

Morphological Diversity of Springtails in Land Use Systems

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ABSTRACT: Springtails (Collembola) are soil organisms with wide morphological diversity and are sensitive to alterations in the soil, regardless of whether they are human-caused or not. The aim of this study was to evaluate the influence of land use on the morphological diversity of springtails and verify their relationships with soil physical, chemical, and microbiological properties. Samples were collected in the eastern region of Santa Catarina, in three municipalities: Joinville, Blumenau, and Timbó. They included the following land use systems (LUSs): native forest (NF), *Eucalyptus* plantation (EP), pasture (PA), integrated crop-livestock (ICL), and no tillage (NT). Samples were collected to determine soil properties, and pitfall traps were set in the winter and summer at the same points. The captured springtails were counted and morphotyped, observing features such as presence or absence of ocelli and setae, pigmentation, antenna length, and furcula length. The data were analyzed based on abundance, the Shannon-Wiener (H') and Margalef diversity indices, Pielou's evenness index (J), morphotype richness, modified Soil Biological Quality index (QBS), and Principal Component Analysis (PCA). Springtails abundance was higher in ICL and PA, whereas morphotype richness was higher in NF and ICL in the winter. The Shannon-Wiener and Margalef indices were higher in the winter in NF. In the summer, only H' differed significantly among the LUSs and was higher in NF. The QBS values did not precisely follow the human intervention gradient in either of the two periods. The PCA showed difference among the periods and LUSs. In the winter, the occurrence of morphotypes was related to soil microbiological and chemical properties, whereas in the summer, the distribution of morphotypes was explained by soil physical and chemical properties. Morphological diversity analysis is a good alternative to study springtail distribution and soil biological quality, especially when associated with multivariate techniques.

Keywords: eco-morphological traits, morphotypes, bioindicators, soil fauna.

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INTRODUCTION

The class Collembola (Ruggiero et al., 2015) is one of the most numerous and well-distributed groups of microarthropods in the soil mesofauna, and although they represent small biomass in this environment, they are excellent representatives of fauna diversity in this habitat (Baretta et al., 2011). Springtails significantly influence soil microbial ecology, nutrient cycling, and fertility, because they may be saprophagous, fragmenting plant residues, or feed on microorganisms (Oliveira Filho and Baretta, 2016).

In addition, they have a distinct distribution in the soil, inhabiting different strata along the vertical profile, and thus perform various functions in the ecosystem (Querner et al., 2013; Potapov et al., 2016). Three forms of life, also called eco-morphological groups, are identified in springtails, which indicate their levels of adaptation to the soil. Springtails are separated into these three groups, based on easily identifiable morphological traits. These traits are associated with the behavior of springtails and their relationship with the environment, and based on their combination, it is possible to define various morphological forms (morphotypes), which are separated into the following eco-morphological groups: edaphic, with morphotypes more adapted to the soil; hemiedaphic, with intermediate adaptation; and epigeic, morphotypes more adapted to litter (Vandewalle et al., 2010; Silva et al., 2016). Therefore, it is possible to study the interference of abiotic factors on these organisms, but without the need for complex taxonomic knowledge (Salmon et al., 2014; Oliveira Filho et al., 2016; Reis et al., 2016).

In addition to not requiring specialized knowledge of taxonomy, this approach related to springtail life strategies also provides a functional point of view of the community and allows comparison of different areas through joint analysis with edaphic properties (Reis et al., 2016), as in the study of Oliveira Filho et al. (2016) conducted on the Santa Catarina Plateau. These authors found various correlations between springtail eco-morphological groups and soil properties, such as the mycelium length of arbuscular mycorrhizal fungi, correlated with hemiedaphic ($r = 0.60$, $p < 0.001$) and epigeic ($r = 0.70$, $p < 0.01$) organisms in an area under no tillage, which suggested differentiation in the trophic niche and feeding strategies of springtails.

In addition, the springtail community may be directly disturbed by indiscriminate or incorrect use of the soil (Baretta et al., 2011) and is sensitive to pesticide application (Silva et al., 2017) and to different practices of land use and management (Zhang et al., 2014; Winck et al., 2017). Additionally, these organisms are sensitive to changes in temperature (Rieff et al., 2014) and rainfall because they depend on water supply, and reduction in or absence of moisture may increase the mortality of more sensitive species (Oliveira Filho and Baretta, 2016).

Given the above, springtails can be considered potential bioindicators of soil conditions, because they are found at various soil depths, are influenced by numerous factors, and show immediate responses; thus, they can provide advance information about balance or disturbance in land use systems (Baretta et al., 2014; Rieff et al., 2014). In other words, any alteration caused by human activity in land use can affect the abundance, diversity, and activity of springtails; springtails are closely associated with soil functionality because they participate in processes which affect soil quality (Oliveira Filho and Baretta, 2016).

Consequently, the concern about reducing the impacts that are responsible for decreasing biodiversity on a global scale has brought management practices such as no tillage and crop rotation to the agricultural sector. These practices prioritize rational use of the soil and maintain its physical, chemical, and biological properties (Portilho et al., 2011; Bartz et al., 2012). Thus, in contrast to traditional soil tillage systems, conservation management systems have been employed in agricultural areas, the main goals of which are to control soil erosion, avoiding depletion or degradation of the areas, and to promote biological diversity, breaking the cycle of diseases, increasing carbon accumulation in the soil, and limiting weeds. An attempt is made to imitate the environmental conditions found in natural areas as closely as possible (Martínez et al., 2013).

Studies focusing on the morphological diversity of springtails and their relationship with soil physical, chemical, and microbiological properties in forest and crop systems in Brazil, especially in the state of Santa Catarina, along a gradient of human intervention are virtually nonexistent. Therefore, the following hypotheses were formulated: i) land use systems interfere with the abundance, richness, and morphological diversity of springtails; ii) environmental variables (soil chemical, physical, and microbiological properties) help explain the distribution of springtail morphotypes in the systems; and iii) eco-morphological groups and soil biological quality are influenced by the intensity of human intervention. This study aimed to evaluate the effect of land use intensity on the morphological diversity of springtails and their relationship with soil chemical, physical, and microbiological properties in the eastern region of Santa Catarina, Brazil.

MATERIALS AND METHODS

Study areas

The study was carried out in the eastern region of Santa Catarina (SC), Brazil, in the municipalities of Blumenau, Joinville, and Timbó (Table 1). According to Alvares et al. (2013), this region has a humid subtropical climate, with hot summer (Köppen system, Cfa). The soils identified in the area were an *Argissolo Vermelho-Amarelo* (Typic Hapludult) derived from granitoid rocks of the Tabuleiro Complex, in Blumenau; a *Gleissolo Háplico* (Aquic Dystrudept) derived from recent alluvial deposits, in Joinville; and a *Cambissolo Háplico* (Typic Dystrudept) derived from recent alluvial deposits, in Timbó.

The land use systems (LUS) studied included native forest (NF), *Eucalyptus* plantation (EP), pasture (PA), integrated crop-livestock (ICL), and no tillage (NT) in order to establish a gradient of human intervention, considering NF as lowest interference and NT as highest interference. The selection of areas in each one of the three municipalities aimed to provide similar environmental conditions to allow for comparison among systems, such as similar history of management, geographic features, and even type of soil. Data on the characteristics and history of the areas are shown in table 1.

Experimental design and sampling

Samples were collected in two different periods: winter (July 2011) and summer (January 2011). Sampling in each treatment (LUS) was performed in a 3 × 3 grid of points spaced at 30 m (to avoid autocorrelation) and 20 m of border, totaling 1 ha for each area, the same scheme used by Oliveira Filho et al. (2016). This sampling would result in 270 samples in all because three municipalities were considered to evaluate five LUSs, which contained nine sampling points each, in two periods (winter and summer). However, for the analysis in the present study, only the data of the first five sampling points cataloged were considered (totaling 150 samples) because the number of springtails per sample was very high. Therefore, five samples were taken as representative of the community.

To evaluate soil chemical and microbiological properties, fifteen subsamples were collected in an area of approximately 0.10-0.20 m surrounding each point of the sampling grid in the 0.00-0.20 m layer to form a representative composite sample. For soil physical properties, undisturbed soil samples were collected in steel rings with 5 cm diameter and 5 cm height.

Sampling and eco-morphological characterization of springtails

Springtails were captured using pitfall traps containing approximately 200 mL of water with detergent (3:1 proportion) set up at each sampling point and kept in the field for 72 h (Baretta et al., 2014). After this period, the traps were collected, and the springtails were sorted, separated, and fixed in absolute alcohol (99.5 %) for conservation.

Table 1. Characteristics and history of use in land use systems (LUS) of native forest (NF), *Eucalyptus* plantation (EP), pasture (PA), integrated crop-livestock (ICL), and no-tillage (NT), for the municipalities of Blumenau, Joinville, and Timbó, in eastern Santa Catarina, Brazil

LUS	Size ha	Geographical coordinates	Age year	Vegetation and management history
Blumenau				
NF	10	Long W 49° 05' 53.677" Lat S 26° 46' 42.087"	+ 50	Atlantic Forest, dense Ombrophilous Forest formation, well-established vegetation
EP	2	Long W 49° 07' 03.571" Lat S 26° 46' 22.745"	7	<i>Eucalyptus</i> sp.
PA	2	Long W 49° 05' 48.365" Lat S 26° 46' 44.558"	+ 50	Native pasture, entrance of animals under animal science production techniques
ICL	1	Long W 49° 05' 54.175" Lat S 26° 46' 51.300"	20	Conventional tillage, crop rotation: corn (<i>Zea mays</i>) and ryegrass (<i>Lolium</i> sp.), entrance of 25 head of cattle
NT	1	Long W 49° 05' 47.837" Lat S 26° 46' 46.777"	20	No-tillage, corn
Joinville				
NF	100	Long W 48° 51' 19.426" Lat S 26° 13' 11.886"	+ 50	Atlantic Forest, dense Ombrophilous Forest formation, well-established vegetation
EP	1	Long W 48° 51' 19.166" Lat S 26° 13' 20.909"	3	<i>Eucalyptus</i> sp. with entrance of cattle
PA	2	Long W 48° 51' 23.993" Lat S 26° 13' 18.989"	+ 10	Native pasture, entrance of 30 head of cattle
ICL	1	Long W 48° 50' 51.274" Lat S 26° 12' 42.527"	50	No tillage system, crop rotation: corn and choice of some forage species, entrance of 30 head of cattle. Liming and application of urea
NT	7.5	Long W 48° 50' 51.034" Lat S 26° 12' 52.643"	8	No-tillage, crop rotation: corn and ryegrass
Timbó				
NF	10	Long W 49° 15' 55.185" Lat S 26° 47' 50.580"	+ 50	Atlantic Forest, dense Ombrophilous Forest formation, well-established vegetation
EP	1.5	Long W 49° 16' 48.799" Lat S 26° 47' 10.228"	7	<i>Eucalyptus</i> sp., entrance of cattle, previously planted to <i>Manihot esculenta</i>
PA	3	Long W 49° 16' 17.720" Lat S 26° 47' 47.840"	100	Native pasture
ICL	1	Long W 49° 16' 41.218" Lat S 26° 46' 50.880"	15	Conventional tillage, crop rotation: corn, oat (<i>Avena</i> sp.) and ryegrass, entrance of 20 head of cattle. Application of urea
NT	1	Long W 49° 16' 18.804" Lat S 26° 47' 45.275"	5	No-tillage, corn, and fallow

The springtails were then counted and separated into different morphotypes using a stereoscopic microscope with magnification of up to 50 times. Springtail adaptation to the soil was assessed according to the eco-morphological index (EMI) (Parisi, 2001; Parisi et al., 2005), which is based on observation of five easily identifiable morphological traits in each springtail: presence or absence of ocelli and setae (and/or scales), pigmentation, antenna length, and furcula length (Reis et al., 2016). A partial EMI value was assigned to each one these traits, and their sum (Total EMI) indicated higher or lower adaptation to the soil. The higher the total EMI, the higher the adaptation to the soil and the lower the organism's power of dispersion, and vice versa. This index can vary from 0 to 20 (Oliveira Filho et al., 2016).

Thus, each different combination among the five traits was associated with one morphotype (morphological form), which allows springtails to be separated into three eco-morphological groups: edaphic (living in the soil), which encompasses morphotypes with total EMI from 14 to 20; hemiedaphic (intermediate), morphotypes with total EMI from 8 to 12; and epigeic (living in the litter), morphotypes with total EMI from 0 to 6. Each combination of the morphological features corresponding to a certain morphotype can be seen in

table 2. Morphotype nomenclature refers to the eco-morphological group to which they belong: Ed is edaphic, H is hemiedaphic, and Ep is epigeic.

Evaluation of chemical, physical, and microbiological properties

Chemical properties were determined according to the methodologies of Tedesco et al. (1995), namely: pH in water, Ca^{2+} , Mg^{2+} , Al^{3+} , potential acidity (H+Al), Mg/K, organic matter (OM), and C/N ratio. Soil physical properties such as total porosity (TP), microporosity (Micro), macroporosity (Macro), and biopores (Bio) were determined according to the methodologies of Claessen (1997). Soil volumetric moisture content was determined in the laboratory, where the samples were dried in the oven at 105 °C for 24 hours. For the properties associated with carbon dynamics in the soil, microbial biomass carbon (MBC) was determined by the fumigation-extraction method (Vance et al., 1987), and microbial activity was determined by microbial basal respiration (MBR) (Alef and Nannipieri, 1995). The results of MBR and MBC were used to calculate the metabolic quotient ($q\text{CO}_2$) (Tótolá and Chaer, 2002). Total organic carbon (TOC) was determined by dry combustion in a CHNS Vario EL Cube elemental analyzer. Dry soil samples were used to quantify microbiological properties, and the results were expressed based on dry soil.

Statistical analysis of abundance, richness, and morphological diversity

The data (without outliers) were transformed, when necessary, to meet the requirements of analysis of variance (Anova, normal distribution and homoscedasticity of error variances).

The analyses were carried out on the LUS level, using the value of three municipalities (five samples per municipality) as true replicates in each LUS ($n = 3 \times 5 = 15$). Each morphotype was considered to be the estimate of one springtail specimen, and then the data were analyzed based on abundance, morphotype richness, Shannon-Wiener (H') and Margalef diversity indices, and Pielou's evenness index (J) for each LUS, in both periods of the year (winter and summer).

Diversity indices were calculated using the program PAST 3.18 (PAST, 2013). To compare the indices among LUSs in each period, Anova was carried out for the main effects, adopting the Newman-Keuls post hoc test ($p < 0.05$) in the program Statistica 7.0 (Statsoft Inc., 2004). Means presented in the text and in the figures were calculated using non-transformed data (\pm standard deviation).

Multivariate statistical analysis

Abundance data were subjected to Detrended Correspondence Analysis (DCA) to obtain the gradient length. Since this length was lower than three (≤ 3), a linear response, Principal Component Analysis (PCA) was applied to each one of the periods studied (winter and summer) because the effect of period was detected ($p \leq 0.05$).

Abundance of morphotypes was used as a response variable (effect), whereas soil physical, chemical, and microbiological properties were used as explanatory environmental variables in the PCAs. Collinear explanatory variables were identified by the Variance Inflation Factor and forward selection procedures through successive Redundancy Analyses (RDA), removing those with collinearity and selecting the ones that best explained data variation ($p \leq 0.05$). This allowed the selection of a minimum set of significant physical, chemical, and microbiological properties that best explained the variation in springtail morphotypes in each LUS and collection period. Thus, only the significant variables of the RDAs were subsequently used in the PCA as explanatory environmental variables that clarified the changes observed in the morphotypes. These analyses were carried out using the statistical program Canoco 4.5 (ter Braak and Smilauer, 2002).

Table 2. Collembola traits and collected morphotypes with their respective abundance (total of individuals), compared to those observed in the study of Oliveira Filho et al. (2016)

Partial Eco-morphological Index (EMI)					Final EMI	Eco-morphological group	Morphotype			
Ocelli	Antenna length	Furca	Setae/ Scales	Pigmentation			Category	Collected	Abundance (total individuals)	Collected by Oliveira Filho et al. (2016)
0-4	0-2-4	0-2-4	0-4	0-2-4						
4	4	4	4	4	20	Edaphic	Ed1	X	2	X
4	4	4	4	2	18	Edaphic	Ed2			X
4	4	2	4	4	18	Edaphic	Ed3	X	156	X
4	2	4	4	4	18	Edaphic	Ed4			X
4	4	4	4	0	16	Edaphic	Ed5			X
4	4	4	0	4	16	Edaphic	Ed6	X	12	X
4	4	2	4	2	16	Edaphic	Ed7	X	5	
4	4	0	4	4	16	Edaphic	Ed8	X	41	X
4	2	4	4	2	16	Edaphic	Ed9			
4	2	2	4	4	16	Edaphic	Ed10			
4	0	4	4	4	16	Edaphic	Ed11			
0	4	4	4	4	16	Edaphic	Ed12			X
4	4	4	0	2	14	Edaphic	Ed13			
4	4	2	4	0	14	Edaphic	Ed14			
4	4	2	0	4	14	Edaphic	Ed15	X	1,224	X
4	4	0	4	2	14	Edaphic	Ed16			X
4	2	4	4	0	14	Edaphic	Ed17			
4	2	4	0	4	14	Edaphic	Ed18			
4	2	2	4	2	14	Edaphic	Ed19			
4	2	0	4	4	14	Edaphic	Ed20			
4	0	4	4	2	14	Edaphic	Ed21			
4	0	2	4	4	14	Edaphic	Ed22			
0	4	4	4	2	14	Edaphic	Ed23			X
0	4	2	4	4	14	Edaphic	Ed24	X	17	
0	2	4	4	4	14	Edaphic	Ed25			
4	4	4	0	0	12	Hemiedaphic	H1			
4	4	2	0	2	12	Hemiedaphic	H2	X	288	
4	4	0	4	0	12	Hemiedaphic	H3			
4	4	0	0	4	12	Hemiedaphic	H4	X	4,844	X
4	2	4	0	2	12	Hemiedaphic	H5			
4	2	2	4	0	12	Hemiedaphic	H6			
4	2	2	0	4	12	Hemiedaphic	H7			
4	2	0	4	2	12	Hemiedaphic	H8			
4	0	4	4	0	12	Hemiedaphic	H9			
4	0	4	0	4	12	Hemiedaphic	H10			
4	0	2	4	2	12	Hemiedaphic	H11			
4	0	0	4	4	12	Hemiedaphic	H12			
0	4	4	4	0	12	Hemiedaphic	H13			X
0	4	4	0	4	12	Hemiedaphic	H14	X	3	
0	4	2	4	2	12	Hemiedaphic	H15	X	13	X
0	4	0	4	4	12	Hemiedaphic	H16			X
0	2	4	4	2	12	Hemiedaphic	H17			
0	2	2	4	4	12	Hemiedaphic	H18			
0	0	4	4	4	12	Hemiedaphic	H19			
4	4	2	0	0	10	Hemiedaphic	H20			
4	4	0	0	2	10	Hemiedaphic	H21	X	36	
4	2	4	0	0	10	Hemiedaphic	H22			
4	2	2	0	2	10	Hemiedaphic	H23			
4	2	0	4	0	10	Hemiedaphic	H24			
4	2	0	0	4	10	Hemiedaphic	H25	X	120	X
4	0	4	0	2	10	Hemiedaphic	H26			
4	0	2	4	0	10	Hemiedaphic	H27			
4	0	2	0	4	10	Hemiedaphic	H28			
4	0	0	4	2	10	Hemiedaphic	H29			
0	4	4	0	2	10	Hemiedaphic	H30			X
0	4	2	4	0	10	Hemiedaphic	H31			
0	4	2	0	4	10	Hemiedaphic	H32	X	3,181	X

Continue

Continuation

0	4	0	4	2	10	Hemiedaphic	H33	X	6	X
0	2	4	4	0	10	Hemiedaphic	H34			
0	2	4	0	4	10	Hemiedaphic	H35			
0	2	2	4	2	10	Hemiedaphic	H36			
0	2	0	4	4	10	Hemiedaphic	H37	X	2	X
0	0	4	4	2	10	Hemiedaphic	H38			
0	0	2	4	4	10	Hemiedaphic	H39			
4	4	0	0	0	8	Hemiedaphic	H40			X
4	2	2	0	0	8	Hemiedaphic	H41			
4	2	0	0	2	8	Hemiedaphic	H42			
4	0	4	0	0	8	Hemiedaphic	H43			
4	0	2	0	2	8	Hemiedaphic	H44			
4	0	0	4	0	8	Hemiedaphic	H45			
4	0	0	0	4	8	Hemiedaphic	H46	X	23	
0	4	4	0	0	8	Hemiedaphic	H47			X
0	4	2	0	2	8	Hemiedaphic	H48	X	4,789	
0	4	0	4	0	8	Hemiedaphic	H49			X
0	4	0	0	4	8	Hemiedaphic	H50	X	5,221	X
0	2	4	0	2	8	Hemiedaphic	H51			
0	2	2	4	0	8	Hemiedaphic	H52			
0	2	2	0	4	8	Hemiedaphic	H53	X	2	
0	2	0	4	2	8	Hemiedaphic	H54			X
0	0	4	4	0	8	Hemiedaphic	H55			
0	0	4	0	4	8	Hemiedaphic	H56			
0	0	2	4	2	8	Hemiedaphic	H57			
0	0	0	4	4	8	Hemiedaphic	H58			
4	2	0	0	0	6	Epigeic	Ep1			X
4	0	2	0	0	6	Epigeic	Ep2			
4	0	0	0	2	6	Epigeic	Ep3			
0	4	2	0	0	6	Epigeic	Ep4			
0	4	0	0	2	6	Epigeic	Ep5	X	351	X
0	2	4	0	0	6	Epigeic	Ep6			
0	2	2	0	2	6	Epigeic	Ep7			
0	2	0	4	0	6	Epigeic	Ep8			X
0	2	0	0	4	6	Epigeic	Ep9	X	465	X
0	0	4	0	2	6	Epigeic	Ep10			
0	0	2	4	0	6	Epigeic	Ep11			
0	0	2	0	4	6	Epigeic	Ep12			
0	0	0	4	2	6	Epigeic	Ep13			X
4	0	0	0	0	4	Epigeic	Ep14			X
0	4	0	0	0	4	Epigeic	Ep15			X
0	2	2	0	0	4	Epigeic	Ep16			
0	2	0	0	2	4	Epigeic	Ep17	X	123	X
0	0	4	0	0	4	Epigeic	Ep18			
0	0	2	0	2	4	Epigeic	Ep19			
0	0	0	4	0	4	Epigeic	Ep20			X
0	0	0	0	4	4	Epigeic	Ep21	X	50	X
0	2	0	0	0	2	Epigeic	Ep22			X
0	0	2	0	0	2	Epigeic	Ep23			
0	0	0	0	2	2	Epigeic	Ep24	X	13	X
0	0	0	0	0	0	Epigeic	Ep25			X

X = morphotypes collected in this study.

Soil Biological Quality index and the weighted mean of the value of the trait in the community

The Soil Biological Quality index (*Qualità Biologica del Suolo* - QBS) was proposed by Parisi (2001) and is based on the concept that the higher the soil quality, the higher the number of microarthropods well adapted to it. The QBS takes the EMI into consideration and, because of that, Parisi et al. (2005) generated EMI values for different groups of soil organisms, trying to encompass various groups of the soil fauna. In the case of organisms

such as springtails, which could have more than one EMI value, due to different adaptations in vertical stratification of the soil, which lead to morphological alterations, the QBS is determined only by the highest EMI, i.e., the organisms most adapted to the soil determine the final value of the index for the group. However, in the present study, an adaptation was used to calculate QBS, also employed by Pompeo et al. (2017), according to which the abundance of springtails of a certain morphotype is multiplied by its respective EMI value, and then the results of this multiplication for all the morphotypes found in the LUS are summed. The aim of this procedure is to provide a more comprehensive idea in terms of the scale of adaptation to the environment and about soil biological quality conditions because it considers all morphotypes that appear in an LUS.

Besides QBS, the weighted mean of the value of the trait in the community (mT) was calculated. This mean considers the total number of springtails of a certain morphotype, divided by the abundance of all organisms and weighted by the specific value assigned to the traits relative to their form of life (EMI) (Vandewalle et al., 2010), thus evaluating its actual participation in relation to all the springtails. In other words, an LUS with index "0" indicates that the traits of the morphotypes found in it have no affinity to soil adaptation because of the conditions found there, whereas a LUS with an index of "20" indicates high affinity of certain traits to soil adaptation. This occurs precisely because there is multiplication by the EMI of the morphotype in question. Thus, edaphic organisms have higher values and epigeic organisms have lower values.

RESULTS

Abundance, richness, and morphological diversity

The land use systems showed differences in structural diversity of springtails. Considering the five land use systems (LUSs), 25 morphotypes of springtails were found in the present study, seven belonging to the edaphic group (Ed), 13 to the hemiedaphic group (H), and five to the epigeic group (Ep). In the winter, 3,644 springtails were found, distributed across 22 morphotypes; in the summer, the number of springtails was 17,323, distributed across 17 morphotypes. The most representative morphotypes for both collection periods in the edaphic group, regardless of the LUS, were Ed15, Ed3, and Ed8, with abundances of 1,224, 156, and 41 individuals, respectively (Table 2). In the hemiedaphic group, the predominant morphotypes were H50, H4, and H48, with total numbers of 5,221, 4,844, and 4,789 individuals, respectively. In the epigeic group, the morphotypes Ep9, Ep5, and Ep17 showed highest abundance, with 465, 351, and 123 individuals, respectively (Table 2).

Analysis of variance for the mean abundance of springtails showed differences among the LUSs in the winter (Figure 1a), when the highest abundance was found in ICL and PA, although PA did not differ statistically from NF, NT, and EP. However, in the summer, no difference was found among the LUSs (Figure 1a).

Regarding the richness of springtail morphotypes in the winter (Figure 1b), the NF and ICL systems showed the highest values, although ICL did not differ statistically from NT and PA, and the lowest richness was found in the EP. In the summer, there was no difference in morphotype richness among the LUSs (Figure 1b).

Differences were found among the LUSs for all diversity indices in the winter. The highest H' and Margalef indices occurred in NF and the other uses did not differ statistically from one another (Table 3). For the J index, EP showed the highest value, although it did not differ from NF, NT, and PA, and the lowest value was found in ICL. In the summer, there were no significant differences in the Margalef and J indexes among the LUSs, whereas the highest H' value was found in NF (Table 3), although it did not differ from PA, EP, and NT; and the lowest value occurred in ICL.

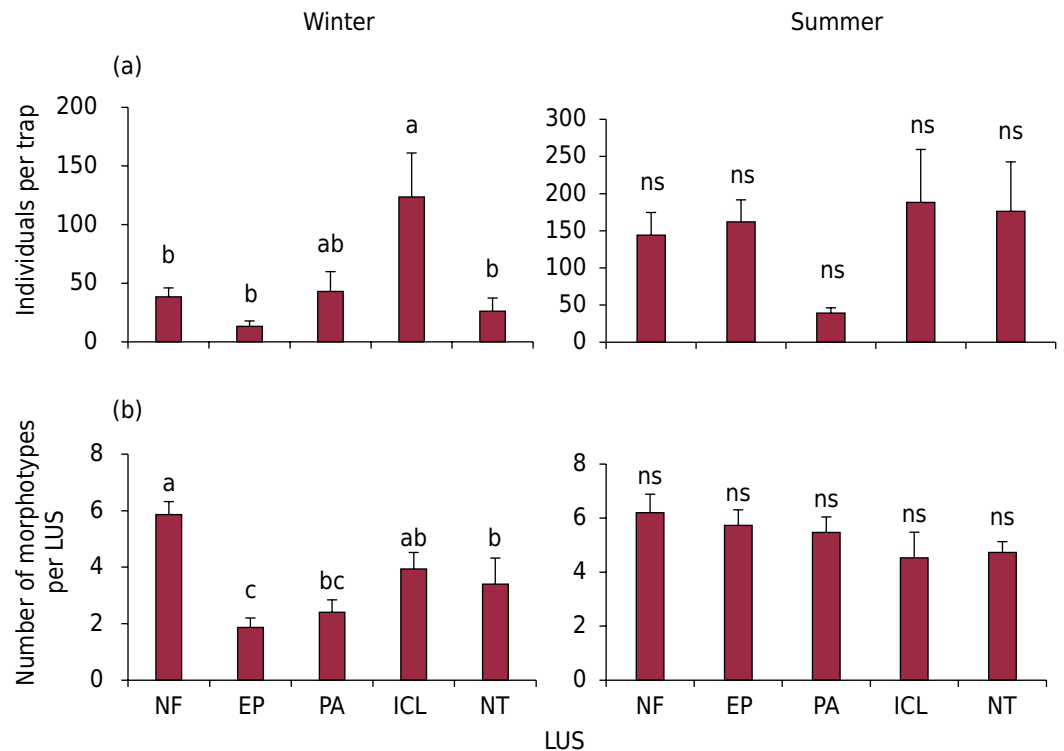


Figure 1. Average abundance of springtails [individuals per trap] (a) and richness of morphotypes [number of morphotypes per LUS] (b), in the land use systems (LUS) of native forest (NF), *Eucalyptus* plantation (EP), pasture (PA), integrated crop-livestock (ICL), and no-tillage (NT), in the winter and summer, in eastern Santa Catarina. Mean values followed by the same letter do not differ from each other by the Newman Keuls test ($p < 0.05$; $n = 15$). ns = non-significant difference.

Table 3. Values of the indices of Shannon diversity (H'), Pielou evenness index (J), and Margalef diversity, in land use systems (LUS) of native forest (NF), *Eucalyptus* plantation (EP), pasture (PA), integrated crop-livestock (ICL), and no-tillage (NT), in the winter and summer, in eastern Santa Catarina

Index	LUS				
	NF	EP	PA	ICL	NT
Winter					
Shannon (H')	1.32 a	0.48 b	0.51 b	0.51 b	0.76 b
Pielou (J)	0.69 ab	0.79 a	0.59 ab	0.48 b	0.66 ab
Margalef	1.42 a	0.37 b	0.61 b	0.69 b	0.84 b
Summer					
Shannon (H')	1.24 a	1.03 ab	1.17 ab	0.77 b	0.95 ab
Pielou (J)	0.59 ns	0.51 ns	0.61 ns	0.48 ns	0.61 ns
Margalef	1.06 ns	1.00 ns	1.29 ns	0.73 ns	0.95 ns

Mean values followed by the same letter in the row do not differ from each other by the Newman Keuls test ($p < 0.05$; $n = 15$). ns = no significant difference.

Principal Component Analysis

The PCAs for the springtail morphotypes in both winter (Figure 2a) and summer (Figure 2b) revealed differences among the LUSs, identified by the relationship between principal components 1 (PC1) and 2 (PC2). In the winter, the abundance of springtail morphotypes explained 34.1 % of the data variability in PC1 and 18.6 % in PC2, for a total of 52.7 % (Figure 2a).

In this period, NF and ICL were close and similar regarding the distribution of springtail morphotypes and showed the highest number of morphotypes (13 in all), which were distributed between the edaphic (Ed) and hemiedaphic (H) eco-morphological groups.

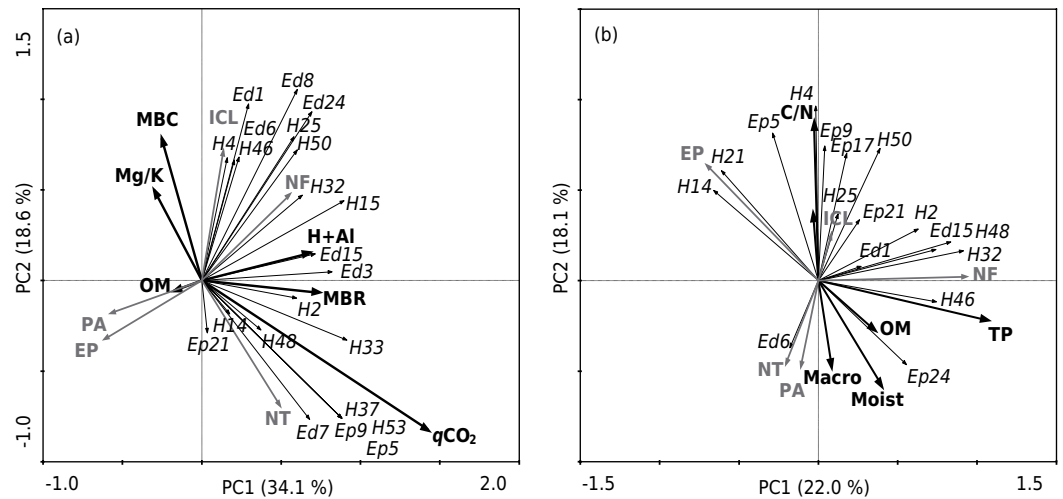


Figure 2. Principal component analysis (PCA) of Collembola morphotypes (in italics), Ed (edaphic), H (hemiedaphic), Ep (epigeic), distinguishing land use systems (gray arrows) and environmental variables (black arrows in bold print) used as explanatory variables, in the winter (a) and summer (b), in eastern Santa Catarina. NF = native forest; EP = *Eucalyptus* plantation; PA = pasture; ICL = integrated crop-livestock system; NT = no-tillage system; PC1 = principal component 1; PC2 = principal component 2; H+Al = potential acidity; Mg/K = magnesium/potassium ratio; OM = organic matter; MBC = microbial biomass carbon, MBR = microbial basal respiration; qCO_2 = metabolic quotient; Bio = biopores; C/N = carbon/nitrogen ratio; TP = total porosity; Macro = macroporosity; Moist = soil moisture.

No-tillage system also showed relationships with various morphotypes (8 morphotypes), especially hemiedaphic (H) and epigeic (Ep). Nonetheless, PA and EP systems were very similar to one another, but not highly related to springtail abundance (Figure 2a).

Environmental variables helped explain the distribution of morphotypes in each LUS through the association they demonstrate after being projected in the PCA. Thus, in the winter, the soil microbiological property MBC contributed to explain the abundance of morphotypes (Ed1, Ed6, Ed8, H4, and H46) in the ICL system, whereas H+Al and MBR explained the morphotypes (Ed3, Ed15, Ed24, H2, H15, H25, H32, H50) associated with the NF. In NT, the qCO_2 explained the abundance of morphotypes (Ed7, H33, H37, H48, H53, Ep5, Ep9, Ep21). In PA and EP, although OM is in the same direction, it is very close to the center, characterizing low relationship with these uses and, therefore, low affinity with morphotype diversity.

For the abundance of springtail morphotypes in the summer, PC1 explained 22.0 % of the data variability and PC2 explained 18.1 %, for a total of 40.0 % (Figure 2b). In this period, the NF and ICL were not as close as they were in the winter but continued to have a higher number of morphotypes compared with the other EP uses (seven morphotypes in each). These morphotypes were distributed in all eco-morphological groups in NF, whereas in ICL, there were only hemiedaphic and epigeic springtails. The EP appeared associated with only two hemiedaphic morphotypes, whereas NT and PA were close to one another, but exclusively related to one edaphic morphotype (Figure 2b).

The environmental variables that explained morphotype distribution in the LUSs in the summer are soil chemical and physical properties. The C/N ratio and biopores (Bio) explained the abundance of morphotypes (H4, H25, H50, Ep5, Ep9, Ep17, Ep21) in the ICL system; whereas OM and TP favored the morphotypes (Ed1, Ed15, H2, H32, H46, H48, Ep24) associated with the NF. Macroporosity (Macro) and moisture (Moist) helped explain the relationship with one morphotype (Ed6) in the NT and PA systems. The EP did not appear associated with any variable that explained the morphotypes occurring in it (H14, H21).

Soil Biological Quality index and the weighted mean of the value of the trait in the community

In both sampling periods, QBS results (Table 4) did not follow the gradient of land use intensification (NF < EP < PA < ICL < NT). However, in the summer, QBS was highest in the NF, followed by ICL, EP, NT, and PA (NF > ICL > EP > NT > PA). In the winter, the ICL system had the highest QBS, followed by NF, PA, NT, and EP (ICL > NF > PA > NT > EP).

The mT values for the LUSs studied in the winter (Table 4) ranged from 10.78 in PA to 13.09 in NT. In the summer, the results for mT (Table 4) ranged from 8.45 in ICL to 10.62 in EP.

DISCUSSION

Abundance, richness, and morphological diversity

Crop rotation and food diversification in the litter, combined with the practices of soil correction and entry of animals in the ICL system, may have favored higher abundance in this system during the winter (Figure 1a). However, one should not ignore that the drastic change in the type of crop during crop rotation may be able to cause a seasonal event of reproduction and this may come to drastically affect springtail abundance in ICL.

Higher richness of springtail morphotypes in NF in the winter (Figure 1b) may have been influenced by factors such as microclimate, soil quality, better conservation of the areas, and high diversity of vegetation, which ensures various trophic resources and habitats for springtails.

Richness of species (or in this case morphotypes) is strongly associated with functional diversity (related to functions that each species performs in the community), because their traits are somewhat different from one another, and that means that communities with higher dissimilarity in these traits tend to have greater functional diversity (Pillar et al., 2013). The highest values of taxonomic and functional indicators of the springtail community in the forest area in Eldorado do Sul, RS, Brazil was found by Winck et al. (2017). That may indicate that the forest area has the highest richness if the relationship that exists between functional diversity and richness of the above-mentioned species is taken into consideration.

Table 4. Soil Biological Quality index (QBS) and the weighted mean of the value of the trait in the community (mT), for the edaphic (Ed), hemiedaphic (H), and epigeic (Ep) eco-morphological groups, in land use systems (LUS) of native forest (NF), *Eucalyptus* plantation (EP), pasture (PA), integrated crop-livestock (ICL), and no-tillage (NT), in the winter and summer, in eastern Santa Catarina

Period	LUS	QBS				Number of morphotypes				mT
		Ed	H	Ep	Total	Ed	H	Ep	Total	
Winter	NF	3,886	3,568	4	7,458	6	9	1	16	12.925 ± 1.16
	EP	582	1,852	0	2,434	3	4	0	7	12.231 ± 2.40
	PA	478	6,458	4	6,940	3	6	1	10	10.776 ± 2.19
	ICL	2,006	20,444	0	22,450	5	8	0	13	12.122 ± 2.93
	NT	3,366	1,728	36	5,130	5	10	2	17	13.087 ± 1.47
Total						7	12	3	22	
Summer	NF	4,228	61,458	380	66,066	1	7	5	13	8.898 ± 1.33
	EP	2,926	21,476	1,412	25,814	1	8	3	12	10.619 ± 1.82
	PA	1,232	4,002	328	5,562	1	7	5	13	9.491 ± 1.06
	ICL	1,224	31,300	3,302	35,826	2	6	4	12	8.447 ± 1.37
	NT	1,222	23,220	148	24,590	2	5	5	12	9.314 ± 1.42
Total						3	9	5	17	

The study of Souza et al. (2016) is noteworthy; they analyzed soil macrofauna groups in the same LUSs and region as the present study. These authors found higher richness in NF in both periods (winter and summer), which was associated with the greater diversity and availability of the food substrate to soil fauna, stimulated by intense cycling of leaves and branches in the forest litter, a condition that could also be favorable to the establishment of springtail morphotypes in the present study, leading to high richness.

The LUS with the lowest intensity of use and human activity (NF) had the highest values of H' and Margalef indices in the winter (Table 3), which indicates that this system has higher diversity compared to the others and, therefore, there is colonization of more springtail morphotypes with different survival strategies in NF than in the other LUSs. Nonetheless, Margalef indices lower than 2.0 are considered indicators of low-diversity areas, and H' usually ranges from 1.5 (low diversity) to 3.5 (high diversity) (Magurran, 2004). Thus, although these indices indicate higher diversity in NF, when analyzed in isolation, these results reiterate that morphotype diversity is low. Despite that, these values are probably demonstrating what occurs naturally in NF, i.e., morphotype diversity can be intrinsic or naturally low in this system and, even so, be superior to those of the other LUSs, since they have lower litter deposition and greater changes in temperature and moisture conditions.

Principal Component Analysis

Regarding the relationship between MBC and the morphotypes in ICL in the winter (Figure 2a), it can be said that springtail activities translocate carbon from the surface litter to the soil and increase the carbon content available to the soil microbial community, (Chamberlain et al., 2006). This claim is supported by the results found by Oliveira Filho et al. (2016), in which MBC was positively correlated with springtails from the edaphic ($r = 0.48$, $p < 0.05$) and hemiedaphic ($r = 0.50$, $p < 0.05$) eco-morphological groups in the ICL system on the Santa Catarina Plateau. These groups contain the morphotypes found in the present study associated with MBC in this LUS.

In addition, Lopes et al. (2012) claimed that carbon accumulation by microbial biomass is due to the continuous and diversified supply of organic matter incorporated in the soil, especially through deposition by plants. Therefore, in the ICL, phytomass production by forage species (along with crop rotation) is probably the factor that influenced microbial biomass and led to high MBC values. This condition may have benefitted the establishment of edaphic and hemiedaphic morphotypes in this LUS, especially because fungi contribute the largest portion of microbial biomass and, just as organic residues, they are important in the springtail diet (Verma et al., 2014). From the aforementioned, interactions between springtail fauna and the soil microbiota are found.

The morphotypes of the NT system appear to be associated with the microbiological indicator qCO_2 in the winter (Figure 2a). Higher qCO_2 values are known as an indicator of a stressful environment for soil microorganisms, because it means that they are oxidizing the carbon of their own cells for their maintenance and adaptation to the soil (Souza et al., 2010). It is important to point out that although this relationship with qCO_2 in NT possibly indicates a stressful environment for the soil microbiota, in the present study, the establishment of various springtail morphotypes, especially hemiedaphic and epigeic ones, were not hampered. Consequently, it may be that when springtails occupy such a stressful environment, they end up modifying it, mitigating the adverse conditions so that microorganisms can establish themselves.

The MBR parameter, which explains the occurrence of morphotypes in NF in the winter, represents microorganism activity and C- CO_2 release in the soil, and this is mainly concentrated in the organic layers of the soil (Cunha et al., 2011). Native forests are known to have constant deposition of material from different plant and animal origins; incorporation of this material, combined with the equilibrium of the environmental conditions of forests, leads to high biomass and microbial activity on these residues (Winck et al., 2017). These

conditions can explain association of the property MBR with edaphic and hemiedaphic springtail morphotypes in the native forest (Figure 2a); springtails may have been affected by these conditions, since their eating habits also are based on organic residues (Oliveira Filho and Baretta, 2016), and when living in forest areas, they are mainly influenced by the microclimate established in these sites (Heiniger et al., 2015).

Regarding the property H+Al (potential acidity), also associated with the morphotypes in NF in the winter (Figure 2a), it is known that springtails are normally sensitive to pH changes, and this relationship shows that acid conditions are favorable to the various morphotypes found there, especially Ed15 and Ed3, which are close to this variable. They live in exclusive contact with the soil and, consequently, can be more rapidly affected by acidity. Collembola species which are controlled by abiotic factors, such as pH and soil water content, were observed by Asif et al. (2016) and Pollierer and Scheu (2017).

In the summer in ICL, there is a relationship between the morphotypes and the physical parameter Bio (Figure 2b), and the biopores presence indicates high activity of organisms of the mesofauna and macrofauna. The presence of biopores is also a good indication of soil quality in this system because this type of structure disappears when the soil is compacted (Lima et al., 2005). Therefore, this variable is important for explaining the activity and establishment of the various hemiedaphic and epigeic morphotypes in this site.

Still in ICL, the association of morphotypes with the chemical property C/N ratio reaffirms that the plant species used in crop rotation (corn, oat, and ryegrass) have slow decomposition and, consequently, high C/N ratio (Medrado et al., 2011). This indicates that its residues remain longer on the soil surface and that its roots also decompose slowly. Thus, the morphotypes related to this explanatory variable in this LUS were benefited by this prolonged presence of residues on the soil, especially the morphotypes H4, Ep5, and Ep9, which appear close to this property. For the morphotypes Ep5 and Ep9, this relationship is even more important, because they belong to the group of epigeic organisms, also known as litter dwellers, i.e., they live in plant residues on the soil.

The study conducted by D'Annibale et al. (2017) in Denmark, suggests that the quality of plant material affects the functionality of the springtail community, because their results indicate that in the spring, when the C/N ratio of the litter was higher (*Lolium perenne* L.), epigeic species prevailed. In contrast, in the winter, when deposited plant material showed lower C/N ratio (*Trifolium repens* L.), edaphic species prevailed. Low litter quality is associated with a high C/N ratio because some of the resources may not be available to the springtail morphotypes. Because of that, the authors highlight that epigeic species were more abundant under this condition, which may indicate that they are less dependent on recent plant resources for food than edaphic species. These considerations help understand the above-mentioned affinity of the morphotypes Ep5 and Ep9. Moreover, according to the same authors, the diet of epigeic morphotypes, when they are in a site with low quality of plant residues, though this is not really an exception, is based on a mixture of fungi and algae or lichens.

For the NF, the OM helps explain the morphotypes in this system in the summer (Figure 2b). Studies such as Pompeo et al. (2016) in the Southern Plateau of Santa Catarina and Scoriza and Correia (2016) in Seropédica, RJ, also found a relationship between OM and the springtail community. In addition, Silva et al. (2006) found a close dependence between the quantity of pores and OM dynamics. Therefore, the condition of high OM accumulation in NF probably had a positive influence on TP in this system (Figure 2b). Soil total porosity can have an impact on the springtail community because these organisms seek shelter and move mainly through these structures. Consequently, reduction in habitable pore space is one of the decisive factors for the abundance of edaphic springtails (Oliveira Filho and Baretta, 2016). This assertion corroborates the results found here, in which the morphotypes of all eco-morphological groups associated with the NF are benefited by TP.

However, factors causing soil deformation and compaction lead to loss of original soil structure, reducing macropore volume and increasing micropore volume and density. Despite that, the relationship between macroporosity (Macro) and the morphotype Ed6 in the PA and NT systems in the summer (Figure 2b) indicates that the management conditions adopted in these areas did not greatly interfere with soil structure and they preserved larger pores. This may clarify the occurrence of this morphotype related to these sites because, according to Beylich et al. (2010), macroporosity is a property that strongly determines the living conditions of springtails, since they live in macropores and frequently show little to no capacity to excavate the soil.

The management practices adopted in PA and NT, in addition to influencing macroporosity, may also have led to more stable and adequate moisture (Moist) conditions, which also benefited the morphotype Ed6. For edaphic springtails, this higher moisture condition is more favorable because these organisms have lower dispersion capacity, since they are in direct contact with the soil throughout their life cycle (Moço et al., 2010).

Soil Biological Quality index and the weighted mean of the value of the trait in the community

Higher QBS values indicate greater adaptation of springtail morphotypes to a certain system (Parisi et al., 2005). Higher QBS in the NF found in the summer (NF > ICL > EP > NT > PA) (Table 4) was expected because this system exhibits high ecological balance, with a greater diversity of residues and a favorable microclimate for the development of soil fauna communities (Rieff et al., 2014). Areas with native forest and agriculture in Nepal were evaluated by Begum et al. (2014), considering that these sites would exhibit two extremes of the soil fauna, and also found higher QBS values in the forest area.

Since human intervention increases in this order: NF < EP < PA < ICL < NT, the second highest index in the summer occurred in ICL (Table 4), which is the penultimate system considering the use intensity gradient. The conditions promoted by crop rotation and entry of cattle in this LUS probably favored springtail adaptation by providing a variety of crop residues and manure, which serve as food and shelter for soil organisms and enhance soil physical and chemical properties. The lowest QBS index in PA (last in the sequence) in the summer may be attributed to the presence of animals during this period, influencing soil physical properties and, consequently, the activity of springtails because they are sensitive to changes in soil properties.

For QBS in the winter (Table 4), the springtail community in the forest may have been changed by specific conditions, such as lower solar radiation on the soil and reduction in temperature (due to the cold season), which may have negatively influenced the springtails. Therefore, the index in ICL stood out (ICL > NF > PA > NT > EP), inverting the sequence that occurred in the summer for these uses, in which QBS was higher in NF. This corroborates the study of Rieff et al. (2014), who comment on springtail sensitivity to changes in temperature and moisture.

In a study conducted in Europe with groups of the soil fauna, Mohamedova and Lecheva (2013) also found higher QBS in cultivated areas. This suggests that, in some cases, these systems may be appropriate for the microarthropods adapted to live in the soil, particularly the hemiedaphic ones in the present study. Based on results obtained by Portilho et al. (2011), integrated crop-livestock systems benefit the maintenance of invertebrate fauna diversity.

Nonetheless, higher adaptation of springtails in the ICL system may also be related to a possible reduction in the activity of predators, since springtails are potential prey for spiders, coleopterans, and scorpions. This is possibly due to the complexity of the habitat because, unlike cultivation systems such as the ICL, more complex habitats like

forests seem to be directly and positively correlated with an increase in the abundance and diversity of natural enemies (Langellotto and Denno, 2004).

The results of QBS found in the present study are highly capable of indicating the influence of LUSs on springtail adaptation. This capability was also found in the study of Menta et al. (2018) conducted in Italy with three land use systems (agriculture, forest, and alfalfa) with groups of soil fauna. Additionally, QBS indicated the interference of the periods (winter and summer), and lower adaptation occurred in the winter (lower temperatures).

In relation to mT in the winter (Table 4), the numbers of edaphic (higher EMI) and hemiedaphic (intermediate EMI) morphotypes in NT were 5 and 10, respectively, in contrast with two epigeic morphotypes (lower EMI). Therefore, edaphic and hemiedaphic organisms had greater participation in the total number of springtails in NT, indicating an mT value with high adaptation to the soil.

The soil properties in NT that may have favored the affinity of the morphotypes Ed and H may be associated with annual plants in a no tillage system, combined with crop rotation and a fallow period (Table 1). These practices are known to benefit the soil in various aspects, including favorable conditions for various soil organisms (Bartz et al., 2012). Furthermore, QBS indices in NT in the winter for the Ed and H groups are much higher than those for Ep (Table 4), coinciding with their greater participation, as proposed in the approach of the value of the trait in the community (mT).

The large number of hemiedaphic morphotypes (intermediate EMI) is noteworthy in all LUSs in the summer (Table 4), and the highest number of springtails was found in EP, the LUS with the highest mT. Thus, hemiedaphic springtails had greater participation compared with the others in this system, once more coinciding with the partial QBS, which is higher for H in the summer (Table 4). An increase in mT value in *Eucalyptus* plantation areas, indicating that the changes in the quality and structure of the organic horizon caused by the exotic plantations lead to alterations in the functional composition of the springtail community, which may favor an increase in the number of morphotypes adapted to the mineral soil layers (edaphic and hemiedaphic) (Vandewalle et al., 2010).

Given the above, the mT allows determination of which eco-morphological group has greater participation in the LUSs. This means that the soil conditions found in a certain LUS, especially pH, soil moisture, and OM (Silva et al., 2016), favor the eco-morphological group of the morphotypes that had greater participation.

The mean value of mT has potential to complement the current soil quality indicators, such as QBS, because the morphological features linked to the springtail form of living are directly related to alterations in the ecosystems (Vandewalle et al., 2010). In a study linking traits and habitat characteristics of the springtail community in Europe, Salmon et al. (2014) noted that, in large part, this is conditioned on the interaction of a combination of parameters, such as vertical stratification, type of humus, habitat closure, air temperature, soil moisture, and soil acidity and, to a lesser extent, rainfall and altitude.

CONCLUSIONS

The Collembola class was influenced by the land use systems (LUSs), especially in the winter, when morphotype richness and morphological diversity were highest in the native forest (NF), indicating that this LUS provides a more preserved environment, as well as trophic resources, habitat, and microclimate favorable to various springtail morphotypes. Among the cultivated systems, integrated crop-livestock (ICL) stood out with the highest abundance of springtails.

In the winter, the occurrence of edaphic and hemiedaphic morphotypes was related to the microbial biomass carbon (MBC) and microbial basal respiration (MBR), in addition to

the H+Al, whereas the metabolic quotient was mainly related to hemiedaphic and epigeic morphotypes. However, in the summer, hemiedaphic and epigeic morphotypes were related to the C/N ratio and biopores (Bio), whereas the total porosity (TP) was associated with morphotypes of all eco-morphological groups, as well as the organic matter. The soil moisture (Moist) and macroporosity (Macro), in the summer, were associated with only one edaphic morphotype.

In all systems, the Soil Biological Quality index (QBS) was influenced by management practices and periods. The weighted mean of the value of the trait in the community (mT) helps clarify that the environmental conditions of the LUS interfere with the eco-morphological groups of springtails.

Analysis of morphological traits is a good alternative for studying springtail distribution and soil biological quality, especially when associated with multivariate techniques, involving physical, chemical, and microbiological properties of the soil.

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