wang, L., He, R., Chen, Y., Xu, Z., Tan, B., Zhang, L., Xiao, J., Zhu, P., Chen, L., Guo, L., Zhang, J., 2019. Higher soil fauna abundance accelerates litter carbon release across an alpine forest-tundra ecotone. Sci. Rep. 9 (1), 10561. <https://doi.org/10.1038/s41598-019-47072-0>.
- Machado, D.L., Pereira, M.G., Maria, E., Diniz, A.R., Eduardo, C., 2015. Soil fauna in successional dynamics of atlantic forest in semi-deciduous seasonal forest in the basin of river “Paraíba do Sul”, Rio De Janeiro State. Cienc. Florest. 25 (1), 91–106. <https://doi.org/10.1590/1980-509820152505091>.
- Mamabolo, E., Gaigher, R., Pryke, J.S., 2024. Litter decomposition is positively related to soil fauna species richness especially in livestock-integrated agricultural fields, 105461 Appl. Soil Ecol. 200, 105461. <https://doi.org/10.1016/j.apsoil.2024.105461>.
- Manetti, P.L., Lopez, A.N., Clemente, N.L., Faberi, A.J., 2010. Tillage system does not affect soil macrofauna in Southeastern Buenos Aires Province, Argentina. Span. J. Agric. Res. 8 (2), 377–384. <https://doi.org/10.5424/sjar/2010082-1189>.
- Manzoni, S., Schimel, J.P., Porporato, A., 2012. Responses of soil microbial communities to water stress: results from a meta-analysis. Ecology 93 (4), 930–938. <https://doi.org/10.1890/11-0026.1>.
- Medeiros, A., de, S., Maia, S.M.F., Santos, T.C. dos, Gomes, T.C., de, A., 2020. Soil carbon losses in conventional farming systems due to land-use change in the Brazilian semi-arid region. agriculture. Ecosyst. Environ. 287, 106690. <https://doi.org/10.1016/j.agee.2019.106690>.
- Melo, F.V., Brown, G.G., Constantino, R., Louzada, J.N., Luizão, F.J., de Morais, J.W., Zanetti, R., 2009. A importância da meso e macrofauna do solo na fertilidade e como bioindicadores. Bol. Inf. da SBCS| Jan. abr 39.
- Meyer, W.M., Ostertag, R., Cowie, R.H., 2011. Macro-invertebrates accelerate litter decomposition and nutrient release in a Hawaiian rainforest. Soil Biol. Biochem. 43 (1), 206–211. <https://doi.org/10.1016/j.soilbio.2010.10.005>.
- National Institute of the Semiarid, I. (2023). O Semiarido Brasileiro. Retrieved March 11, 2023, from Instituto Nacional do Semiárido - INSA website: (<https://www.gov.br/instituto/pt-br/semiárido-brasileiro#:~:text=O%20Semi%C3%A1rido%20Brasileiro%20se%20estende>).
- National Research Council, 2005. Mineral tolerance of animals. The National Academies Press, Washington DC.
- Oliver, I., Beattie, A.J., 1996. Invertebrate morphospecies as surrogates for species: a case study. Conserv. Biol. 10 (1), 99–109. <https://doi.org/10.1046/j.1523-1739.1996.1001009.x>.
- Patoine, G., Thakur, M.P., Friese, J., Nock, C., Höning, L., Haase, J., Scherer-Lorenzen, M., Eisenhauer, N., 2017. Plant litter functional diversity effects on litter mass loss depend on the macro-detritivore community. Pedobiologia 65, 29–42. <https://doi.org/10.1016/j.pedobi.2017.07.003>.
- Paul, E.A., Clark, F.E., 1989. Soil microbiology and biochemistry. Academic Press, p. 275. <https://doi.org/10.1016/c2009-0-02814-1>.

- Pech, T., Fockink, G.D., Siminski, A., Niemeyer, J.C., 2021. Role of soil fauna to litter decomposition in pine stands under Atlantic Forest biome. *Ciência Florest.* 31 (4), 1849–1866. <https://doi.org/10.5902/1980509852839>.
- Peguero, G., Sardans, J., Asensio, D., Fernández-Martínez, M., Gargallo-Garriga, A., Grau, O., Llusià, J., Margalef, O., Márquez, L., Ogaya, R., Urbina, I., Courtois, E.A., Stahl, C., Van Langenhove, L., Verryckt, L.T., Richter, A., Janssens, I.A., & Peñuelas, J. (2019). Nutrient scarcity strengthens soil fauna control over leaf litter decomposition in tropical rainforests. *Proceedings of the Royal Society B: Biological Sciences*, 286(1910), 20191300. <https://doi.org/10.1098/rspb.2019.1300>.
- Peng, Y., Holmstrup, M., Kappel Schmidt, I., Ruggiero Bachega, L., Schelfhout, S., Zheng, H., Hedéne, P., Yue, K., Vesterdal, L., 2022. Tree species identity is the predominant modulator of the effects of soil fauna on leaf litter decomposition. *For. Ecol. Manag.* 520, 120396. <https://doi.org/10.1016/j.foreco.2022.120396>.
- Peng, Y., Vesterdal, L., Peñuelas, J., Peguero, G., Wu, Q., Hedéne, P., Yue, K., Wu, F., 2023. Soil fauna effects on litter decomposition are better predicted by fauna communities within litterbags than by ambient soil fauna communities. *Plant Soil* 487 (1–2), 49–59. <https://doi.org/10.1007/s11104-023-05902-1>.
- Pereira, D.G.C., Portugal, A.F., Giustolin, T.A., Maia, V.M., Megda, M.X.V., Kondo, M.K., 2023. Litter decomposition and nutrient release in different land use systems in the Brazilian Semi-Arid region. *Catena* 231, 107345. <https://doi.org/10.1016/j.catena.2023.107345>.
- Phukongchai, W., Kaewpradit, W., Rasche, F., 2022. Inoculation of cellulolytic and ligninolytic microorganisms accelerates decomposition of high C/N and cellulose rich sugarcane straw in tropical sandy soils. *Appl. Soil Ecol.* 172, 104355. <https://doi.org/10.1016/j.apsoil.2021.104355>.
- Pieper, S., Weigmann, G., 2008. Interactions between isopods and collembolans modulate the mobilization and transport of nutrients from urban soils. *Appl. Soil Ecol.* 39 (2), 109–126. <https://doi.org/10.1016/j.apsoil.2007.11.012>.
- Popovic, G.C., Francis, Warton, D.I., 2021. Fast model-based ordination with copulas. *Methods Ecol. Evol.* 13 (1), 194–202. <https://doi.org/10.1111/2041-210x.13733>.
- Potapov, A.M., Beaulieu, F., Birkhofer, K., Bluhm, S.L., Degtyarev, M.I., Devetter, M., Goncharov, A.A., Gongalsky, K.B., Klärner, B., Korobushkin, D.I., Liebke, D.F., Maraun, M., Mc Donnell, R.J., Pollierer, M.M., Schaefer, I., Shrubovych, J., Semenyuk, I.I., Sendra, A., Tuma, J., Túmová, M., 2022. Feeding habits and multifunctional classification of soil-associated consumers from protists to vertebrates. *Biol. Rev.* 97 (3), 1057–1117. <https://doi.org/10.1111/brv.12832>.
- Pragana, R.B., Ribeiro, M.R., Nóbrega, J.C.A., Ribeiro Filho, M.R., Costa, J.A. da, 2012. Qualidade física de Latossolos Amarelos sob plantio direto na região do Cerrado piauiense. *Rev. Bras. De Ciência Do Solo* 36 (5), 1591–1600. <https://doi.org/10.1590/S0100-06832012000500023>.
- Prescott, C.E., 2010. Litter decomposition: what controls it and how can we alter it to sequester more carbon in forest soils? *Biogeochemistry* 101 (1–3), 133–149. <https://doi.org/10.1007/s10533-010-9439-0>.
- Pritchard, S.G., 2011. Soil organisms and global climate change. *Plant Pathol.* 60 (1), 82–99. <https://doi.org/10.1111/j.1365-3059.2010.02405.x>.
- Rafael, J.A., Melo, G., Carvalho, C., Casari, C.A., Constantino, R. (2012). Insetos do Brasil: Diversidade e Taxonomia. Ribeirão Preto, Brazil, Holos.
- Rief, A., Knapp, B.A., Seeber, J., 2012. Palatability of selected alpine plant litters for the decomposer *lumbricus rubellus* (lumbricidae). *PLoS ONE* 7 (9), e45345. <https://doi.org/10.1371/journal.pone.0045345>.
- Riegelhaupt, E., Pareyn, F.G.C., Bacalini, P., 2010. O manejo florestal na caatinga: resultados da experimentação. GARIGLIO. MA Et. al. Uso Sustent. Ável. e Conserv. Cão. Recur. Floresta da Caatinga. Brasília 256–275.
- Sá, J.C.M., Tivet, F., Lal, R., Briedis, C., Hartman, D.C., dos Santos, J.Z., dos Santos, J.B., 2014. Long-term tillage systems impacts on soil c dynamics, soil resilience and agronomic productivity of a brazilian oxisol. *Soil Tillage Res.* 136, 38–50. <https://doi.org/10.1016/j.still.2013.09.010>.
- Sales, R.P., Pegoraro, R.F., Portugal, A.F., Moreira, J.A.A., Kondo, M.K., 2017. Organic matter fractions of an irrigated oxisol under no-till and conventional tillage in the brazilian semi-arid region. *Rev. Caatinga* 30 (2), 303–312. <https://doi.org/10.1590/1983-21252017v30n205rc>.
- Santos, G.R. (2016). Produção e decomposição de folhedo em vegetação secundária com a influência do eucalipto na zona ripária. Dissertação (Mestrado)-Universidade Estadual Paulista "Júlio de Mesquita Filho", Botucatu.
- Scoriza, R.N., Pereira, M.G., Pereira, G.H.A., Machado, D.L., Silva, E.M.R., 2012. Métodos para coleta e análise de serrapilheira aplicados à ciclagem de nutrientes. *Floresta Ambiental* 2, 1–18.
- Silva, H.F., Barreto, P.A.B., Sousa, G.T. de O., Azevedo, G.B., Gama-Rodrigues, E.F., Oliveira, F.G.R.B., 2014. Decomposição de serrapilheira foliar em três sistemas florestais no sudeste da bahia. *Rev. Bras. De Biociências* 12 (3). (<https://seer.ufrgs.br/index.php/rbrasbioci/article/view/114838>) (Recuperado de).
- Silva, R.M., da Silva, R.M., da Souza, J.R.M., de, Geddeski, T.P., Lima, S.S. de, Lima, E., 2021. Fauna do solo como bioindicadora da qualidade do solo em cultivos de cana-de-açúcar: um referencial teórico. *Res. Soc. Dev.* 10 (10), e239101018741. <https://doi.org/10.33448/rsd-v10i10.18741>.
- Silva, J.D.F., Silva, T.R.B.F., de Oliveira, M.L., de Oliveira, G., Mishra, M., Guimarães Santos, C.A., Marques da Silva, R., dos Santos, C.A.C., 2025. Parameterized models for estimating atmospheric longwave radiation and surface net radiation in the Brazilian semi-arid region. *J. South Am. Earth Sci.* 160, 105534. <https://doi.org/10.1016/j.jsames.2025.105534>.
- Singh, J., Hundal, J.S., Sharma, A., Singh, U., Sethi, A.P.S., Singh, P., 2018. Phosphorus nutrition in dairy animals: a review. *Int. J. Curr. Microbiol. Appl. Sci.* 7 (04), 3518–3530. <https://doi.org/10.20546/ijcmas.2018.704.397>.
- Six, J., Paustian, K., Elliott, E.T., Combrink, C., 2000. Soil structure and organic matter. *Soil Sci. Soc. Am. J.* 64 (2), 681. <https://doi.org/10.2136/sssaj2000.642681x>.
- Snedecor, G.W., Cochran, W.G., 1989. *Statistical Methods*, 8th Edition. Iowa State University Press, Ames.
- Soil Survey Staff (1999). Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys (2nd ed.). Agriculture Handbook No. 436, USDA-NRCS. ([https://www.nrcs.usda.gov/Internet/FSE\\_DOCU](https://www.nrcs.usda.gov/Internet/FSE_DOCU)).
- Song, X., Peng, H., Wang, J., Ning, G., Sun, Z., 2020. Small universal asynchronous spiking neural P systems with multiple channels. *Neurocomputing* 378, 1–8. <https://doi.org/10.1016/j.neucom.2019.06.104>.
- Souto, P.C. (2006). Acumulação e decomposição da serrapilheira e distribuição de organismos edáficos em área de caatinga na Paraíba, Brasil.
- Stroud, J.L., Irons, D.E., Watts, C.W., White, R.P., McGrath, S.P., Whitmore, A.P., 2016. Population collapse of *lumbricus terrestris* in conventional arable cultivations and response to straw applications. *Appl. Soil Ecol.* 108, 72–75. <https://doi.org/10.1016/j.apsoil.2016.08.002>.
- Swart, W.J., Seaman, M.T., Roux, le, Janecke, B.B., 2020. A tribute to Frederick (Fred) J. Kruger. *Koedoe* 62 (2). <https://doi.org/10.4102/koedoe.v62i2.1639>.
- Tartaglia, M., Bastida, F., Sciarillo, R., Guarino, C., 2020. Soil metaproteomics for the study of the relationships between microorganisms and plants: a review of extraction protocols and ecological insights. *Int. J. Mol. Sci.* 21 (22), 8455. <https://doi.org/10.3390/ijms21228455>.
- Taylor, P.G., Cleveland, C.C., Wieder, W.R., Sullivan, B.W., Doughty, C.E., Dobrowski, S. Z., Townsend, A.R., 2017. Temperature and rainfall interact to control carbon cycling in tropical forests. *Ecol. Lett.* 20 (6), 779–788. <https://doi.org/10.1111/ele.12765>.
- Timis-Gansac, V., Dinca, L., Constandache, C., Murariu, G., Cheregi, G., Timofte, C.S.C., 2025. Conservation biodiversity in arid areas: a review. *Sustainability* 17 (6), 2422. <https://doi.org/10.3390/su17062422>.
- Vezzani, F.M., Mielińczuk, J., 2009. Uma visão sobre qualidade do solo. *Rev. Bras. De Ciência Do Solo* 33 (4), 743–755. <https://doi.org/10.1590/S0100-06832009000400001>.
- Wang, Y., Naumann, U., Wright, S.T., Warton, D.I., 2012. mvabund- anRpackage for model-based analysis of multivariate abundance data. *Methods Ecol. Evol.* 3 (3), 471–474. <https://doi.org/10.1111/j.2041-210x.2012.00190.x>.
- Wang, Z., Yin, X., Li, X., 2015. Soil mesofauna effects on litter decomposition in the coniferous forest of the Changbai Mountains, China. *Appl. Soil Ecol.* 92, 64–71. <https://doi.org/10.1016/j.apsoil.2015.03.010>.
- [83] Wider, R.K., Lang, G.E., 1982. A critique of the analytical methods used in examining decomposition data obtained from litter bags. *Ecology* 63 (6), 1636. <https://doi.org/10.2307/1940104>.
- Wieder, W.R., Cleveland, C.C., Townsend, A.R., 2009. Controls over leaf litter decomposition in wet tropical forests. *Ecology* 90 (12), 3333–3341. <https://doi.org/10.1890/08-2294.1>.
- Xie, Y., 2020. A meta-analysis of critique of litterbag method used in examining decomposition of leaf litters. *J. Soils Sediment.* <https://doi.org/10.1007/s11368-020-02572-9>.
- Xu, X., Sun, Y., Sun, J., Cao, P., Wang, Y., Chen, H.Y.H., Wang, W., Ruan, H., 2020. Cellulose dominantly affects soil fauna in the decomposition of forest litter: a meta-analysis. *Geoderma* 378, 114620. <https://doi.org/10.1016/j.geoderma.2020.114620>.
- Yu, S., Mo, Q., Li, Y., Li, Y., Zou, B., Xia, H., Li, Z., Wang, F., 2019. Changes in seasonal precipitation distribution but not annual amount affect litter decomposition in a secondary tropical forest. *Ecol. Evol.* 9 (19), 11344–11352. <https://doi.org/10.1002/ece3.5635>.
- Yue, K., de Frenne, P., van Meerbeek, K., Ferreira, V., Fornara, D.A., Wu, Q., Ni, X., Peng, Y., Wang, D., Hedéne, P., Yang, Y., Wu, F., Peñuelas, J., 2022. Litter quality and stream physicochemical properties drive global invertebrate effects on instream litter decomposition. *Biol. Rev.* 97 (6), 2023–2038. <https://doi.org/10.1111/brr.12880>.
- Yue, K., García-Palacios, P., Parsons, S.A., Yang, W., Peng, Y., Tan, B., Huang, C., Wu, F., 2018. Assessing the temporal dynamics of aquatic and terrestrial litter decomposition in an alpine forest. *Funct. Ecol.* 32 (10), 2464–2475. <https://doi.org/10.1111/1365-2435.13143>.