FOREST SYSTEMS, SOIL FAUNA, AND SOIL FEATURES: HOW FIELD MANAGEMENT CHANGE THIS RELATIONSHIP?

SISTEMAS FLORESTAIS, FAUNA DO SOLO E ATRIBUTOS DO SOLO: MUDANÇAS NESSA RELAÇÃO DEPENDEM DO MANEJO?

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Abstract

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The objective of this study was to identify differences in land use systems and forest management on the diversity of soil fauna and Collembola eco-morphotypes, and their relationship with physical-chemical attributes of the soil. Sampling was carried out in Native Forest (NF), *Araucaria* Reforestation (AR) and *Eucalyptus* (ER). In all, 19 taxonomic groups were identified, of which Formicidae and Collembola were the most abundant, in addition to 21 morphotypes of springtail. For TSBF, AR presented the highest abundance and NF the highest values of wealth and diversity of groups. Potassium and magnesium contents, total porosity, pore volume, penetration resistance (Rpen), organic matter, and pH were the environmental variables that contributed to explain the distribution of the soil fauna. In pitfalls traps, ER showed the greatest abundance, NF the greatest richness and AR the greatest diversity. Rpen and soil moisture contributed to explain the distribution of soil fauna. NF provided greater abundance, diversity, and richness of Collembola eco-morphotypes and biopores, macropores, clay, manganese and copper levels affected the community structure. Different forest systems affect the structure of the soil community, showing improvement in biological indicators in the Native Forest areas, *Araucaria*, and *Eucalyptus* Reforestation, under the influence of physical and chemical attributes.
Keywords: Soil quality. Forest management. Soil invertebrates. Multivariate analysis.

Resumo

O objetivo do estudo foi identificar diferenças nos sistemas de usos do solo e manejos florestais sobre a diversidade da fauna do solo e eco-morfotipos de colêmbolos, e suas relações com atributos físico-químicos do solo. Foram realizadas coleta em Floresta Nativa (NF), Reflorestamento de Araucária (AR) e Eucalipto (ER). Foram identificados 19 grupos taxonômicos, sendo Formicidae e Collembola os mais abundantes, além de 21 morfotipos de colêmbolos. Para TSBF, AR apresentou a maior abundância e NF os maiores valores de riqueza e diversidade de grupos. Teores de potássio e magnésio, porosidade total, volume de poros, resistência à penetração (Rpen), matéria orgânica e pH foram as variáveis ambientais que contribuíram para explicar a distribuição da fauna do solo. Nas armadilhas de queda, ER apresentou maior abundância, NF a maior riqueza e AR a maior diversidade. A Rpen e a umidade contribuíram para explicar a distribuição da fauna do solo. A NF proporcionou maior abundância, diversidade e riqueza de eco-morfotipos de colêmbolos e bioporos, macroporos, argila, teores manganês e cobre afetaram a estrutura da comunidade. Diferentes sistemas florestais afetam a estrutura da comunidade edáfica, apresentando melhora de indicadores biológicos nas áreas de Floresta Nativa, Reflorestamento de Araucária e Eucalipto, sob influência de atributos físico e químicos.
Palavras-chave: Qualidade do solo. Manejo florestal. Invertebrados do solo. Análise multivariada.

1. INTRODUCTION

The soil is a shelter to a wide range of organisms that play important roles in providing ecosystem services, such as fiber, energy, and food production (Anikwe; Ife, 2023). Intending society to fully enjoy the result of these services, different processes – from nutrient cycling to maintenance of the food chain, need to take place in the soil. The soil fauna, keeping in constant balance to the environmental conditions, carries out and mediates several activities that result in these processes (Frouz *et al*., 2013; Pompeo *et al*., 2016a). However, anthropic activities that entail intensive use and/or inadequate soil management can change the composition of these communities, causing environmental imbalances and favoring species with greater adaptation

(Rosa *et al*., 2015), besides interfering in processes of biogeochemical cycles, compromising the quality and functional capacity of the soil (Araújo *et al.*, 2010; Paz-Lima *et al.*, 2016).

The exploitation of forests is an economic activity of global importance, especially in the Americas: Brazil is currently one of the main producers and exporters of forest products, with the south of the country being the main producing region (36.1%) (IBGE, 2017). It is also an activity with a crucial ecological role, as it helps to regulate the hydrological cycle, carbon sequestration, and pollutant filtering, as well as sheltering an enormous soil biodiversity (França *et al.*, 2016; Oliveira Filho *et al.*, 2018). However, changes in forest composition from a native environment to the implantation of a planted forest can result in imbalances and change in the community below ground (Korboulewsky; Perez; Chauvat, 2016). Thus, it is necessary, in addition to monitoring the exploited plant species, to establish an analysis of the attributes and quality of the soil, ensuring that changes caused by use do not lead to a definitive loss of faunal groups.

Soil quality can be defined as the capacity of the soil to function within the limits of an ecosystem, sustaining biological production and maintaining the quality of the environment through the interaction between physical, chemical, and mainly biological properties (Huera-Lucero *et al*., 2020). Changes in these interactions may reflect on the ability to function, and its assessment is used as an indicator of soil quality (Araújo *et al.*, 2012).

The index of diversity, abundance and richness of taxonomic faunal groups can be used together with multivariate statistics as a data analysis tool (Baretta; Brown; Cardoso, 2010; Pompeo *et al*., 2016b; Rosa *et al*., 2015) to contribute to the assessment of soil quality, which allows for a more robust understanding of ecological interactions and the factors that affect them in forest or agricultural environments (Pereira *et al.*, 2020; 2021; Kraft *et al*., 2021). Other tools can also be used, such as the use of key groups in the community, for example, springtails (Collembola), which significantly influence various processes in the soil due to their high and diverse activity and food preference (Oliveira Filho; Baretta, 2016). As they respond sensitively to changes in the environment according to land use and management, they are considered bioindicators (Santos *et al.*, 2018; Machado *et al*., 2019; Ortiz *et al*., 2019).

Despite the high relevance, practicality and widespread use of diversity index based on taxonomic identification (Shannon richness and diversity) in the assessment of soil biological quality, this method does not consider the functional variability between species of the same group, which is extremely high for the springtail community (Vandewalle *et al.*, 2010). In this sense, the approach of eco-morphological characteristics (traits) proves to be an important tool in ecological studies, as the evaluation of these characteristics can help to understand both the effects of environmental changes on the distribution of communities (Kaustuv; Jablonski; Valentine, 2001; Berg *et al*., 2010; Diamond *et al*., 2011), and the effects of the composition of soil communities in the provision of ecosystem services (Luck *et al.*, 2012; Brittain *et al*., 2013; Deraison *et al*., 2015).

The use of springtail eco-morphological traits has recently gained prominence and has been used to assess changes in these communities related to environmental changes. Makkonen *et al*. (2011) noticed that there are significant differences in the size of organisms related to environmental humidity, which were also observed by Winck *et al*. (2017) for drought resistance. Abgrall *et al*. (2017) concluded that the characteristics of body size and the presence of setae and scales are related to habitat preference: The type of vegetation cover, for example, also had effects on the color and antennae of springtails. Thus, adopting an integrated taxonomic approach to trait evaluation allows the identification of variations in the structure and composition of the

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community, evaluating responses of these organisms to environmental variations (Parisi *et al*., 2005; Santorufo *et al*., 2015; Silva *et al*., 2016).

The environmental services provided by soil communities are essential for the maintenance of forest systems. Despite, the impact of changes and management in forest areas, as well as their correlation with chemical, physical and biological attributes are still poorly understood. Thus, the objectives of this study were; i) identify whether forest systems with different degrees of intervention affect community composition and soil fauna diversity; ii) verify which chemical and physical variables contribute to explain the fauna distribution in forest systems, and; iii) to evaluate the morphological diversity of springtails (Collembola) as well as their relationships with chemical and physical attributes in the forest systems of *Eucalyptus dunnii* reforestation, *Araucaria angustifolia* reforestation and Native Forest belonging to the Atlantic Forest biome in the Catarinense Plateau, Brazil.

2. MATERIAL AND METHODS

2.1 Characterization of study areas

The study was carried out in in the municipality of Campo Belo do Sul, Santa Catarina, Brazil, with an evaluation of three forest systems of area and location illustrated in Table 1 and with the following management characteristics:

1) *Eucalyptus* Reforestation (*Eucalyptus dunnii*) (ER): 2.5 × 2.5 m spacing, with four prunings between the first and fourth year of planting and four scheduled thinning, between the fifth and sixteenth year. Recently (2016, age 12), the third thinning was made; 2) *Araucaria* Reforestation (*Araucaria angustifolia*) (AR): a thinning was made in 2015, with an intensity of 40% of the density. 20% of thinning was systematic, in the fifth row, and 20% selective from the top, benefiting the development of dominant trees; 3) Native Forest (NF): belonging to the Atlantic Forest biome in the Mixed Ombrophilous Forest (FOM) phyto physiognomy, the NF area is located within the Private Natural Heritage Reserve – Emilio Einsfeld Filho (RPPN – Emilio Einsfeld Filho).

Table 1. Characteristics and history of use in *Eucalyptus* Reforestation (ER), *Araucaria* Reforestation (AR), and Native Forest (NF) areas in Campo Belo do Sul, SC.

System	Area (ha)	Coordenates	Age	Historyc
ER	60	S27°58’20,8” W50°48’40,6”	12	Crop/pasture
AR	10	S27°58’20,8” W50°48’44,4”	19	Crop/pasture
NF	6.328,6	S27°57’47,5” W50°49’58,1”	-	RPPN Emilio Einsfeld Filho

Source: The authors, 2022.

The climate region is humid subtropical, with Four well-defined seasons and well-distributed rainfall throughout the year. There are negative temperatures in winter and summer they can reach 30°C. It is partially classified as *Cfb* (subtropical, without dry season and warmest month temperature < 22°C) and *Cfa* (subtropical, without the dry season and warmest month temperature > 22°C) by the Köppen method. According to a survey carried out by Guedes (2005), based on *Sistema Brasileiro de Classificação de Solos*, the most representative soil of the place is the *Nitossolo Háplico*, with *Cambissolo* and *Neossolo Litólico* associations in the steeper areas. The physical-chemical characterization of the areas can be seen in Table 2 below.

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Table 2. Physical-chemical characteristics of the *Eucalyptus* Reforestation (ER), *Araucaria* Reforestation (AR), and Native Forest (NF) areas in Campo Belo do Sul, SC.

Variables	**Forest system**		
	ER	**AR**	**NF**
pH H_20	5.80 ± 0.79	5.00 ± 0..10	4.60 ± 0.10
P (mg dm^{-3})	5.63 ± 1.16	4.83 ± 0.85	6.00 ± 1.31
K (mg dm^{-3})	36.00 ± 8.00	61.33 ± 20.13	144.00 ± 12.00
OM (%)	5.43 ± 0.60	5.00 ± 0.80	4.73 ± 0.50
Al ($cmol_c$ dm^{-3})	0.40 ± 0.69	2.63 ± 0.25	8.37 ± 1.10
Ca ($cmol_c$ dm^{-3})	6.90 ± 2.17	4.17 ± 0.25	1.53 ± 0.21
Mg ($cmol_c$ dm^{-3})	4.20 ± 0.92	2.80 ± 0.46	1.43 ± 0.15
Cu (mg dm^{-3})	1.77 ± 0.92	3.66 ± 0.71	5.67 ± 0.57
Mn (mg dm^{-3})	7.33 ± 4.75	18.40 ± 4.03	27.93 ± 7.04
H+Al ($cmol_c$ dm^{-3})	4.99 ± 2.98	8.81 ± 2.75	14.64 ± 1.84
$CEC_{pH\ 7.0}$	16.18 ± 0.30	15.93 ± 3.03	17.98 ± 2.11
PT (m^3 m^{-3})	0.63 ± 0.06	0.69 ± 0.04	0.75 ± 0.06
Bio (m^3 m^{-3})	0.08 ± 0.03	0.09 ± 0.02	0.08 ± 0.03
Mic (m^3 m^{-3})	0.02 ± 0.01	0.03 ± 0.01	0.03 ± 0.01
Mac (m^3 m^{-3})	0.10 ± 0.05	0.06 ± 0.02	0.13 ± 0.06
PV (g cm^{-3})	0.37 ± 0.06	0.31 ± 0.04	0.25 ± 0.06
Rpen (Kpa)	1217.18 ± 269.52	2179.08 ± 222.602	1467.96 ± 177.63
Moisture (%)	45.14 ± 3.80	26.30 ± 2.30	35.74 ± 4.50

pH: potential hydrogen; P: phosphorus; K: potassium; MO: organic matter; Al: aluminum; Ca: calcium; Mg: magnesium; H+Al: potential acidity; CEC pH 7.0: cation exchange capacity by pH 7.0; Bio: Biopores; Mic: Micropores; Mac: Macropores; PV: Volume of solid particles; Rpen: resistance to penetration; ± standard deviation of the mean.

Source: The authors, 2022.

2.2 Sample design

In each forest system, samples were collected to determine the physical and chemical attributes of the soil, and the diversity of soil mesofauna and macrofauna, in September 2016. Soil and fauna sampling were done using a sampling grid of 3 × 3 points, with a space of 30 m between each point, respecting 20 m of the border, a total of 9 points, and a total area of 1 ha in each system was evaluated (Figure 1).

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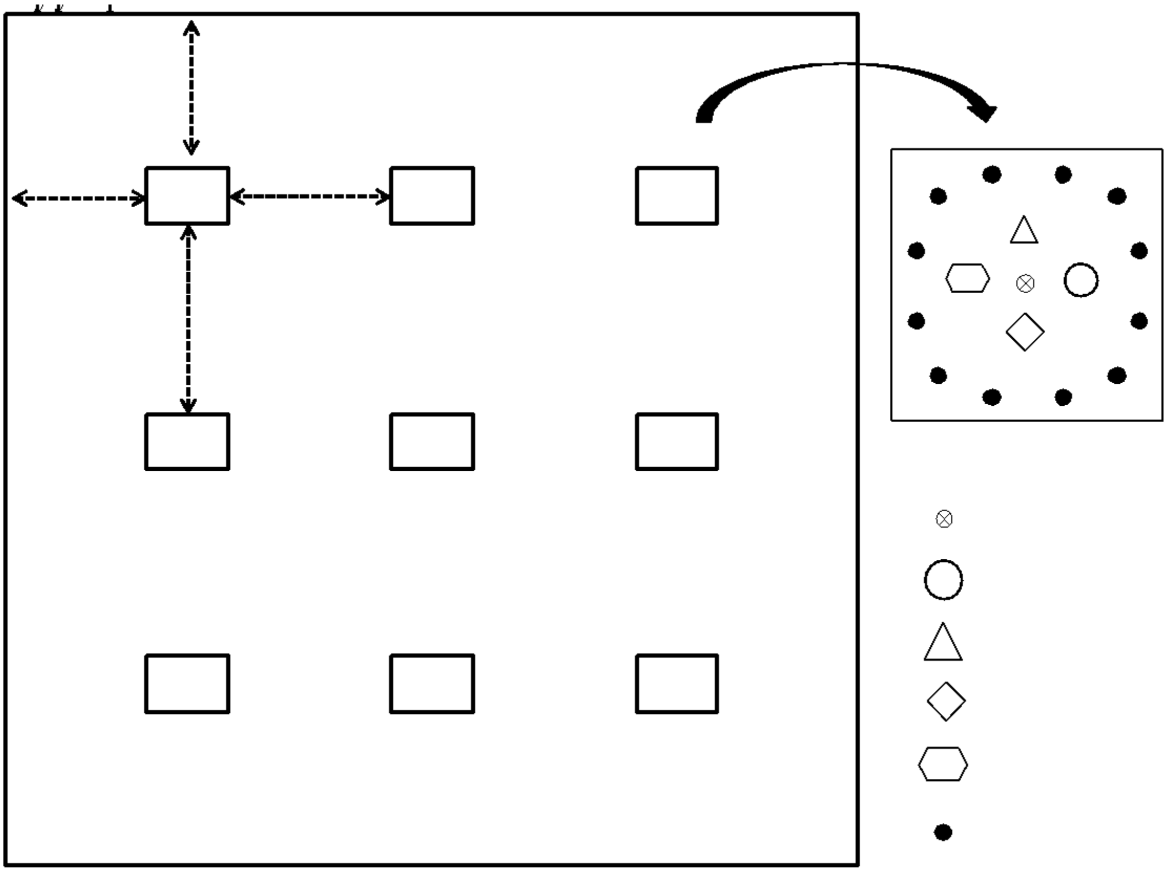
Figure 1. Sampling scheme to determine the physical and chemical attributes of the soil and the soil meso and macrofauna.



Source: Adapted from Rosa *et al.* (2015); Oliveira Filho *et al.* (2016).

2.3 Collected variables

Soil macrofauna was sampled using the Tropical Soil Biology and Fertility (TSBF) method described by Anderson and Ingran (1993), which consists of collecting soil monoliths 25 × 25 cm wide and 20 cm deep, with the aid of a marker made of galvanized iron sheets. The collected soil monoliths were placed in plastic bags and taken to the Soil Ecology laboratory at UDESC/CAV, Lages, SC, where manual screening was performed. Organisms visible to the naked eye were preserved in plastic containers containing 70% alcohol. Subsequently, with the aid of a stereo microscope (40x) the organisms were identified at levels of Class / Subclass / Order / Epifamily (Ruggiero *et al*., 2015).

Pitfall-traps were used to sample soil mesofauna, which consists of installing cylindrical bottles with an opening of 8 cm in diameter and a volumetric capacity of 500 mL, containing 200 mL of 0.5% detergent solution (v/v) and buried with its open end level with the soil surface (Baretta *et al*., 2014). The containers were kept in the field for three days (72 h) and then taken to the laboratory, where they were washed in 0.100 mm mesh sieves and the samples were preserved in plastic containers with lids containing 70% alcohol. They were later identified at the order level, in the same way as for the TSBF method.

To sampling the springtails, soil samples with preserved structure (cores) were used, collected with the aid of stainless-steel rings (5 × 5 cm) following the ISO 23611-2 (2006)

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methodology. The samples were placed in a cooler and transported to the laboratory for extraction during seven days in Berlese-Tullgren funnels (Aquino *et al.*, 2006). The samples were washed in a sieve (150 µm) and stored in 70% ethyl alcohol for later identification. The identification and counting of springtails were performed with the aid of a stereoscopic tool (40x). Morphotyping (analysis of morphological characteristics) was based on the eco-morphological index (EMI) (Parisi, 2001; Parisi *et al*., 2005), separating the organisms according to their degree of adaptation to the soil, through its morphological characteristics (Oliveira Filho *et al*., 2016).

Sampling to determine the chemical attributes of the soil analyzed according to Tedesco *et al*. (1995), was carried out around each collection point. Twelve subsamples (0 - 10 cm) were collected with the aid of a Dutch auger, which were homogenized and formed a sample composed of a point (Fig. 1). pH in water, P, K, Al^{3+}, Ca^{2+}, Mg^{2+}, MO, H+Al, $CTC_{pH\ 7.0}$, and the sum of bases were determined. The physical attributes determined were: I) total porosity, biopores, macropores and micropores (Oliveira, 1968); II) resistance to penetration [Rpen in Kg pascal (Kpa)], determined in the field using a digital penetrometer and; III) volumetric soil moisture content (moisture), determined by using a portable Hidrofarm-type meter.

2.4 Statistical analysis

From the abundance data of fauna organisms, edaphic groups, and springtail eco-morphotypes, the Shannon-Wiener (H') diversity index was calculated, aiming to verify how different forest systems affect the diversity of these organisms. The results of soil fauna abundance and springtail eco-morphotypes were also submitted to multivariate analysis of Directed Correspondence Analysis (ACD), followed by Principal Component Analysis (PCA).

To investigate relationships between environmental variables, soil fauna, and springtail eco-morphotypes, the data were submitted to Redundancy Analysis (RA). Using the Variation Inflation Factor (FIV) and forward selection operations, using successive Redundancy Analysis (AR) based on permutations by Monte-Carlo test (n = 9999) for each type of variable, removing those that presented collinearity and selecting those that best explained the variation in the data.

The method allowed the choice of a minimum set of significant physical and chemical variables to explain the variation of the soil fauna and springtail eco-morphotypes for each evaluated area. Significant variables of the ARs were later used in the PCAs as passive explanatory environmental variables for the changes observed in the faunal groups. The data of richness and abundance of springtail eco-morphotypes were submitted to analyses of normality and homogeneity, and then the means were compared by the LSDtest ($p < 0.05$) between forest systems.

3. RESULTS and DISCUSSION

3. 1 Results

3.1.1 General fauna

A total of 1289 individuals were found using the TBSF method, while 1698 were found using pitfall traps, distributed in 19 taxonomic groups (Table 3). In the TSBF Formicidae (43.29%), Isoptera (18.77%), and Coleoptera larvae (6.28%) were the most abundant groups, while Collembola (60.84%), Formicidae (10.95%), and Araneae (10.36%) dominated in pitfall traps. Regardless of the method and system of land use Formicidae was the most representative

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group (24.90%). For the TSBF method, the AR area had the highest abundance of individuals, while the NF area had the highest Shannon-Wiener (H') richness and diversity when compared to the other areas. In pitfall traps, ER presented greater abundance, NF greater richness, and AR the highest values of the H' index.

Table 3. Abundance values of the taxonomic groups of the soil fauna sampled by the TSBF method and pitfall traps, Shannon-Wiener (H') diversity, and Pielou (J) Equability indexes, in *Eucalyptus* Reforestation (ER), *Araucaria* Reforestation (AR), and Native Forest (NF) systems.

	TSBF			Pitfall traps		
Groups	ER	AR	NF	ER	AR	NF
Acari	4	2	8	30	4	7
Araneae	16	20	19	120	22	34
Blattodea	3	1	4	0	1	0
Chilopoda	16	2	3	0	0	1
Coleoptera	5	12	32	13	35	44
Collembola	0	0	0	677	124	232
Dermaptera	4	1	3	0	1	0
Diplopoda	0	2	24	2	0	1
Diplura	0	0	1	0	0	0
Enchytraeidae	27	31	8	0	0	0
Formicidae	204	247	107	105	21	60
Hemiptera	8	2	0	0	1	1
Hymenoptera	1	0	0	5	16	1
Isopoda	0	2	50	0	0	0
Isoptera	0	101	141	3	0	0
Larvae Coleoptera	17	26	38	2	9	6
Mollusca	0	3	2	0	0	1
Oligochaeta	14	3	2	0	0	0
Orthoptera	0	0	1	66	2	6
Outros[1]	9	36	26	4	17	22
Thysanoptera	1	0	0	1	0	1
Abundance	329	491	469	1028	253	417
Richness	13	15	16	11	11	13
H'	1.44	1.46	1.98	1.17	1.54	1.34

[1]Unidentified individuals

Source: The authors, 2022.

For the TSBF method, the total variability of the abundance data was explained in 28.7% by the principal component 1 (PC1) and 23.9% by the principal component 2 (PC2), totaling 52.6% (Figure 2). The groups of soil invertebrates were more related to the NF and AR areas, while ER was closer to the center of the order, not being strongly associated with any of the groups or with the explanatory environmental variables.

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Figure 2. Principal component analysis (ACP) for macrofauna groups sampled by the TSBF methodology and land use systems. Abbreviations: *Eucalyptus* Reforestation (ER); *Araucaria* Reforestation (AR); Native Forest (NF); Coleoptera Larva (Col larva); Potassium (K); total porosity (TP); solid particle volume (PV); Hydrogen potential (pH); Magnesium (Mg); Penetration resistance (Rpen); Organic matter (OM).

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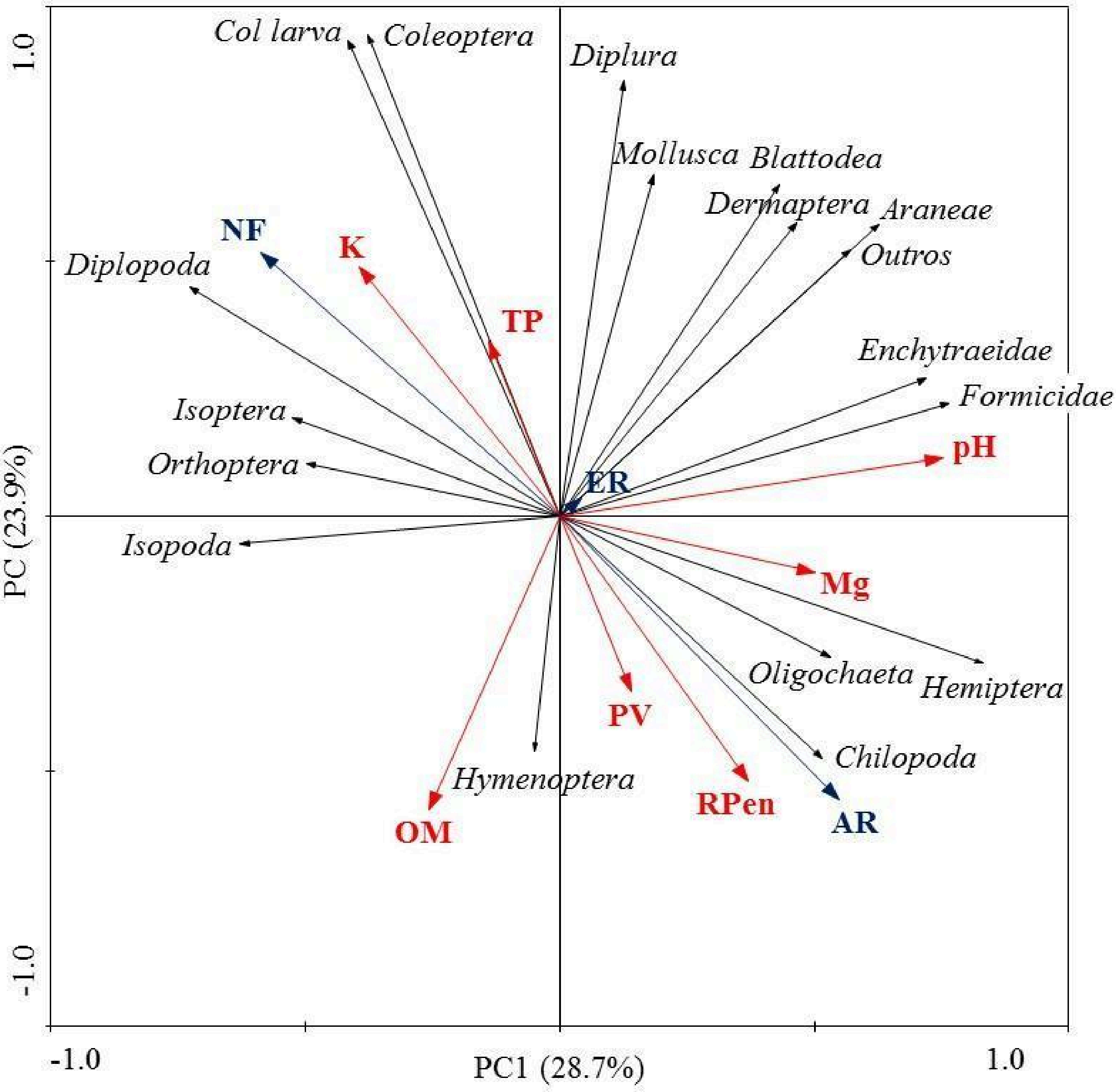

Source: The authors, 2022.

The groups Oligochaeta, Hemiptera, Chilopoda and Hymenoptera became more associated with AR, while the groups most associated with NF were Isopoda, Isoptera, Orthoptera, Diplopoda, Coleoptera larva, and Coleoptera. Regarding to the environmental variables, Potassium (K) and total porosity (PT) were the ones that most contributed to explain the distribution of groups in the NF area. Magnesium (Mg), penetration resistance (RPen) and solid particle volume (VP) contributed to explain the distribution in the AR area.

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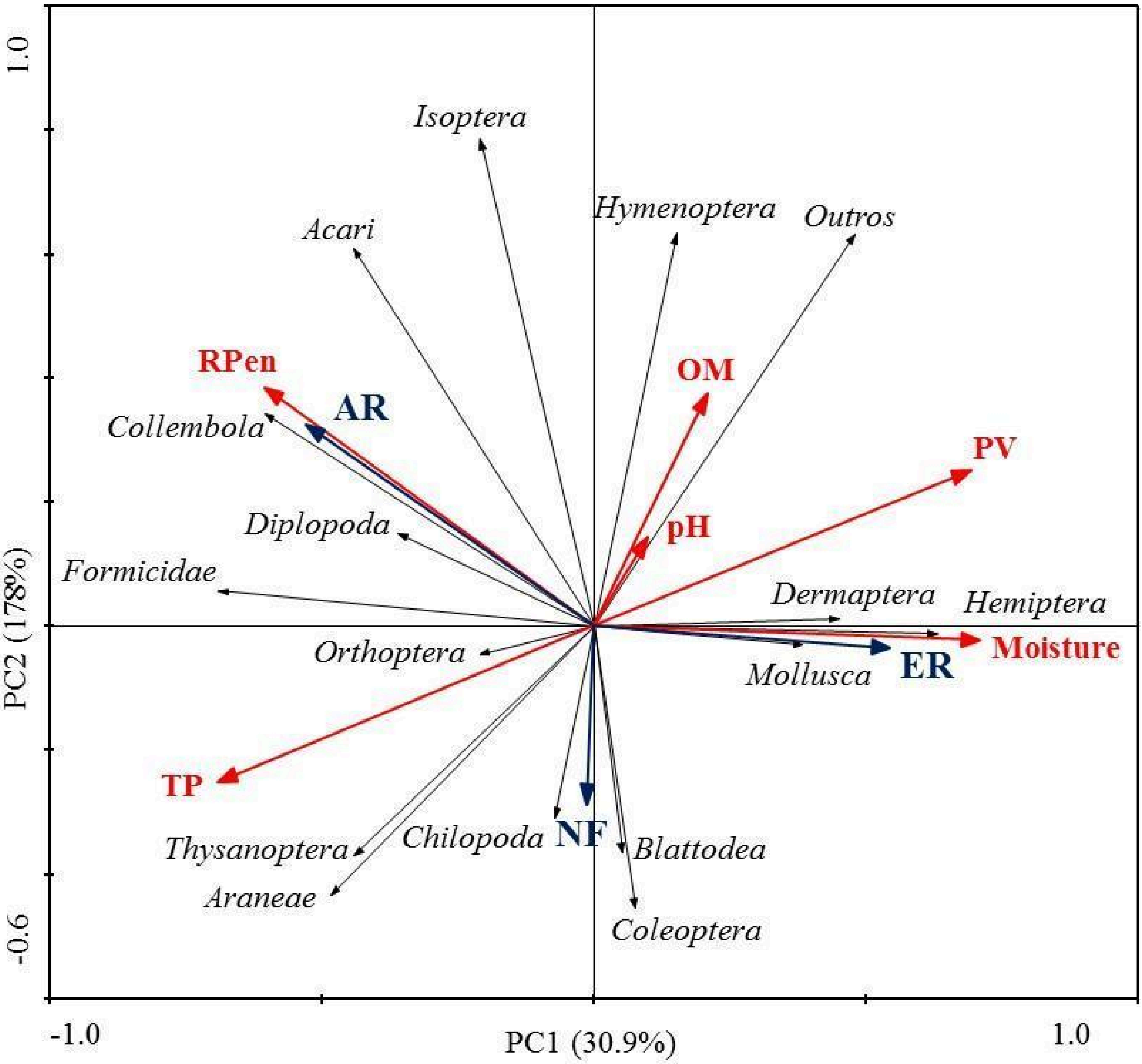
For pitfall traps, the PCA (Figure 3) considering the total abundances of the groups demonstrated a distinction between land uses, through the relationship between the PC1 and the PC2. PC1 explained 30.9% and PC2 explained 17.2%, totaling 48.7% of the data variability.

Figure 3. Principal component analysis (PCA) for groups of soil fauna sampled by pitfall traps and land use systems in Campo Belo do Sul, SC. Abbreviations: *Eucalyptus* Reforestation (ER); *Araucaria* Reforestation (AR); Native Forest (NF); total porosity (TP); Organic matter (OM); Moisture; Hydrogen potential (pH); Penetration resistance (RPen); Solid particle volume (PV).



Source: The authors, 2022.

The Collembola, Formicidae, Diplopoda and Acari groups were more associated with the AR area, while for NF the groups were Chilopoda, Blattodea and Coleoptera and for ER Mollusca, Dermaptera and Hemiptera. Regarding the environmental variables, RPen had a greater

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contribution to explain the distribution of groups in AR and Soil Moisture in ER. The NF did not have the distribution of groups strongly associated with any environmental variable.

3.1.2 Collembola

Twenty-one different springtail morphotypes were identified in the evaluated forest systems. Of these, seven belong to the Edaphic eco-morphological group (Ed), seven to the Hemiedaphic group (H) and seven to the Epigeic (Ep). The most representative morphotypes were Ed8 (17%), Ed1 (9%) and H16 (9%). Among the areas evaluated, NF had the greatest abundance, group richness and H' index, followed by ER and AR (Table 4).

Table 4. Density values (ind. m^{-2}) of springtail morphotypes sampled by the "cores" sampling method, Shannon-Wiener (H') diversity indexes, Pielou (J) Equability indexes and morphotype richness, in *Eucalyptus* Reforestation (ER), *Araucaria* Reforestation (AR), and Native Forest (NF) systems.

	Forest Systems		
Morphotypes	**ER**	**AR**	**NF**
Ed1	1019	0	509
Ed3	509	0	0
Ed6	0	0	509
Ed8	509	1528	1019
Ed10	0	0	1019
Ed12	0	0	1019
Ed20	0	0	509
H4	509	0	0
H12	0	509	0
H14	0	509	0
H16	0	0	1528
H30	509	0	0
H50	0	0	509
H54	0	0	509
Ep3	0	509	0
Ep9	509	0	509
Ep15	509	0	0
Ep17	509	0	509
Ep21	509	0	509
Ep22	0	0	509
Ep24	0	0	509
Abundance	5091	3055	9675
Richness	9	4	14
H'	2.16	1.24	2.55

Source: The authors, 2022.

Density and richness of springtails according to the eco-morphological groups are presented in Table 5. The composition of the springtail community varied according to the

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eco-morphological groups, showing a significant difference both in the abundance and in the richness of Edaphic morphotypes in areas of NF being superior to AR but not differing from ER.

Table 5. Springtail density (number of individuals per square meter) and richness (number of morphotypes per forest system) according to eco-morphological groups in *Eucalyptus* Reforestation (ER), *Araucaria* Reforestation (AR), and Native Forest (NF) systems.

	Forest Systems				
	ER	**AR**	**NF**	**F**	**p**
			Density		
Epigeic	509[ns]	509	2547	0.518	0.60
Hemiedaphic	1019[ns]	1019	2037	0.652	0.52
Edaphic	1528 ab	509 b	4584 a	5.227	0.01
			Richness		
Epigeic	1 [ns]	1	5	0.518	0.60
Hemiedaphic	2 ab	2 b	4 a	6.648	0.016
Edaphic	3 ab	1 b	9 a	6.641	0.005

[ns] Not significative. Different letters on the line indicate statistical difference according to LSD test (p < 0,05).
Source: The authors, 2022.

For total abundances of Collembola morphotypes, PCA demonstrated a distinction between land uses by the relationship between the PC1 and the PC2. PC1 explained 38.5% and PC2 explained 21.2%, totaling 59.7% of the data variability (Figure 4). Native Forest showed a greater richness of associated morphotypes, namely: Ed10, Ed12, Ed6, Ed20, Ep24, Ep22, Ep17, and Ep21, mainly influenced by the contents of Cu^{+2} and Mn^{+2} in the areas. While on the other side of the order were the areas of ER and AR, which showed a strong association with the morphotypes H12, H14, H30, H4, and Ep3. Therefore, verifying the predominance of Hemiedaphic morphotypes in these areas were influenced mainly by the clay content and amount of biopores.

Figure 4. Principal component analysis (PCA) for Collembola morphotypes and land use systems in Campo Belo do Sul, SC. Abbreviations: *Eucalyptus* Reforestation (ER); *Araucaria* Reforestation (AR); Native Forest (NF); Macropores (Mac); Biopores (Bio); Manganese (Mn); Copper (Cu); Clay content; Edaphic (Ed); Hemiedaphic (H); and Epigeic (Ep).

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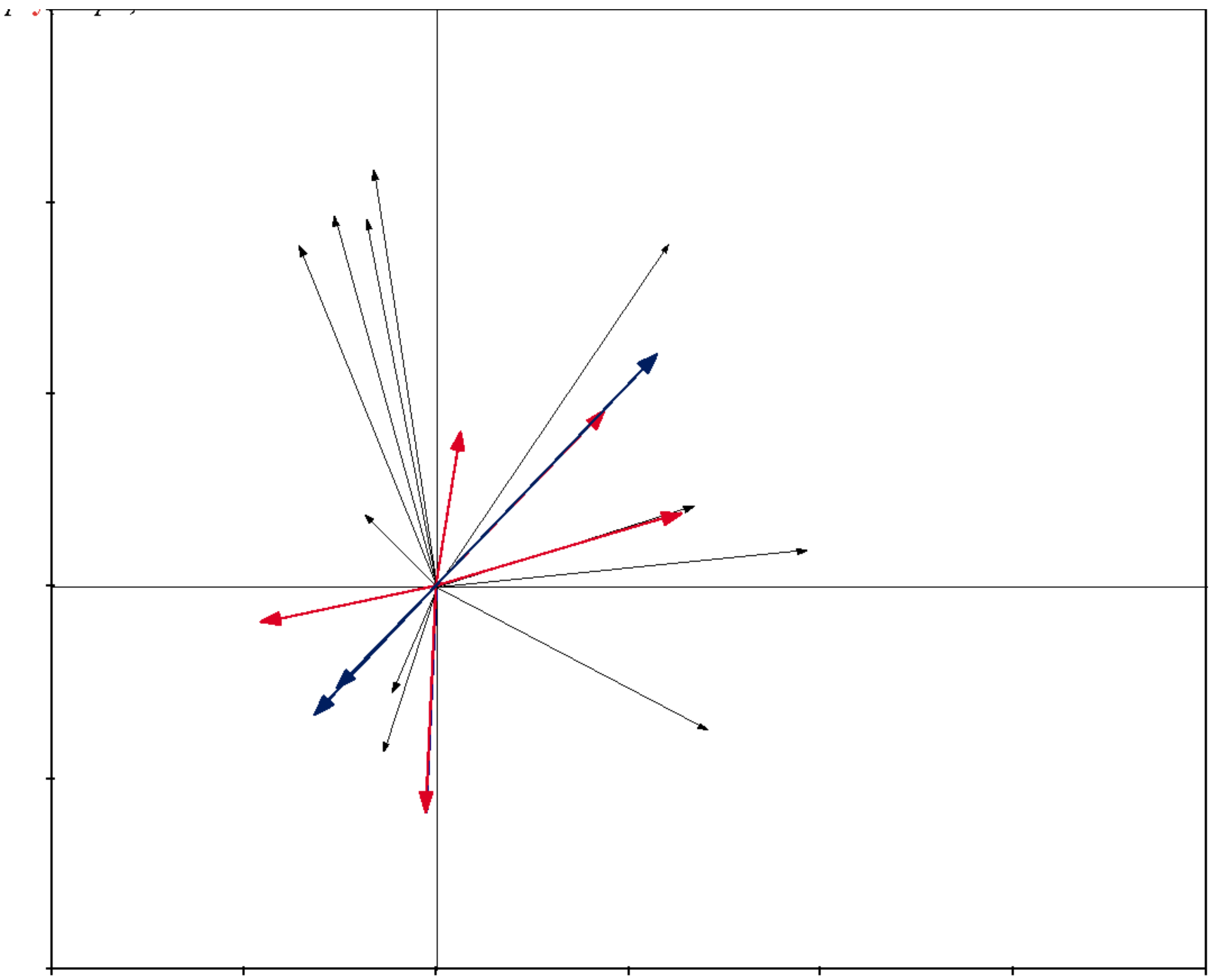

Source: The authors, 2022.

3.2. Discussion

Forest systems affected the composition of the soil community. For the AR area, the Formicidae group was one of the most representative. Considered abundant in most terrestrial ecosystems, they can help in the processes of infiltration and distribution of water into the soil (Viles; Goudie; Goudie, 2021). However, they are also considered pests for forest crops, especially those planted such as pine and *Eucalyptus*, with the use of chemical products for control since before the transposition of seedlings (Cavigliasso *et al.*, 2023; Scherf *et al.*, 2022), which could be correlated with the low incidence of this group in ER. Also, for this area, there was a lower occurrence in relation to ER, of groups such as Oligochaeta and Chilopoda (TSBF) belonging to soil macrofauna. Oligochaetas also interfere with water fluxes and gas exchange in the soil, construction of macro and biopores, in addition to increasing the stability of soil aggregates (D'hose *et al.*, 2018). Chilopodas, on the other hand, are generalist predators, they can persist in converted ecosystems due to their ability to adapt and change to alternative prey populations and are often related as an antagonistic predator to pests (Klarner *et al.*, 2017).

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A measure that can be used to indicate the physical quality of the soil is the resistance of the soil to penetration (Jiang *et al*., 2020). In the present study, being directly opposite to porosity showed higher values in AR (Table 2) and demonstrated a correlation with Oligochaeta. Although earthworms are known for their digging habit, depending on the species and their interactions, it can make the soil more compact or loose (Sharma; Tomar; Chakraborty, 2017). Currently, this physical property has been widely used, as it demonstrates advantages such as easy and quick measurement and is directly associated with plant growth. The AR was the area that presented the lowest soil moisture values. According to Lira *et al*. (2016), these two soil properties are related, as soil moisture inversely influences penetration resistance.

Mites and springtails had great expression in AR. Used as bioindicators of soil quality, showing rapid population decline when soil changes occur (Merlim *et al*., 2005; Griesang *et al.*, 2016). Even though the *A. angustifolia* reforestation area is an environment of anthropogenic changes (management and input of machinery) it presented an association with these groups. It is believed, therefore, that even being a monoculture, the fact of being a native species provided better conditions for these organisms. According to Baretta *et al.* (2008), the native *Araucaria* forest provides better soil conditions for the development of greater diversity of springtail families, compared to areas that had greater human interference. Another point that can contribute to these soil groups is the condition of lower soil moisture when compared to other forest systems (Figure 3). Changes in soil moisture can have great importance on the soil community (Jansson; Hofmockel, 2020), however, the responses on abundance and richness of mite and springtail species can be different for the same condition (Kardol *et al*., 2011).

For ER, a low correlation with soil groups was observed, especially with the use of the TSBF method. For pitfall traps, only the Hemiptera and Mollusca groups were highlighted, often cited as pests in several forest crops Cao *et al*. (2018), observed a network of antagonistic relationships between Hemiptera-Plant in forest under subtropical climatic conditions. A determining factor for the presence of these two groups in the area may be the high soil moisture, which is the environmental variable that best explained the distribution of fauna in this system. The Mollusca group is influenced by certain soil and environmental characteristics, including high humidity (Ganguly *et al*., 2020). This variable is among the most important environmental selection factors and population dynamics of the soil fauna (Kuoppamäki; Setälä; Hagner, *et al.*, 2021). According to the authors, Mollusca have a permeable epidermis and spend water in many physiological and ecological processes, being, therefore, more abundance and diverse in forest systems rich in this resource

The lower richness of groups was also reflected in the diversity index (ER < H' in relation to AR and NF), which could be expected from a more intense management with the use of agricultural inputs, such as pesticides, especially in the pre-planting and initial months.

As could be expected, the NF area showed a strong correlation with several groups of soil fauna, mainly those considered ecosystem engineers, represented by Isoptera, Isopoda, Diplopoda, Coleoptera larva and Coleoptera. These data corroborate the work by Rosa *et al.* (2015), who, when evaluating the soil macrofauna in different land use systems (native forest, pine reforestation and native grassland) in southern Brazil, also found Coleoptera and Diplopoda among the orders of highest correlation with NF.

Due to their ability to create specific structures for their movement within the soil (Velásquez *et al*., 2010), they can modify the chemical and physical characteristics of the soil (Korasaki *et al*., 2013). The high correlation between these groups and soil porosity, which influences aeration, water/solutes/gas/heat transfer, resistance to penetration, and root branching,

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in addition to the development of microorganisms (Costa *et al*., 2016) highlights this information. Sperandio *et al*. (2013) also observed higher porosity values for the native forest area when compared to pasture and coffee areas.

In areas of native forest there is greater leaf fall and diversity of plant material present in the litter when compared to planted forests. In addition to this, without disturbing the environment, a more efficient decomposition of the organic material can take place. This process results in the increase of nutrients in the soil and its availability to plants (Hoffland *et al*., 2020). This balance and availability of material may contribute to justify the greater amount of potassium (K) and its contribution to the distribution of faunal groups in the NF area, especially regarding the association of beetles and beetle larvae (Figure 2) with the area. Dunxion *et al*. (1999) reported that Coleoptera of the Staphylinidae and Scarabeidae families, for example, are related to soils with higher concentrations of potassium, phosphorus, and organic material.

Corroborating to the literature, the work by Rosa *et al.* (2015) resulted in higher H' diversity values for native forest compared to other evaluated land uses. A greater diversity for NF, regardless of the collection method, was observed by Pompeo *et al*. (2016b), who assessed the soil fauna also in southern Brazil. In the present work, NF presented a higher H' for the TSBF collection method, but not for the pitfall traps. These findings suggest that the TSBF collection method is more effective in capturing the diversity of soil fauna in native forests compared to pitfall traps. The discrepancy in results between collection methods could be due to differences in the types of organisms captured or the sampling efficiency of each method. Further research is needed to determine the underlying factors influencing these variations in diversity measurements for native forests.

3.2.1 Relationship between springtail morphological diversity and soil chemical and physical attributes

The evaluation of springtail morphological diversity in the different forest systems highlighted the importance of NF areas for the conservation of the diversity of this group. Not only, concerning density, when observed by eco-morphological groups, NF stood out with the largest amount of Edaphic springtail, thus reflecting a better soil condition in depth. This is probably due to the lack of entry of machines, which does not occur in other areas, combined with greater plant diversity. The improvement in soil quality in NF can also be observed a greater richness of the Epigeic and Hemiedaphic eco-morphological groups. According to Oliveira Filho *et al*. (2016), morphotype richness is a more refined tool to indicate differences between systems, Hemiedaphic and Edaphic morphotypes indicated differences between systems, although this difference was not found in Epigeic morphotypes in the univariate analysis (Table 4).

The use of multivariate analysis tools such as PCA proved to be important to emphasize the relationship of forest systems to springtail eco-morphotypes, which again highlighted the less favorable conditions of the AR and ER areas for Edaphic morphotypes in relation to NF. The data obtained by Ortiz *et al*. (2019), corroborate what was obtained in the present work. The authors evaluated the effect of land use intensity on the diversity of springtail morphotypes and their relationship with chemical and physical soil variables, also showing the predominance of morphotypes such as Ep21, Ep24 and Ed6 in native forest. In the present study, these morphotypes were mainly affected by organic matter content, average aggregate size and soil moisture (organisms sampled by pitfall traps).

Among the environmental variables that influenced the distribution of springtail eco-morphotypes, biopores and macropores stood out, structures used as shelters by these

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organisms, as well as to move within the soil (Santos *et al*., 2018). This is also demonstrated by Oliveira Filho and Baretta (2016), where the reduction of soil porosity can promote changes in the springtail community. Corroborating the large amount of Edaphic and Hemiedaphic springtails related to these variables in the present study.

Soil clay contents were correlated to Hemiedaphic springtails, which in turn have high vertical activity in the soil. The variable in question has a positive relationship with the soil water retention capacity (Gao *et al.*, 2021), due to greater adsorption of soil particles and high presence of micropores (responsible for water retention). This greater availability of moisture in the soil is important for soil fauna such as springtails (Oliveira Filho *et al*., 2016; Machado *et al*., 2019; Ortiz *et al*., 2019), especially for eco-morphotypes that have wide mobility vertical.

5. FINAL CONSIDERATIONS

Our results highlight that forest systems planted with *Araucaria* make it possible to maintain a great diversity of groups of soil fauna, as well as high abundances, possibly because it is a native species and adaptation to regional ecological dynamics. On the other hand, *Eucalyptus* plantations proved inadequate in supporting soil fauna biodiversity compared to both *Araucaria* and native forests. Multivariate analysis revealed significant environmental influences on soil fauna distribution, including pH, organic matter content, total porosity, pore volume, penetration resistance, and K and Mg contents. Through multivariate analysis, the distribution of soil fauna was found to be significantly influenced by environmental variables such as pH, organic matter, total porosity, pore volume, penetration resistance, and K and Mg contents. Moreover, the study also emphasizes the significance of native forests in preserving springtail morphological diversity, exhibiting better soil conditions and richness in eco-morphological groups.

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