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CROP PROTECTION

Evaluation of soil fauna diversity in maize crops using Shannon, Margalef, and Pielou indices

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ABSTRACT. Soil organisms are vital for soil quality and can indicate environmental conditions. This study aimed to understand the diversity of soil fauna and its connection to plant residue decomposition and maize grain yield across various locations and crop seasons in a subtropical setting. We conducted experiments in Frederico Westphalen, Santa Maria, and São Vicente do Sul, Rio Grande do Sul State, Brazil, during two crop seasons in 2020/2021, totalling six experiments. We assessed parameters such as plant residue decomposition rate, soil fauna abundance, and grain yield. Results showed significant variations in decomposition rate, fauna abundance, and diversity measures (Shannon, Margalef, and Pielou indices, plus relative frequency) across environments. Four taxonomic groups comprised over 80% of collected individuals, with Araneae and Coleoptera showing more than half of relative frequency Our analysis revealed that areas with higher grain yields had faster decomposition rates, suggesting they fostered greater organism activity and nutrient cycling, indicating their potential as soil quality indicators.

Keywords: soil fauna; waste decomposition; litter bag method; *Zea mays* L.

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Introduction

Soil is a dynamic system shaped by the interaction of organic matter and minerals (Bünemann et al., 2018). It hosts diverse microhabitats with distinct physicochemical gradients and experiences varying environmental conditions. These habitats are inhabited by a plethora of organisms that profoundly influence soil processes and hence its physical, chemical, and biological properties (Baizán, Vicente, & Fernandez, 2021). These organisms, known as edaphic fauna, are categorized by size into microfauna (smaller than 0.1 mm, e.g., protozoa and nematodes), mesofauna (0.1 to 2.0 mm, e.g., Collembola and mites), and macrofauna (larger than 2.0 mm, e.g., Coleoptera and earthworms) (Saxena & Kottapalli, 2016).

Edaphic organisms have specific habitat preferences and tolerance limits (Perry, Amaranthus, Borchers, Borchers, & Brainerd, 1989). Human or natural interventions can disrupt their diversity. Factors like climate (rainfall, air temperature, and humidity), soil characteristics (type, temperature, humidity, pH, minerals, organic matter, texture, and structure), plant material (plant species, stage of development, cover, and carbon/nitrogen ratio), topography (altitude and slope), and historical actions (anthropic and natural) may affect edaphic fauna (Machado, Pereira, Correia, Diniz, & Menezes, 2015). Therefore, these organisms serve as rapid indicators of environmental quality amidst agricultural disturbances.

These same factors influence crop performance. Yet, the relationship between soil bioindicators and crop productivity needs more study. Understanding this connection is vital for sustainable management practices aimed at increasing yield while minimizing the use of chemical inputs. Hence, our study aims to characterize edaphic fauna using diversity indices regarding plant residue decomposition and maize yield across varied locations and crop seasons in a subtropical setting.

Material and methods

The study was conducted at three sites in Rio Grande do Sul State (Southern Brazil), namely: Frederico Westphalen (FW; 27°23'50" S, 53°25'35" W), Santa Maria (SM; 29°43'27" S, 53°43'39" W), and São Vicente do

Sul (SVS; 29°42'27" S, 54°41'28" W). The climate at all three sites is classified as humid subtropical with hot summers (*Cfa*) according to Köppen's classification (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013). Meteorological data were gathered from automatic weather stations located up to 600 m from the experimental areas.

The soils at FW are classified as typical Oxisol (or *Latossolo Vermelho distrófico* in the Brazilian Soil Classification System – SiBCS), while the soils at SM and SVS are classified as Ultisol (or *Argissolo Vermelho distrófico* – SiBCS). Soil chemical characterization was performed in each of the 54 experimental units. Samples were extracted from the 0-10 cm depth using an auger, 20 days before each sowing, and the attributes obtained were utilized for fertilization calculations. The assessed attributes included: clay content (g kg^{-1}, measured using a densimeter); pH (measured in water at a ratio of 1:1); organic matter (OM; g kg^{-1}, determined using the Walkley-Black carbon method); phosphorus (P; mg dm^{-3}, analyzed using the Mehlich-1 extraction method); potassium (K; mg dm^{-3}, analyzed using the Mehlich-1 extraction method); calcium (Ca; $cmol_c$ dm^{-3}, measured using KCl); magnesium (Mg; $cmol_c$ dm^{-3}, measured using KCl); aluminium (Al; $cmol_c$ dm^{-3}, measured using KCl); hydrogen + Al (H + Al; $cmol_c$ dm^{-3}, determined via titration); effective cation exchange capacity ($cmol_c$ dm^{-3}); Al saturation (%); and base saturation (%); and calcium-magnesium ratio (Ca: Mg).

During the 2020/2021 crop year, the experiment took place in two sowing seasons: the latter half of September (season 1) and the latter half of October (season 2). Sowing dates were selected based on agricultural zoning for each location (FW, SM, and SVS) within maize cultivation areas. Six experiments were executed (three locations multiplied by two sowing seasons). The trials in FW and SM were conducted under rainfed conditions, whereas the SVS experiment utilized centre pivot irrigation.

The winter crop preceding maize cultivation comprised a cover crop consortium of black oats (*Avena strigosa* L.) and forage turnips (*Raphanus sativus* L.). After desiccation of the cover crops, fertilization was administered using a seed drill to attain a target grain yield of 12 t ha^{-1}. Subsequently, maize was manually sown at a density of 70,000 plants ha^{-1}. The experiments were arranged in randomized blocks, featuring three representative maize hybrids commonly cultivated in the regions (AG 9025 PRO3, MG 300 PW, and DKB 230 PRO3), with each experiment replicated three times. Each experimental unit comprised six rows spaced 0.50 m apart and measuring five meters in length, totalling an area of 15 m^2. Cultural practices including nitrogen fertilization, and applications of fungicide, herbicide, and insecticide adhered to recommended guidelines for maize cultivation in Rio Grande do Sul State, Brazil (Da Rosa, Emygdio, & Bispo, 2017).

The rate of plant residue decomposition by soil organisms was assessed using the litter bag method, adapted from Bocock and Gilbert (1957). Nylon bags, sized 20 × 15 cm with a mesh size of 0.5 × 0.5 cm, were fabricated to enable decomposer organisms from the soil fauna to access the content. These bags were filled with green leaves from the middle third of maize plants, amounting to 20 g of dry mass (achieved by drying the leaves in a forced air oven at 60°C for 72 hours). Four bags were evenly distributed in each experimental unit, placed in direct contact with the soil, between the phenological stages of VT and R1. Following a 45-day incubation period, the bags were retrieved and dried to determine the remaining dry mass and half-life time. The decomposition constant (k) was computed using the equation proposed by Thomas and Asakawa (1993), as follows:

$$Xt = X0.e^{-kt}$$

where: *Xt* represents the dry mass of the remaining material after *t* days, and X0 is the initial dry mass at t equals zero.

Soil fauna was retrieved from the litter bags before subjecting plant materials to drying. Manual sorting was performed in the laboratory, with organisms being preserved in 70% alcohol. Organisms larger than 1 mm were identified and quantified at the order level. Grain yield (GY) was estimated within an 8 m^2 area in each plot, comprising four central rows measuring four meters in length. Harvesting occurred when the grains reached 20% humidity, which was subsequently adjusted to 13%. Grain yield was determined accordingly.

As for the variables remaining mass, half-life, and decomposition constant (k), the mean values of the four litter bags in each plot were computed. Likewise, the abundance (individuals per litter bag), relative frequency (%) of individuals in each order, and diversity indices (Shannon [H'], Margalef [D_{Mg}], and Pielou [J']) were calculated for the soil fauna. Thus, only one value per experimental unit was generated for each variable analyzed, including grain yield.

Subsequently, a linear correlation study was conducted using Pearson's correlation method with a 5% significance level.

Soil fauna data were analyzed using Past® software (Hammer, Harper, & Ryan, 2001). Canonical correlation analyses were conducted to explore the relationships between groups of variables, with findings depicted as canonical cross-loadings. The significance of canonical correlations was assessed using the chi-square test at a 5% significance level. Additionally, the other variables underwent analysis using the Wilcoxon non-parametric test, also at a 5% significance level. All statistical analyses were carried out using R software (R Development Core Team, 2019) and Microsoft Office Excel®.

Results and discussion

During the experiments, weather conditions were significantly different in rainfall and distribution across locations and crop seasons (Figure 1). After installing litter bags in the field, cumulative rainfall, coupled with irrigation in SVS, varied by 50, 130, and 175 mm between both seasons for FW, SVS, and SM, respectively. The lowest values across the three sites were observed during season 2 in FW and season 1 in SM and SVS. Water availability was more uniformly distributed in SVS during both crop seasons due to improved irrigation management. Across both seasons, the total water supply (precipitation + irrigation) was higher in SVS, and the consistent availability of water without any periods of water deficit before and during the exposure of the litter bags fostered more favourable environments for the development of soil-dwelling organisms involved in plant residue decomposition.

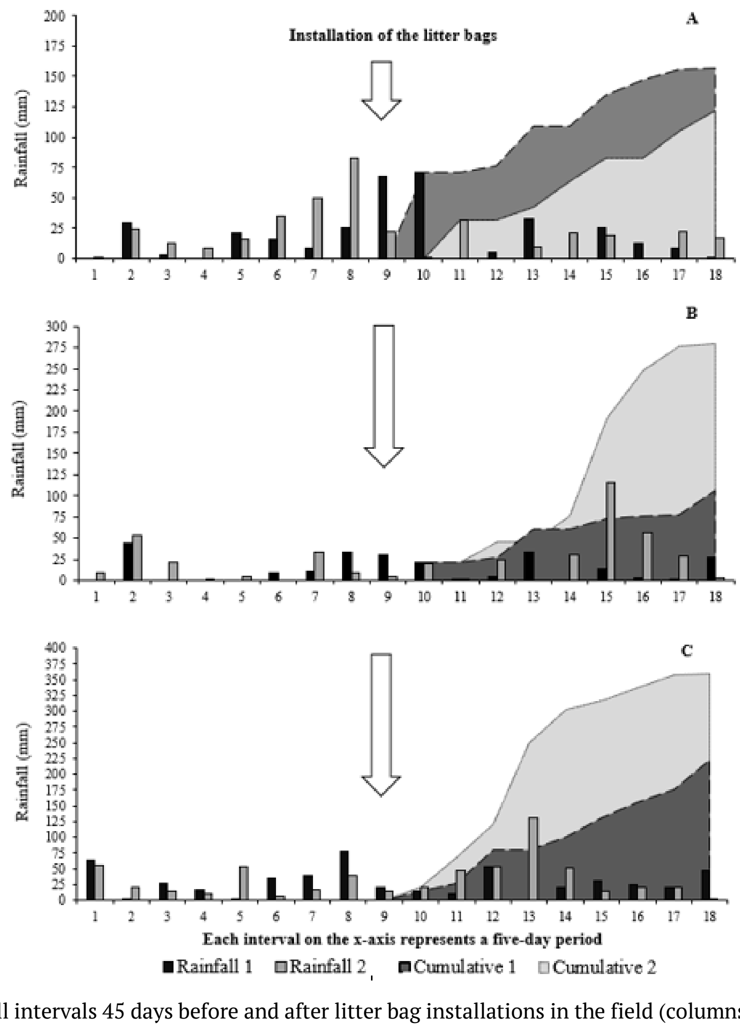

Figure 1. Five-day rainfall intervals 45 days before and after litter bag installations in the field (columns), along with accumulated rainfall post-installation (shaded area) for two maize crop seasons in Frederico Westphalen (A), Santa Maria (B), and São Vicente do Sul (C) in Rio Grande do Sul State (Southern Brazil). In São Vicente do Sul, rainfall was supplemented with central pivot irrigation.

Before installing the litter bags, FW experienced higher rainfall occurrences. Season 1 saw significant rainfall shortly after installation, aiding organisms in plant residue degradation. Conversely, SM 1 had low rainfall levels pre-installation. The substantial rainfall accumulation in SM 2 resulted from a single rainfall event 30 days after bag placement, enhancing organism activity in the final 15 days before bag removal.

Soil chemical analysis across the six experiments revealed variations in clay content (Table 1). FW had clay levels exceeding 600 g kg^{-1}, while SM ranged between 200 and 300 g kg^{-1}; in contrast, SVS values were below 150 g kg^{-1}. Another notable difference was observed in OM. FW fell within the medium class with values above 30 g kg^{-1}, while SM and SVS had low values equal to or below 25 g kg^{-1}. Phosphorus content in FW and SM was categorized as low and high in SVS. Potassium content was classified as high in SM and SVS and extremely high in FW, according to the Fertilization and Liming Guidelines (CQFS, 2016). Soil pH values were similar across the environments, ranging between 5 and 5.5. Nonetheless, despite the low values, Al content was also low.

Research has indicated that soil properties such as clay content, OM, P, and K significantly vary among soils and can influence the abundance, richness, and diversity of soil fauna (Table 1). For instance, Briones and Schmidt (2017) reported that soils with higher clay content (>350 g kg^{-1}) supported a richer oligochaete community. Souza et al. (2016) noted that soil OM levels influenced the abundance and richness of macrofauna, while variations in P content in native and cultivated lands affected the abundance of various groups, including Acarina, Coleoptera, Collembola, and Oligochaeta. Baretta et al. (2014) emphasized the effect of K levels on the richness and abundance of soil fauna across different management systems. All soils in the current study were acidic, with pH values ranging from 5.1 to 5.4 (Table 1). Kraft et al. (2021) found that soil fauna remained unaffected within this pH range, although more acidic conditions (pH 4.0–4.7) had a detrimental impact. Similarly, Silva, Lima, Andrade, and Brown (2019) observed that soil pH influenced the composition of soil fauna.

Maize GY significantly correlates with soil fertility (Zhang et al., 2018), and the low pH at all three locations is typical in soils of Rio Grande do Sul State (Althaus et al., 2018) (Table 1). Soil pH directly impacts nutrient availability, influencing fertilizer use efficiency and playing a pivotal role in achieving higher grain yields (Li, Cui, Chang, & Zhang, 2019). Acidic soils often harbour Al^{3+} ions, which can be detrimental to plants, although these values were low across all three locations. In FW and SM, P deficiency was noted, requiring a P_2O_5 supply (200 kg ha^{-1}) to attain the desired maize GY potential of 12 t ha^{-1}. Conversely, SVS required only 90 kg ha^{-1} of P_2O_5 to meet the crop's P requirements. Regarding K, SM, and SVS required 120 kg ha^{-1} of K_2O, while FW needed 60 kg ha^{-1} of P_2O_5 (Comissão de Química e Fertilidade do Solo [CQFS], 2016; Da Rosa et al., 2017). Variations in OM content among the soils are attributed to clay content and its physical protection (Sarkar, Singh, Mandal, Churchman, & Bolan, 2018). OM content is used to determine the nitrogen fertilization dose. Consequently, the nitrogen requirements in SM and SVS soils were 190 kg ha^{-1}, while FW soils required 170 kg ha^{-1} (CQFS, 2016; Da Rosa et al., 2017).

GY reached its peak in SVS 1 and its lowest point in FW 2, with intermediate values recorded for SVS 2, SM 1, SM 2, and FW 1 (Table 1). Its mean variation within environments exceeded 3,000 kg ha^{-1}, with values from 15,000 to below 10,000 kg ha^{-1} in SVS 1. Standard deviation values within each environment primarily stem from differences in the productive potential of the selected hybrids, which were chosen for their representation among maize growers and to provide genetic variability.

Table 1. Soil properties during two maize crop seasons in Frederico Westphalen (FW), Santa Maria (SM), and São Vicente do Sul (SVS) in Rio Grande do Sul State (Southern Brazil).

	Location					
Property	FW 1	FW 2	SM 1	SM 2	SVS 1	SVS 2
Clay (g kg^{-1}, densimeter)	661.0	615.0	286.0	235.0	131.0	125.0
pH (in water 1:1)	5.3	5.1	5.2	5.4	5.3	5.1
OM (g kg^{-1}, Walkley-Black carbon)	37.0	34.0	23.0	29.0	16.0	23.0
P (mg dm^{-3}, Mehlich-1)	10.4	6.7	11.0	11.4	52.3	88.3
K (mg dm^{-3}, Mehlich-1)	352.0	256.0	100.4	136.4	104.0	100.4
Ca (cmol$_c$ dm^{-3}, KCl)	6.2	6.2	5.2	5.9	4.7	4.7
Mg (cmol$_c$ dm^{-3}, KCl)	3.0	3.2	2.9	3.3	1.6	1.5
Al (cmol$_c$ dm^{-3}, KCl)	0.1	0.1	0.3	0.0	0.3	0.2
H+Al (cmol$_c$ dm^{-3}, titration)	5.4	6.6	7.9	5.4	5.5	5.8
Effective CEC (cmol$_c$ dm^{3})	10.3	10.2	8.8	9.6	6.9	6.7
Al saturation (%)	1.3	0.9	4.2	0.7	5.0	3.9
Base saturation (%)	64.9	60.6	52.6	63.9	54.4	53.4
Ca: Mg	2.0	1.9	1.8	1.7	2.9	3.0
GY (kg ha^{-1})	8385.0	3062.0	9407.0	7928.0	11076.0	8898.0
Standard deviation (kg ha^{-1})	± 2155.0	± 1598.0	± 2298.0	± 1089.0	± 3232.0	± 1838.0

OM – Organic matter; CEC – cation exchange capacity; GY – grain yield. Nine soil samples were taken from each environment.

Notably, SVS 1 experienced well-distributed rainfall, facilitated by the central pivot irrigation system. This system optimized solar radiation use, benefiting from longer daylight hours during plant development compared to SVS 2. Consequently, the grain-filling period coincided with peak radiation levels. Conversely, high rainfall volumes in SVS 2 led to days with reduced radiation, adversely affecting potential GY. Additionally, SM 1 and SM 2 exhibited a slight inclination towards higher production in the first season, attributable to the solar radiation advantage mentioned earlier. Furthermore, SM 2 and FW 2 encountered more pronounced water deficits, notably during flowering and grain filling in FW 2. This, combined with elevated air temperatures, negatively impacted GY compared to SM 1 and FW 1.

A total of 2,880 soil fauna organisms were identified from the litter bags in the six experiments. Abundance and relative frequency within taxonomic groups were significantly different across the experiments (Table 2). FW 2 and SVS 1 showed significantly higher abundance compared to other environments. Changes in the environment, such as microclimate formation and plant resource input, alongside plant material surface accumulation and type, contributed to the increased organism abundance (Pessotto et al., 2020). The predominant taxonomic groups were larvae (38.63%) in FW 1, Dermaptera (35.55%) in FW 2, Coleoptera (63.95 and 30.23%, respectively) in SM 1 and 2, and Araneae (27.10 and 39.18%, respectively) in SVS 1 and 2. These variations may be associated with meteorological variables like precipitation, food availability, and sources (Zheng et al., 2020; Góes, Freitas, Lorentz, Vieira, & Weber, 2021).

Table 2. Relative frequency, total abundance, diversity indices of edaphic fauna and maize residue decomposition rates during two maize crop seasons in Frederico Westphalen (FW), Santa Maria (SM), and São Vicente do Sul (SVS) in Rio Grande do Sul State (Southern Brazil).

	Relative frequency (%)					
Group	FW 1	FW 2	SM 1	SM 2	SVS 1	SVS 2
Acarina	0 c [(1)]	0 c	0 c	14.95 a	2.93 b	11.20 ab
Araneae	30.20 ab	14.46 c	22.21 b	19.34 b	27.10 ab	39.18 a
Coleoptera	5.89 e	17.91 cd	63.95 a	30.23 b	24.89 bc	11.34 de
Dermaptera	19.92 b	35.55 a	0 d	0.21 d	17.54 b	5.88 c
Diptera	1.75 ab	0 b	0.76 ab	2.06 a	1.26 ab	1.17 ab
Hymenoptera	2.01 b	9.13 b	4.25 b	22.91 a	9.84 ab	4.86 b
Larvae	38.63 a	21.04 b	6.35 c	1.68 d	3.10 cd	1.56 d
Oligochaeta	0.28 b	0.51 b	0 b	0.65 b	10.01 a	18.66 a
Chilopoda	0 c	1.05 b	0 c	2.96 ab	2.86 ab	6.14 a
Others [(2)]	1.31 b	0.35 b	2.47 ab	5.01 a	0.47 b	0 b
	Diversity index					
Abundance [(3)] (38.65) [(4)]	34 cd	93 a	44 c	47 bc	75 ab	27 d
Shannon (13.87)	1.39 b	1.54 b	1.02 c	1.70 a	1.60 ab	1.51 b
Margalef (20.61)	1.32 bc	1.19 c	0.94 d	1.68 a	1.51 ab	1.46 abc
Pielou (10.31)	0.82 a	0.83 a	0.70 b	0.86 a	0.80 ab	0.87 a
Variables	Plant residue decomposition rate					
Remaining mass (%)	58.81 c	68.59 a	66.95 ab	63.80 bc	59.10 c	26.22 d
Decomposition constant k (g^{-1} day^{-1})	0.0119 b	0.084 d	0.0089 cd	0.0100 bc	0.0120 b	0.0301 a
Half-life (in days)	59.67 c	82.86 a	78.15 ab	70.36 bc	61.98 c	23.42 d

[(1)] Means followed by the same letter within rows do not differ statistically from each other by the Wilcoxon test ($p \leq 0.05$). [(2)] The groups Blattodea (cockroaches), Diplopoda (millipedes), Lepidoptera (moths), Odonata (dragonflies), Orthoptera (crickets and grasshoppers), and Pulmonata (slugs and snails) were clustered under "Others" due to the small number of individuals collected. [(3)] Abundance is reported as the number of individuals per litter bag. [(4)] The coefficient of variation is presented as a percentage (CV%).

Among the observed taxonomic groups, dominance variations were noted across the six environments. In FW 1, Araneae, Dermaptera, and larvae constituted over 88% of the collected individuals. With the addition of the order Coleoptera in FW 2, the predominance of these four orders surpassed 88%. In SM 1, Araneae and Coleoptera alone represented 86% of individuals, while in SM 2, these two orders accounted for only 49%, indicating a shift in individuals depending on the sowing season. However, Acarina and Hymenoptera were more prominent, comprising 87% of individuals from these four orders. In SVS 1, Araneae, Coleoptera, Dermaptera, and Oligochaeta dominated, making up 79% of the frequency of individuals, whereas in SVS 2, Acarina, Araneae, Coleoptera, and Oligochaeta were the predominant groups, comprising 80% (Table 2). Taxonomic groups present in smaller numbers, such as Blattodea, Diplopoda, Lepidoptera, Odonata, Orthoptera, and Pulmonata, are grouped as "Others" (Table 2). These groups play crucial roles in ecosystem functioning, contributing to decomposition, organic residue incorporation into the soil, nutrient mineralization, and bio-pore formation (Bartz, Pasini, & Brown, 2013), thereby promoting soil improvement.

In the SM 1 experiment, the lowest rainfall was recorded after installing litter bags in the field (Figure 1B). This 45-day period of limited water availability significantly restricted the activity of most soil fauna groups, leading to a strong dominance of groups adapted to low humidity, such as Araneae and Coleoptera. Conversely, in the SM 2 experiment, accumulated precipitation during the presence of litter bags in the field was 174% higher than in SM 1. The improved moisture conditions boosted the abundance of most groups, displacing Coleoptera and reducing their dominance (Bernardes et al., 2020). When examining the diversity indices, SM 1 was the only environment that exhibited statistical differences for all indices, indicating lower diversity compared to other environments. The low diversity value in SM 1 is attributed to the predominance of only two taxonomic groups: Araneae and Coleoptera. Similar findings of a few taxonomic groups with high relative frequencies have also been reported in the literature (Rosa & Dalmolin, 2009; Fialho et al., 2021; Góes et al., 2021).

Although SM 1 and SM 2 showed no statistical difference in the abundance of individuals, they represented the lowest (H' = 1.02c; D_{Mg} = 0.94d) and highest (H' = 1.70a; D_{Mg} = 1.68a) diversity values, respectively, for the H' and D_{Mg} indices. However, only three taxonomic groups, namely Coleoptera, Hymenoptera, and Acarina, exhibited significant differences in their relative frequency between the two environments. Notably, Coleoptera predominated in season 1, while Hymenoptera predominated in season 2, suggesting competition between these groups for space and food sources, which limited their coexistence. These findings align with those of Rosa and Dalmolin (2009), who identified Hymenoptera and Coleoptera as predominant groups in maize crops in an experiment in Santa Maria (Rio Grande do Sul State, southern Brazil). Similarly, research by Góes et al. (2021) in the same region encompassing SM and SVS reported Hymenoptera and Acarina as the most abundant taxonomic groups, a trend that persisted across different collection periods.

The presence of mites was higher in SVS 2 and SM 2 compared to SVS 1 and SM 1, respectively. This difference can be attributed to significantly higher accumulated rainfall in the second season at these locations compared to the first growing season. Soil mites are highly responsive to increased water availability in the soil (Manu et al., 2022). Moreover, mites can indirectly affect nutrient cycling and soil fertility through the fragmentation of plant debris, consumption of organisms, and subsequent interference with microbial activity (Barreta et al., 2011).

The speed at which plant residues break down affects the number and activity of soil organisms, as shown by Resende et al. (2013). In our study, we found that FW 2 and SVS 1 had slower decomposition rates compared to FW 1 and SVS 2, respectively. Therefore, there was more leftover plant material in litter bags at these sites, providing more food for soil fauna at collection time. This explains the higher abundance in FW 2 and SVS 1 (Table 2). Moreover, these observations are further supported by linear correlation analysis, which assesses the strength and direction of linear relationships between two variables. This analysis revealed a negative correlation between soil fauna abundance and plant residue decomposition rates during the second season (Figure 2).

The litter bags with less decomposed plant material had more Coleoptera and Dermaptera individuals in both SVS and FW. However, we found a negative relationship between the decomposition rate and the proportion of Coleoptera individuals in both seasons, as well as with Dermaptera, Hymenoptera, and larvae in season 2. On the other hand, Araneae, Oligochaeta, and Chilopoda showed a positive relationship with the decomposition rate. These findings suggest that distinct groups of organisms prefer plant residues at distinct stages of decomposition. Those negatively correlated with the decomposition rate tend to prefer less degraded residue, using it for food, shelter, and predation (Peng et al., 2023). Conversely, the groups positively correlated with the decomposition rate prefer residues that are more advanced in decomposition. This is observed with earthworms, which play a key role in nutrient cycling and microbial community organization (Ma, Song, Liu, Li, & Li, 2022), and spiders, which stay in one place longer due to their predatory nature. These spiders can be indicative of soil quality (Barreta et al., 2011).

Decomposition rates differed significantly among the six environments (Table 2). While SVS 2 had the lowest remaining mass (26.22%) and the highest decomposition constant (k) (0.0301 g^{-1} day^{-1}), FW 2 exhibited the lowest decomposition rate (0.0084 g^{-1} day^{-1}) and a half-life of over 80 days. Conversely, SM 1, SM 2, FW 1, and SVS 1 displayed intermediate rates, with k values of 0.0089, 0.0100, 0.0119, and 0.0120 g^{-1} day^{-1}, respectively. In environments, numerous factors can influence plant residue decomposition rates, including air temperature, rainfall, sand content, soil pH (Cai et al., 2021), and plant material quality (Innangi et al., 2018).

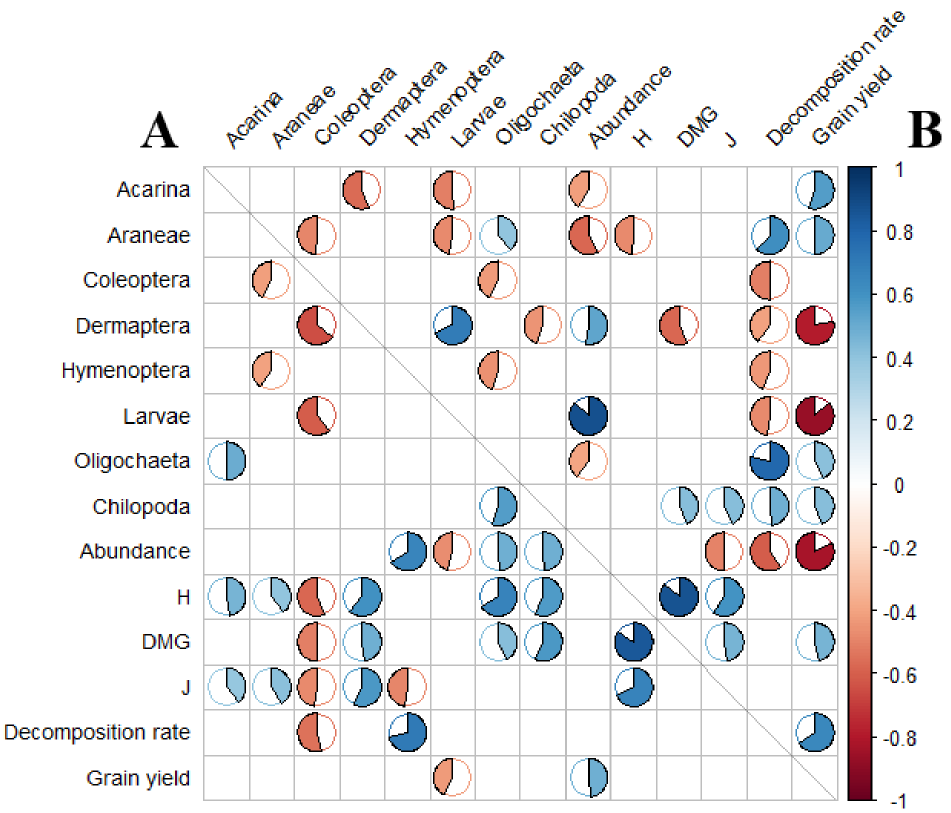

Figure 2. Pearson's correlation analysis between taxonomic groups for diversity indices, decomposition rates, and grain yield across two maize crop seasons in Frederico Westphalen, Santa Maria, and São Vicente do Sul, Rio Grande do Sul State (Southern Brazil). A) Season 1 correlations are shown in the lower diagonal; B) Season 2 correlations are shown in the upper diagonal. H' – Shannon index; D_{Mg} – Margalef index; J' – Pielou index. All displayed correlations are significant at $p \leq 0.05$, as determined by the t-test.

Among the environments studied, SVS 2 exhibited the highest decomposition rate (k value of 0.0301 g^{-1} day^{-1}), a finding supported by Cai et al. (2021). This high decomposition rate in SVS 2 can be attributed to the central pivot irrigation system, which ensured a consistent water supply and prolonged site humidity. Additionally, a significant amount of rainfall (~358 mm) was recorded during the 45-day exposure of the litter bags in the field, marking a 60% increase in volume compared to SVS 1 (Figure 1). This abundant precipitation contributed to a greater decomposition of maize residue. Peña-Peña and Irmler (2016) also observed faster decomposition in the wet season compared to the dry season. Moreover, Santana et al. (2021) suggested that effective irrigation management promotes a higher abundance of edaphic fauna, including macrofauna and mesofauna, which in turn accelerates the decomposition process (Peña-Peña & Irmler, 2016).

Meteorological factors affecting residue decomposition also impact the dynamics of edaphic fauna (Zheng et al., 2020). Variations in soil properties and environmental conditions lead to differences in the composition and activity of edaphic fauna (Zheng et al., 2020). Santana et al. (2021) discovered that soil physical and chemical characteristics, such as macronutrient levels, pH, effective cation exchange capacity, as well as climatic factors like temperature and solar radiation, influence the composition of edaphic fauna. Ji et al. (2022) observed a positive relationship between soil-available P content and plant residue decomposition. Moreover, certain soil microorganisms can make otherwise inaccessible P fractions in the soil soluble, indicating the symbiotic relationship between soil organisms and plants (Basílio et al., 2022).

Our findings reveal a negative correlation between primary taxonomic groups reliant on plant residue for sustenance or shelter and the decomposition rate (Table 3). Conversely, secondary groups like spiders, which serve as predators and engage in longer-term environmental interactions, exhibit a positive correlation with decomposition rate. The presence of food resources may influence the occurrence of these secondary groups. Hence, we can infer that environmental conditions, exposure duration, and the degree of plant residue decay determine the hierarchy of taxonomic groups. Initially, upon deploying the litter bags in the field, we anticipated that organisms feeding on plant material would be attracted first, followed by predatory groups and decomposers. As plant residue continues to decompose, some taxonomic groups may migrate to other environments in search of new food sources.

Table 3. Correlations and canonical cross-loadings estimated between two groups of variables in two harvest seasons.

Variable	Canonical cross-loading	
	Season 1	Season 2
	Group 1	
Acarina	0.410	-0.404
Araneae	0.008	-0.306
Coleoptera	-0.393	0.608
Dermaptera	0.133	0.841
Hymenoptera	0.732	0.277
Larvae	0.016	0.782
Oligochaeta	0.058	-0.428
Chilopoda	-0.089	-0.096
Pielou index	0.007	-0.353
Shannon index	0.155	-0.032
Margalef index	0.162	-0.397
Abundance	0.380	0.830
	Group 2	
Decomposition rate	0.901	-0.767
Grain yield	0.281	-0.952
Canonical correlation (r)	0.904	0.972
p-value	0.019*	0.002*
Variance explained	0.818	0.946

*Significant by the χ^2 test at the 5% probability of error.

In the second season, better water availability led to increased plant productivity and soil fauna activity. This was evident in the positive correlation between taxonomic groups (Acarina, Araneae, Oligochaeta, and Chilopoda) for diversity indices, residue decomposition rates, and grain yield (Table 3). Our findings stress the vital role of water availability in ecosystem dynamics, especially considering the intensified precipitation fluctuations due to global climate change (Pisoni, Pazini, & Seidel, 2023; Siqueira, Nery, & Carfan, 2023). These shifts can worsen water deficits and decrease crop productivity, as seen in our study. Moreover, our results shed light on the symbiotic relationship between plants and soil life, where favourable conditions boost soil fauna diversity, activity, residue decomposition, and plant nutrition. This promotes enhanced plant growth and grain production, supplying more OM to the soil and sustaining a beneficial cycle (Kraft et al., 2021).

Conclusion

In subtropical climates, our study highlights a more significant difference in the relative frequency of individuals among locations than between crop seasons concerning fauna diversity. Across the study areas, four main taxonomic groups account for over 80% of collected individuals, with Araneae and Coleoptera making up more than half of the observed relative frequency alone. The relationship between soil fauna, residue decomposition rates, and maize grain yield varies with the crop's sowing season. Higher yields were observed in areas favouring rapid residue decomposition, leading to increased organism activity and nutrient cycling. In the second season, a direct correlation was found between residue decomposition rates, Margalef and Pielou diversity indices, and taxonomic groups such as Acarina, Araneae, Oligochaeta, and Chilopoda with grain yield.

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