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Collembola Community Structure as a Tool to Assess Land Use Effects on Soil Quality

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ABSTRACT: Collembolan species are differently affected by soil tillage (conventional, minimum tillage, and no-tillage) and are known to modify plant growth. This study relies on the relationships between Collembola community structures and land use systems as a proxy for characterizing changes in soil quality. Thus, Collembola community structure (eco-morphological groups – edaphic, hemiedaphic and epigeic, and morphotypes) were examined in a no-tillage system and crop-livestock integration system to evaluate the discriminative power of the Collembola community structure and to determine which soil properties drives structural diversity. Thirty-eight morphotypes of Collembola were recorded in this study, 11 belonging to the edaphic eco-morphological group, 14 hemiedaphic, and 13 epigeic. The hemiedaphic and epigeic groups, in the no-tillage system, were more influenced by changes in soil properties (total organic carbon, particulate organic carbon, total N, Ca, Mg, moisture, bulk density) and mycelium length than the groups in the crop-livestock integration system (mycorrhizal inoculum potential, and soil properties as dehydrogenase, particulate organic carbon, Mg, sand). Collembola eco-morphological groups were better predictors for ecosystem functioning than Collembola density and can be used to distinguish differences between soil uses, reducing laboratory analysis time.

Keywords: soil fauna, morphotypes, no-tillage, crop-livestock integration.

INTRODUCTION

Soil springtails are good representatives of the diversity of soil fauna (Cassagne et al., 2003) that interacts with ecosystem processes in several ways. These soil microarthropods have significant influence on soil microbial ecology, nutrient cycling, and soil fertility by feeding on soil microorganisms and dead organic matter. In turn, microarthropods also respond to a variety of environmental and ecological factors, like changes in soil chemistry, microhabitat configuration, and agricultural practices (Hopkin, 1997).

One of the main limitations of Collembola study is the lack of available taxonomists (Zeppelini Filho and Bellini, 2004). An alternative approach has been studied by Parisi (2001), who proposed the concept of eco-morphological (EM) value. The aim of the EM value is to group specimens of each species in accordance with their degree of adaptation to the soil (soil profile and litter layer), ranked according to a specific EM value determination and separated in life-forms (morphotypes).

Collembolan species are differently affected by soil tillage (conventional, minimum tillage, and no-tillage) (van Capelle et al., 2012) and are known to modify plant growth (Eisenhauer et al., 2011). In agricultural systems, springtails are sensitive to different soil use practices (Bandyopadhyaya et al., 2002; Sousa et al., 2006; Chang et al., 2013). A few studies have reported on the Collembola community structure in non-inversion deep tillage and conventional plowing (Petersen, 2002a), agricultural land use as arable land, permanent grasslands, shrublands, and woodlands on a slope (Parisi et al., 2005), landscape diversity (Querner et al., 2013), and different land use types (forests, grasslands, and arable lands) (Martins da Silva et al., 2015). However, there is no published study focusing on the structure of the Collembola community in no-tillage and crop-livestock integration.

In this study, we analyzed the structural diversity of springtails, and explore possible applications of EM groups and morphotypes of Collembola as potential soil bioindicators. Thus, we propose to assess the relationships between EM groups of Collembola biodiversity and land use systems with a history of no-tillage and integrated crop-livestock. We hypothesize there are differences in structural diversity between the two land use systems, and that determination at the level of morphotypes will allow observation of these differences. This study was conducted with two objectives: assess the discriminative power of the Collembola community structure (EM groups - edaphic, hemiedaphic, and epigeic, and morphotypes) in two soil use systems; and verify which soil properties drive the structural diversity of the systems under study.

MATERIALS AND METHODS

Study site

The study area is located in the plateau area of Santa Catarina (southern Brazil). Three municipalities were selected, Campo Belo do Sul, Lages, and Otacílio Costa, each municipality was considered as a replicate. Two different land use systems (LUS) were studied in the municipality: no-tillage crops (NT) and integrated crop-livestock systems (ICL).

Climate in the region is Cfa (humid subtropical) by the Köppen classification system (Peel et al., 2007), with mean temperatures ranging from 14 to 18 °C. The region shows no marked dry season and there is rainfall throughout the year. Soils of the sites are clayey and loamy brown *Nitossolo Bruno* (Oxisols) or *Cambissolo Húmico* (Inceptisols) (Embrapa, 2006).

No-tillage systems are managed completely without soil tillage; the only soil disturbance is caused by seeding and during harvest and by retaining crop residues on or near the soil surface (Kassam et al., 2009). No-tillage fields ranged from 1.1 to 5.5 ha in size and had

been under an NT system for 7-11 yr (Bartz et al., 2014b). The synergy among pasture, livestock, and crops in an ICL system can provide permanent soil cover and input of crop residue, improving overall soil fertility, and through production of dung and urine, soil biological activity and nutrient recycling can increase (Dubeux et al., 2009; Silva et al., 2014). The ICL fields ranged from 4 to 14 ha in size and had been under an ICL systems for 10-25 yr (Bartz et al., 2014b). The environmental and land use characteristics of each sample site are shown in table 1.

Experimental design and sampling

Sampling was carried out in winter (May 2013), when the areas (NT and ICL) had corn plant residues on the soil surface and before seeding of oats for soil cover. In each system, nine centering points were georeferenced in grid sampling (centered in a 1 ha plot), at a distance of 30 m from each other and 20 m from the edge. Around the centering point, nine soil samples were collected (soil plus all plant residues on the soil surface) for microarthropods (Collembola) and microbiological, physical, and chemical analyses of the soil (Figure 1).

Table 1. Environmental and use characteristics of sampling sites and land use systems in each municipality studied in Santa Catarina, Brazil

Municipality[1]	No-tillage (NT)	Integrated crop-livestock
Campo Belo do Sul		
Altitude (m)	923	947
UTM (J22 zone)	534167.46 - 6917279.1	534356.22 - 6915002.2
Size (ha)	1.1	4
Age (yr)	11	25
Vegetation and management	No-tillage (soybean - *Glycine max* (L.) Merrill, corn - *Zea mays* L., wheat - *Triticum* spp., and fallow). Use of herbicides, insecticides, and fungicides.	No-tillage with crop rotation (soybean, corn, wheat, and oat - *Avena sativa* L.). Use of herbicides, insecticides, and fungicides.
Soil texture	Clay	Clay
Organic matter (dag kg^{-1})	4.0	4.3
Lages		
Altitude (m)	883	873
UTM (J22 zone)	539402.33 - 6925122.7	539289.77 - 6925346.4
Size (ha)	4	14
Age (yr)	7	10
Vegetation and management	No-tillage (soybean, corn, and wheat). Use of herbicides, insecticides (physiological), and fungicides.	No-tillage with crop rotation (soybean, corn, oat, and ryegrass - *Lolium multiflorum* Lam.). Use of herbicides, insecticides (physiological), and fungicides.
Soil texture	Clay	Clay
Organic matter (dag kg^{-1})	4.1	4.3
Otacílio Costa		
Altitude (m)	879	902
UTM (J22 zone)	612712.11 - 6944460.5	603859.81 - 6951380.3
Size (ha)	5.5	11.3
Age (yr)	10	12
Vegetation and management	No-tillage (soybean, corn, and fallow). Use of herbicides, insecticides, and fungicides	No-tillage with crop rotation (soybean, corn, oat, and ryegrass). Use of herbicides, insecticides, and fungicides.
Soil texture	Loam	Sandy clay loam
Organic matter (dag kg^{-1})	5.3	5.6

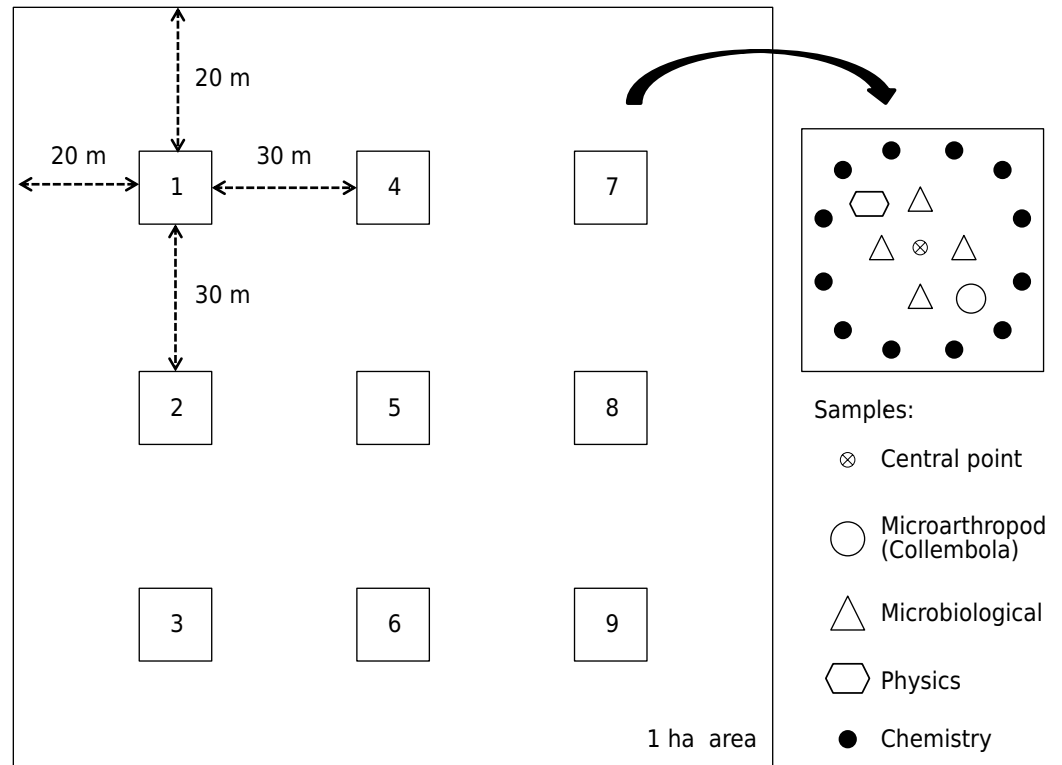[1] Modified from Bartz et al. (2014b).

Figure 1. Sampling scheme for the collection points of biological, physical, and chemical soil analysis.

For microbiological analysis, samples were collected from a depth of 0.10 m, sieved (<0.002 m), and kept refrigerated (4 °C) for analyses. For chemical analysis, samples were collected from a depth of 0.10 m, air-dried, sieved (<0.004 m), and stored until analysis. For physical analysis, disturbed and undisturbed samples were collected (from a depth of 0.10 m). Disturbed samples were air-dried, sieved (<0.004 m), and stored. Undisturbed samples were kept intact and sealed to prevent loss of moisture.

Collembola sampling and eco-morphological characterization

The evaluation of microarthropods was restricted to Collembola and their community structure through categorization into life-form groups (edaphic, hemiedaphic, and epigeic) and morphotypes within each group.

The separation into EM groups and morphotypes was carried out as follows: microarthropods were collected using a metal cylinder (5 cm diameter × 5 cm depth). Soil samples were taken to the laboratory immediately after collection, where a modified Berlese-Tullgren funnel was used to extract microarthropods from them using heat and light as repellents. The samples remained in the funnels for 14 days. All organisms were removed and fixed in 80 % ethanol. The content of microarthropods was analyzed in each soil sample separately, sorted, and identified using Zeiss stereomicroscopes.

To recognize the different adaptation levels for Collembola, the method requires searching for morphological characteristics (traits) that are connected to adaptation of each collembolan species to the soil environment. The traits used are presence of ocelli, antenna length, development of furca, presence or absence of body hairs/scales, and pigmentation (Table 2), a procedure modified from Vandewalle et al. (2010). For each individual organism, the traits receive a score (partial EM value), and the final EM value will be the sum of all scores from each individual trait. Structural diversity of springtails or EM groups were classified as epigeic, hemiedaphic, or edaphic, which can range from 0 (epigeic forms, indicating a species with higher adaptation to the surface layers)

to 20 (edaphic forms, indicating a species with higher adaptation to deep soil layers); hemiedaphic (i.e., intermediate) forms have an index rating proportional to their degree of specialization. Hence, the higher the EM value, the smaller the dispersion power of the organism and the higher its adaptation to the soil profile. A morphotype was attributed to the different combination of traits (final EM value). As a general rule, edaphic forms get a final EM = 20-14, hemiedaphic forms get a final EM = 12-8, while epigeic forms get a final EM = 6-0 (Table 3).

Table 2. Traits used to calculate eco-morphological (EM) value for Collembola

Trait[1]	Codification	Partial EM value
Ocelli	Present	0
	Absent	4
Antenna length	Antenna length > body length	0
	Antenna length > 0.5 × body length	2
	Antenna length < 0.5 × body length	4
Furca	Fully developed	0
	Reduced/short	2
	Absent	4
Hairs/Scales	Present	0
	Absent	4
Pigmentation	Colored and with patterns	0
	Colored but not uniformly pigmented	2
	Absent (white color or transparent)	4

[1] Adapted from Vandewalle et al. (2010).

Table 3. Collembola traits, formed categories of morphotypes, and collected categories

Ocelli 0-4	Antenna length 0-2-4	Furca 0-2-4	Hairs/Scales 0-4	Pigmentation 0-2-4	Final EMV	EM group	Category	Collected
4	4	4	4	4	20	Edaphic	Edaphic 1	x
4	4	4	4	2	18	Edaphic	Edaphic 2	x
4	4	2	4	4	18	Edaphic	Edaphic 3	x
4	2	4	4	4	18	Edaphic	Edaphic 4	x
4	4	4	4	0	16	Edaphic	Edaphic 5	x
4	4	4	0	4	16	Edaphic	Edaphic 6	x
4	4	2	4	2	16	Edaphic	Edaphic 7	
4	4	0	4	4	16	Edaphic	Edaphic 8	x
4	2	4	4	2	16	Edaphic	Edaphic 9	
4	2	2	4	4	16	Edaphic	Edaphic 10	
4	0	4	4	4	16	Edaphic	Edaphic 11	
0	4	4	4	4	16	Edaphic	Edaphic 12	x
4	4	4	0	2	14	Edaphic	Edaphic 13	
4	4	2	4	0	14	Edaphic	Edaphic 14	
4	4	2	0	4	14	Edaphic	Edaphic 15	x
4	4	0	4	2	14	Edaphic	Edaphic 16	x
4	2	4	4	0	14	Edaphic	Edaphic 17	
4	2	4	0	4	14	Edaphic	Edaphic 18	

Continue...

Continuation...

4	2	2	4	2	14	Edaphic	Edaphic 19	
4	2	0	4	4	14	Edaphic	Edaphic 20	
4	0	4	4	2	14	Edaphic	Edaphic 21	
4	0	2	4	4	14	Edaphic	Edaphic 22	
0	4	4	4	2	14	Edaphic	Edaphic 23	x
0	4	2	4	4	14	Edaphic	Edaphic 24	
0	2	4	4	4	14	Edaphic	Edaphic 25	
4	4	4	0	0	12	Hemiedaphic	Hemiedaphic 1	
4	4	2	0	2	12	Hemiedaphic	Hemiedaphic 2	
4	4	0	4	0	12	Hemiedaphic	Hemiedaphic 3	
4	4	0	0	4	12	Hemiedaphic	Hemiedaphic 4	x
4	2	4	0	2	12	Hemiedaphic	Hemiedaphic 5	
4	2	2	4	0	12	Hemiedaphic	Hemiedaphic 6	
4	2	2	0	4	12	Hemiedaphic	Hemiedaphic 7	
4	2	0	4	2	12	Hemiedaphic	Hemiedaphic 8	
4	0	4	4	0	12	Hemiedaphic	Hemiedaphic 9	
4	0	4	0	4	12	Hemiedaphic	Hemiedaphic 10	
4	0	2	4	2	12	Hemiedaphic	Hemiedaphic 11	
4	0	0	4	4	12	Hemiedaphic	Hemiedaphic 12	
0	4	4	4	0	12	Hemiedaphic	Hemiedaphic 13	x
0	4	4	0	4	12	Hemiedaphic	Hemiedaphic 14	
0	4	2	4	2	12	Hemiedaphic	Hemiedaphic 15	x
0	4	0	4	4	12	Hemiedaphic	Hemiedaphic 16	x
0	2	4	4	2	12	Hemiedaphic	Hemiedaphic 17	
0	2	2	4	4	12	Hemiedaphic	Hemiedaphic 18	
0	0	4	4	4	12	Hemiedaphic	Hemiedaphic 19	
4	4	2	0	0	10	Hemiedaphic	Hemiedaphic 20	
4	4	0	0	2	10	Hemiedaphic	Hemiedaphic 21	
4	2	4	0	0	10	Hemiedaphic	Hemiedaphic 22	
4	2	2	0	2	10	Hemiedaphic	Hemiedaphic 23	
4	2	0	4	0	10	Hemiedaphic	Hemiedaphic 24	
4	2	0	0	4	10	Hemiedaphic	Hemiedaphic 25	x
4	0	4	0	2	10	Hemiedaphic	Hemiedaphic 26	
4	0	2	4	0	10	Hemiedaphic	Hemiedaphic 27	
4	0	2	0	4	10	Hemiedaphic	Hemiedaphic 28	
4	0	0	4	2	10	Hemiedaphic	Hemiedaphic 29	
0	4	4	0	2	10	Hemiedaphic	Hemiedaphic 30	x
0	4	2	4	0	10	Hemiedaphic	Hemiedaphic 31	
0	4	2	0	4	10	Hemiedaphic	Hemiedaphic 32	x
0	4	0	4	2	10	Hemiedaphic	Hemiedaphic 33	x
0	2	4	4	0	10	Hemiedaphic	Hemiedaphic 34	
0	2	4	0	4	10	Hemiedaphic	Hemiedaphic 35	
0	2	2	4	2	10	Hemiedaphic	Hemiedaphic 36	
0	2	0	4	4	10	Hemiedaphic	Hemiedaphic 37	x
0	0	4	4	2	10	Hemiedaphic	Hemiedaphic 38	
0	0	2	4	4	10	Hemiedaphic	Hemiedaphic 39	
4	4	0	0	0	8	Hemiedaphic	Hemiedaphic 40	x
4	2	2	0	0	8	Hemiedaphic	Hemiedaphic 41	
4	2	0	0	2	8	Hemiedaphic	Hemiedaphic 42	

Continue...

Continuation...

4	0	4	0	0	8	Hemiedaphic	Hemiedaphic 43	
4	0	2	0	2	8	Hemiedaphic	Hemiedaphic 44	
4	0	0	4	0	8	Hemiedaphic	Hemiedaphic 45	
4	0	0	0	4	8	Hemiedaphic	Hemiedaphic 46	
0	4	4	0	0	8	Hemiedaphic	Hemiedaphic 47	x
0	4	2	0	2	8	Hemiedaphic	Hemiedaphic 48	
0	4	0	4	0	8	Hemiedaphic	Hemiedaphic 49	x
0	4	0	0	4	8	Hemiedaphic	Hemiedaphic 50	x
0	2	4	0	2	8	Hemiedaphic	Hemiedaphic 51	
0	2	2	4	0	8	Hemiedaphic	Hemiedaphic 52	
0	2	2	0	4	8	Hemiedaphic	Hemiedaphic 53	
0	2	0	4	2	8	Hemiedaphic	Hemiedaphic 54	x
0	0	4	4	0	8	Hemiedaphic	Hemiedaphic 55	
0	0	4	0	4	8	Hemiedaphic	Hemiedaphic 56	
0	0	2	4	2	8	Hemiedaphic	Hemiedaphic 57	
0	0	0	4	4	8	Hemiedaphic	Hemiedaphic 58	
4	2	0	0	0	6	Epigeic	Epigeic 1	x
4	0	2	0	0	6	Epigeic	Epigeic 2	
4	0	0	0	2	6	Epigeic	Epigeic 3	
0	4	2	0	0	6	Epigeic	Epigeic 4	
0	4	0	0	2	6	Epigeic	Epigeic 5	x
0	2	4	0	0	6	Epigeic	Epigeic 6	
0	2	2	0	2	6	Epigeic	Epigeic 7	
0	2	0	4	0	6	Epigeic	Epigeic 8	x
0	2	0	0	4	6	Epigeic	Epigeic 9	x
0	0	4	0	2	6	Epigeic	Epigeic 10	
0	0	2	4	0	6	Epigeic	Epigeic 11	
0	0	2	0	4	6	Epigeic	Epigeic 12	
0	0	0	4	2	6	Epigeic	Epigeic 13	x
4	0	0	0	0	4	Epigeic	Epigeic 14	x
0	4	0	0	0	4	Epigeic	Epigeic 15	x
0	2	2	0	0	4	Epigeic	Epigeic 16	
0	2	0	0	2	4	Epigeic	Epigeic 17	x
0	0	4	0	0	4	Epigeic	Epigeic 18	
0	0	2	0	2	4	Epigeic	Epigeic 19	
0	0	0	4	0	4	Epigeic	Epigeic 20	x
0	0	0	0	4	4	Epigeic	Epigeic 21	x
0	2	0	0	0	2	Epigeic	Epigeic 22	x
0	0	2	0	0	2	Epigeic	Epigeic 23	
0	0	0	0	2	2	Epigeic	Epigeic 24	x
0	0	0	0	0	0	Epigeic	Epigeic 25	x

Microbiological properties

The enzymes studied are involved in the biogeochemical cycles of N - potential nitrification, PN (Berg and Rosswall, 1985); P, acid phosphatase, AP (Margesin, 1996); and microbial activity, dehydrogenase activity, DHA (Öhlinger, 1996).

Determination of microbial biomass carbon (MBC) was performed with the fumigation-extraction method (Vance et al., 1987). Basal respiration (BR; CO_2-C) was estimated using 50 g of soil

(Alef and Nannipieri, 1995), by quantifying the CO_2 released from the microbial respiration process in a period of 10 days of incubation at 28 °C. Eco-physiological parameters, such as metabolic quotient (qCO$_2$) (Anderson and Domsch, 1993) and microbial quotient (qMic) (Sparling, 1992), were calculated by dividing basal respiration by MBC, and by the expression (MBC/Corg)/10, respectively.

Mycelium length of arbuscular mycorrhizal fungi (AMF) was assessed using the method proposed by Melloni and Cardoso (1998). The mycorrhizal infectivity of the soil was measured as percent of infection (mycorrhizal inoculum potential or MIP), as described by Reeves et al. (1979).

Fresh soil samples were used to quantify microbiological properties, and all results were expressed on a dry soil basis.

Physical and chemical properties

Soil samples were analyzed for the following physical properties: particle size (Gee and Bauder, 1986), moisture, bulk density (Bd), total porosity (TP), microporosity (Mi), and macroporosity (Ma) according to Claessen (1997); biopores (BP) according to Ringrose-Voase (1991); and aggregate stability (AS) according to Kemper and Chepil (1965). Soil resistance to penetration (SRP) was performed using the "Falker penetroLOG" penetrometer to a depth of 0.10 m. Chemical properties analyzed were pH (in H_2O), exchangeable cations (Al^{3+}, Ca^{2+}, Mg^{2+}, and K^+), available phosphorus (P), total organic carbon (TOC) content, and total nitrogen (TN) content according to Tedesco et al. (1995); and particulate organic carbon (POC) according to Cambardella and Elliott (1992).

Statistical analysis

Prior to statistical analysis, the number of springtails was used to estimate density (ind m^{-2}), and data (without outliers) were transformed ($\sqrt{x+1}$), if necessary, to comply with the requirements of analysis of variance (Anova; normal distribution and homoscedasticity of error variances). Main effects in Anova was used to compare the density and richness of springtails and the microbiological, physical, and chemical properties between the different land uses using the software STATISTICA 7.0. Analyses were conducted at the LUS level, using the value of the three municipalities (nine soil samples per municipality) as replicates (n = 27 in each LUS). Means presented in figures were calculated using non-transformed data. Comparisons of means were performed using Tukey's HSD test ($p < 0.05$).

In order to study the community structures, the morphotypes were ranked (transformed Ln) in decreasing order of their density, and a SIMPER analysis was performed to identify which EM groups and morphotypes were responsible for differences between the systems using the software PRIMER 5.2.6. In addition, we calculated a Pearson correlation matrix between all variables pairwise for each land use system, using the three municipalities as co-variable, with a significance threshold of $p < 0.05$ to analyze the relationship between Collembola, EM groups, and soil properties, using STATISTICA 7.0.

RESULTS

Community structure of Collembola

The two LUS (habitat types – NT and ICL) showed different springtail structural diversity. Although the two LUS have the same density of springtails (Figure 2a), the community structure varied based on the EM groups. In NT, there was better distribution among groups, while in the ICL, a predominance of edaphic springtails was observed.

Collembola density (7,130 ind m^{-2} in NT and 7,074 ind m^{-2} in ICL) and groups of edaphic springtails (3,094 ind m^{-2} in NT and 4,829 ind m^{-2} in ICL) were not significantly different between LUS (Figures 2a and 2b). In contrast, the hemiedaphic (1,320 ind m^{-2} in NT and

717 ind m^{-2} in ICL) and epigeic (2,716 ind m^{-2} in NT and 1,528 ind m^{-2} in ICL) groups exhibited differences (Figures 2c and 2d), and proved to be more sensitive than the use of adopted indicators, resulting in a better reference in regard to ecosystem functioning. In fact, SIMPER analysis confirms that hemiedaphic and epigeic groups are more sensitive because they are responsible for major dissimilarities between LUS at levels of 89 % (hemiedaphic) and 78 % (edaphic).

Richness morphotypes for Collembola in NT (5.6) was higher than in ICL (3.7) (Figure 2e). The same was observed for richness of hemiedaphic (1.6 in NT and 0.5 in ICL) and epigeic (2.5 in NT and 1.5 in ICL) EM groups (Figures 2g and 2h). This reinforces the discriminating power of EM groups.

Rank abundance of morphotypes

In total, 38 morphotypes of Collembola were recorded in this study, 11 belonging to the edaphic EM group, 14 hemiedaphic, and 13 epigeic (Table 3). Figure 3 shows the number of morphotypes in each group and their contribution to each LUS. Both systems had a different number of morphotypes and composition; NT showed the highest number of morphotypes in the three EM groups.
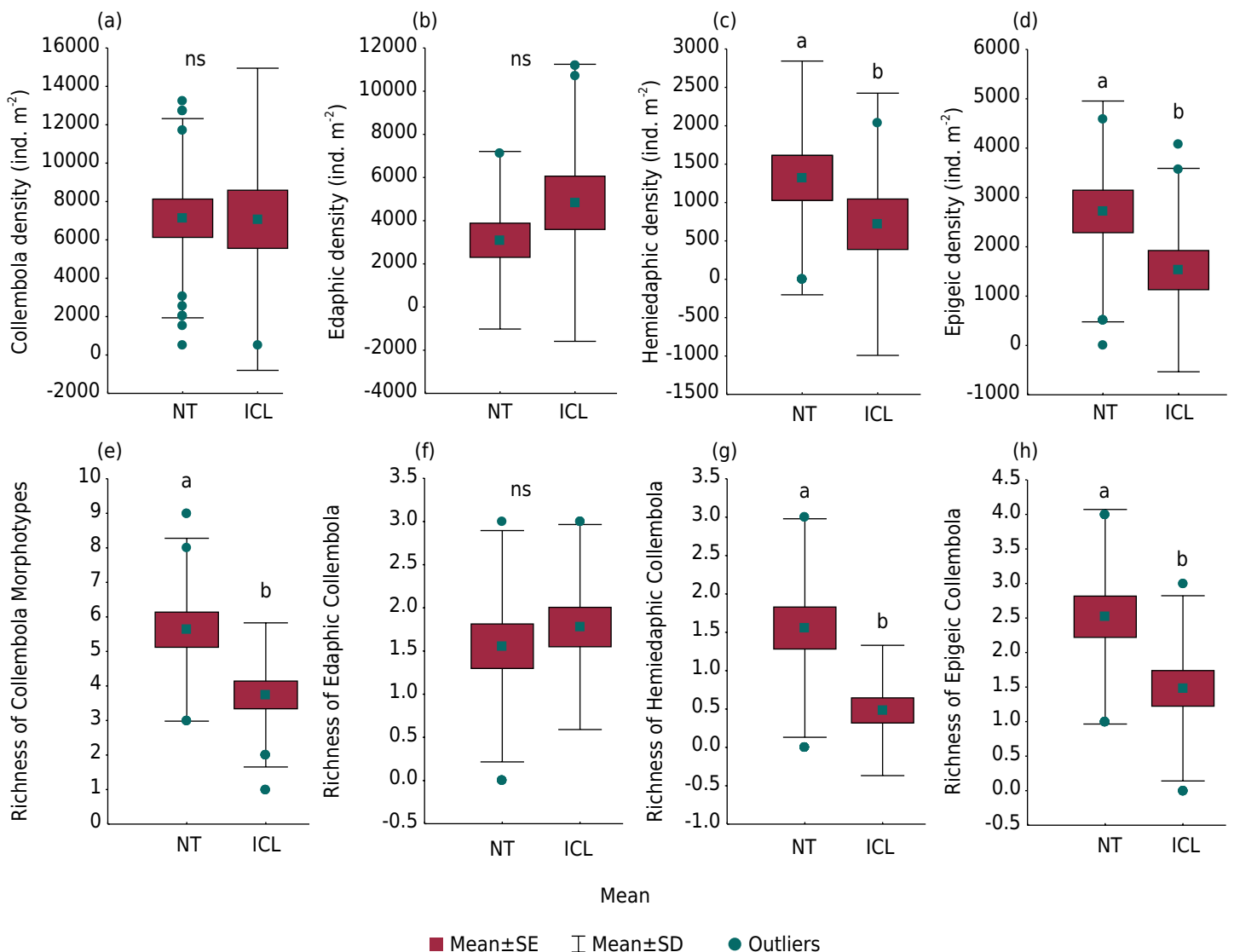
Figure 2. Density and richness of springtails and eco-morphological groups in land use systems - no-tillage (NT) and integrated crop-livestock (ICL). Different letters indicate significant differences (Tukey HSD test, p<0.05). ns: no significance.
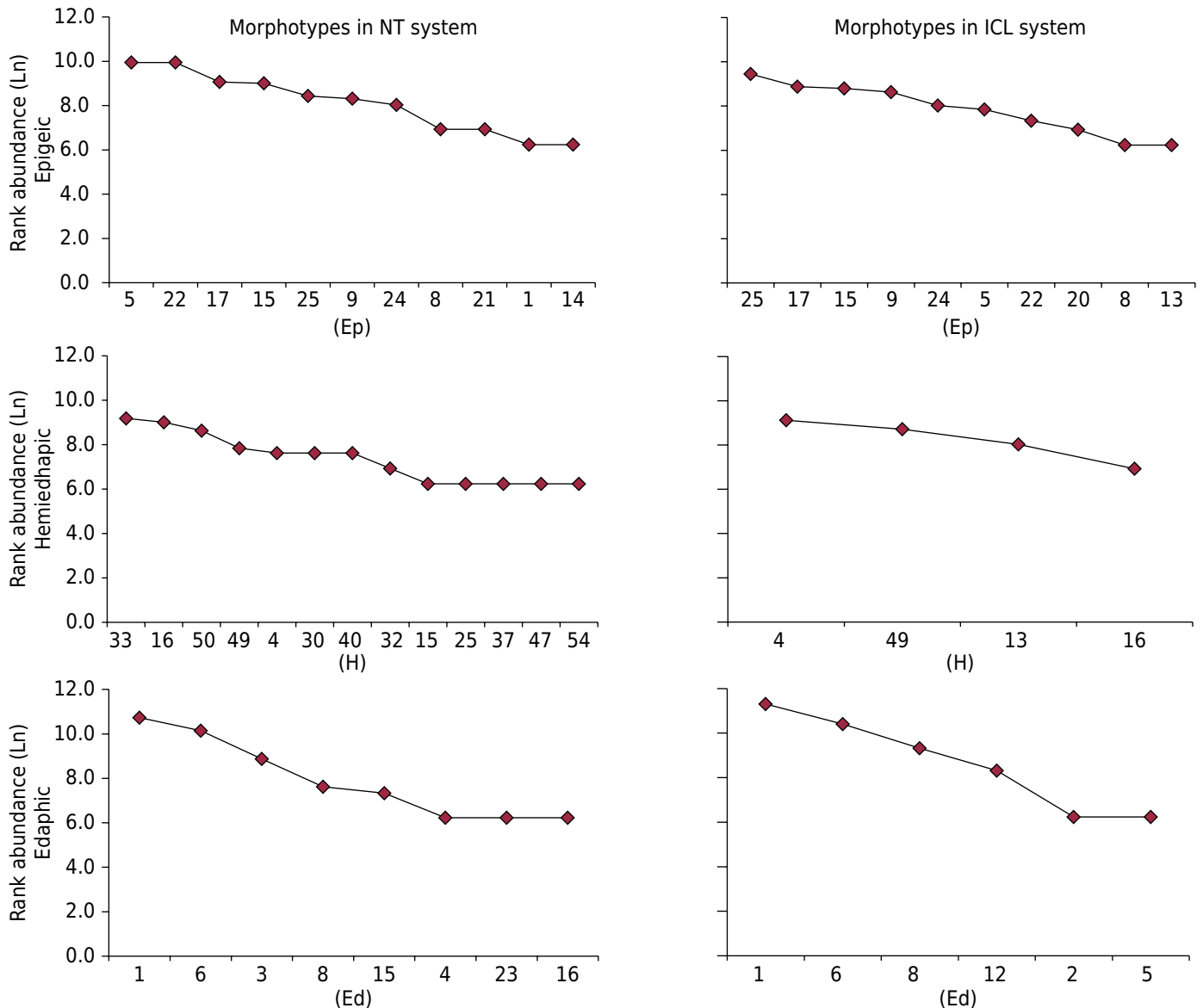
Figure 3. Rank abundance of Collembola morphotypes sampled, where Ed = Edaphic, H = Hemiedaphic, and Ep = Epigeic.

In the edaphic group, the Ed1 and Ed6 morphotypes were dominant in both systems, with similar abundances. This confirms the SIMPER analysis, where Ed1 (33 %) and Ed6 (26 %) had the highest contributions to dissimilarity between areas, followed by the Ed3 morphotype (13 %), Ed8 (13 %), and Ed23 (7 %), while Ed3 and Ed23 were exclusive to the NT system.

For the hemiedaphic group, the NT system showed 3.25 times more morphotypes that the ICL system. Morphotypes H4, H49, and H16 appeared in both systems. According to SIMPER analysis, the major contributions to dissimilarity were from H4 (24 %) and H49 (21 %) morphotypes; followed by H33 with 16 % (exclusive to the NT); H16 with 14 %; and H50 (exclusive to the NT), H4, and H32 (exclusive in the NT), with 10 %, 4 %, and 3 %, respectively.

Epigeic morphotype composition was better distributed between the LUS, but the morphotypes Ep1, Ep14, and Ep21 were exclusive in NT, and Ep13 and Ep20 in ICL. However, SIMPER analysis showed the morphotypes which most contributed to dissimilarity in the systems were Ep17 (18 %), Ep22 (17 %), Ep5 (16 %), Ep9 (15 %), Ep25 (11 %), Ep15 (9 %), and Ep24 (7 %).

Correlations of Collembola and soil properties in land use systems

The mycelium length of arbuscular mycorrhizal fungi, pH, P, Al, macroporosity, and sand were higher in the NT system than in the ICL system (Table 4). Soil properties affected EM groups, determining the composition of the community structure of Collembola (Table 5). Hemiedaphic and epigeic groups showed correlations with some of the biological, chemical, and physical soil properties in both LUS, especially in NT.

In the NT, the hemiedaphic and epigeic groups were more influenced by changes in soil properties, while the edaphic group showed no correlations with the properties studied. However, the groups of the ICL system were less influenced by soil properties.

DISCUSSION

Soil fauna is vulnerable to the mechanical disturbance caused by soil tillage. It is important to adopt tillage methods which promote the highest possible yield while causing minimum damage to microorganisms and fauna in the soil (Petersen, 2002b) and also find properties that indicate changes in soil quality as a result of the uses adopted.

Table 4. Soil properties (mean ± SD) in land management systems, no-tillage and integrated crop-livestock, of the Catarinense Plateau (state of Santa Catarina, Brazil)

Soil property	No-tillage	Integrated crop-livestock
MBC (μg C g^{-1})	280 ± 113	284 ± 66
BR (μg g^{-1} h^{-1} CO$_2$-C)	32.04 ± 12.95	36.91 ± 12.70
qCO$_2$ (μg g^{-1} h^{-1} CO$_2$-C)	0.16 ± 0.13	0.14 ± 0.07
qMic (%)	0.80 ± 0.33	0.80 ± 0.25
AP (μg pNP^{-1} g dm^{-1} h^{-1})	319 ± 36	309 ± 58
PN (μg NO$_2$-N^{-1} g dm^{-1} 5 h^{-1})	876 ± 496	642 ± 253
DHA (μg pNP^{-1} g dm^{-1} h^{-1})	13.67 ± 3.63	12.71 ± 5.30
AMF - ML (m g^{-1})	0.72 b ± 0.23	0.84 a ± 026
AMF - MIP (%)	44.26 ± 14.11	53.81 ± 8.84
TOC (g kg^{-1})	36.02 ± 12.10	36.84 ± 8.32
POC (g kg^{-1})	1.71 ± 0.73	2.42 ± 1.75
TN (g kg^{-1})	2.61 ± 0.79	2.70 ± 0.48
pH(H$_2$O)	5.57 a ± 0.26	5.32 b ± 0.24
P (mg dm^{-3})	5.67 b ± 2.01	8.57 a ± 5.29
K (mg dm^{-3})	128 ± 64	135 ± 51
Al^{3+} (cmol$_c$ dm^{-3})	0.13 b ± 0.37	0.44 a ± 0.49
Ca^{2+} (cmol$_c$ dm^{-3})	7.47 ± 1.56	7.22 ± 1.30
Mg^{2+} (cmol$_c$ dm^{-3})	3.81 ± 0.81	3.77 ± 1.45
Moisture (%)	38.74 ± 9.58	39.87 ± 8.55
Bd (Mg m^{-3})	1.01 ± 0.10	1.01 ± 0.06
TP (m^3 m^{-3})	0.650 ± 0.032	0.652 ± 0.023
Ma (m^3 m^{-3})	0.199 a ± 0.023	0.186 b ± 0.022
Mi (m^3 m^{-3})	0.451 ± 0.037	0.466 ± 0.029
BP (m^3 m^{-3})	0.015 ± 0.017	0.015 ± 0.015
SRP (MPa)	1.85 ± 0.69	1.94 ± 0.60
Sand (g kg^{-1})	185.2 b ± 104.0	259.2 a ± 187.0
Clay (g kg^{-1})	471.2 ± 227.7	499.5 ± 221.8
Silt (g kg^{-1})	338.0 ± 150.0	241.3 ± 66.9
AS %	2.03 ± 0.28	2.14 ± 0.42

MBC: microbial biomass carbon; BR: basal respiration; qCO$_2$: metabolic quotient; qMic: microbial quotient; AP: acid phosphatase; PN: potential nitrification; DHA: dehydrogenase; AMF: arbuscular mycorrhizal fungi, ML: mycelium length, MIP: mycorrhizal inoculum potential; TOC: total organic carbon; POC: particulate organic carbon; TN: total nitrogen; pH in H$_2$O (1:2.5); Bd: bulk density; Ma: macroporosity; Mi: microporosity; BP: biopores; SRP: soil resistance to penetration; AS: aggregate stability. Different letters indicate significant differences (Tukey HSD test, p<0.05).

Table 5. Correlations between springtail abundance, eco-morphological groups, and soil properties in each land use system, no-tillage (NT) and integrated crop-livestock (ICL), of the Catarinense Plateau (state of Santa Catarina, Brazil)

	No-tillage				Integrated crop-livestock			
	Coll	Edap	Hemied	Epig	Coll	Edap	Hemied	Epig
MBC	ns	ns	0.53**	0.51*	0.48*	0.48*	0.50*	ns
BR	ns	ns	ns	0.42*	ns	ns	ns	ns
qMic	ns	ns	ns	ns	ns	0.51*	0.51*	-0.43*
PN	ns	ns	0.63**	0.39*	ns	ns	ns	ns
DHA	ns	ns	ns	ns	ns	ns	ns	-0.61**
AMF-ML	ns	ns	0.60***	0.70**	ns	ns	ns	ns
AMF-MIP	ns	ns	0.40*	0.52**	ns	ns	ns	0.61***
TOC	ns	ns	0.76***	0.66***	ns	ns	ns	0.47*
POC	ns	ns	0.67***	0.71***	ns	ns	ns	0.50**
TN	ns	ns	0.72***	0.65***	ns	ns	ns	0.46*
pH(H_2O)	ns	ns	ns	ns	ns	ns	-0.45*	ns
P	ns	ns	0.40*	ns	ns	ns	ns	ns
K	ns	ns	-0.54**	-0.53**	ns	ns	ns	-0.43*
Ca	ns	ns	0.68***	0.50*	-0.48*	-0.46*	-0.46*	ns
Mg	ns	ns	0.69***	0.54**	ns	ns	ns	0.55**
Moisture	ns	ns	0.70***	0.68***	ns	ns	ns	ns
Bd	ns	ns	-0.73***	-0.69***	ns	ns	ns	ns
Ma	ns	ns	0.41*	0.52**	ns	ns	ns	ns
Sand	ns	ns	0.61**	0.62**	ns	ns	ns	0.50**
Clay	ns	ns	-0.52**	-0.52**	ns	ns	ns	-0.49*

Coll: collembola; Edap: edaphic; Hemied: hemiedaphic; Epig: epigeic; MBC: Microbial Biomass Carbon; BR: basal respiration; qCO$_2$: metabolic quotient; qMic: microbial quotient; PN: potential nitrification; DHA: dehydrogenase; AMF: arbuscular mycorrhizal fungi, ML: mycelium length, MIP: mycorrhizal inoculum potential; TOC: total organic carbon; POC: particulate organic carbon; TN: total nitrogen; pH in H_2O (1:2.5); Bd: bulk density; Ma: macroporosity. Asterisks indicate significance: * p<0.05, ** p<0.01, *** p < 0.001. ns: not significant.

Few studies have worked with the possibility of using EM groups of springtails as indicators of the effects of soil use (Parisi, 2001; Parisi et al., 2005; Vandewalle et al., 2010). Changes in the density and community structure of springtails can have long-term consequences in provision of ecosystem services and show differences between soil uses systems, indicating which system is more conservationist. In addition, there are few studies that report on springtails in integrated crop-livestock systems (Portilho et al., 2011; Bartz et al., 2014a). Moreover, there are no reports of studies exclusively comparing the NT and ICL systems.

Collembola community structure differentiates land use systems

This study found 7,130 ind m^{-2} in NT and 7,074 ind m^{-2} in ICL (Figure 2a). In fact, the total density value for Collembola was not enough to demonstrate differences between systems. Domínguez et al. (2014) reported a density of <6,000 ind m^{-2} of Collembola and there were similar abundances in natural grasslands, organic farming, and no-tillage, with significantly less abundance in conventional tillage. Nevertheless, the density is relevant and might indicate changes between the systems studied, as reported by Sousa et al. (2006), where the abundance of Collembola decreased along a gradient of soil-use intensification in a typical Mediterranean landscape dominated by cork-oak.

When EM groups are observed, the community structure is different between the LUS, confirming our hypothesis. The density and richness of EM hemiedaphic and epigeic groups increased significantly when tillage changed (Figures 2c, 2d, 2g, and 2h). This seems to imply that the NT system has a better-structured surface (litter layer) than

the ICL, since these two groups occupy surface niches up to 0.05 m deep and have greater ability for dispersion, and Ma had a positive correlation with NT (Table 5) and was significantly higher in NT (Table 4). In fact, the dispersing ability and preference habitat of morphotypes restrict the ability to reach and occupy different niches of an ecosystem (Auclerc et al., 2009). In contrast, as there were no differences for the edaphic group and this group had the highest densities, this suggests that in both systems the mineral soil is physically well structured (Bd 1.01 Mg m^{-3}; Table 4), since low dispersion capacity requires in habitat quality.

Thus, the use of total density of springtails without differentiating morphotypes did not help in differentiating the LUS. Since Collembola density did not differ between the LUS, it appears to be an indicator with low sensitivity to changes in land use. However, the richness of collembolans regarding morphotypes, a more refined tool, indicates differences between the systems studied. Likewise, the hemiedaphic and epigeic morphotypes also indicate differences between the systems, though this difference was not found in edaphic morphotypes (Figure 2). This may be related to the fact that the NT system is geared to crop production while the ICL system is used for animal and plant production; the entrance of animals can affect the physical structure of the soil surface, resulting in these differences between morphotypes. The presence of certain morphotypes indicated that the SIMPER analysis explains the variation in soil use systems. Thus, these morphotypes may come to be considered as the most important in these LUS (Figure 3). However, from identification on the species level, these morphotypes can provide information for possible use as bioindicators and what ecosystem services that morphotypes are able to change . It is also important to identify which driver influences the presence of morphotypes in these systems.

Although eco-morphological groups were separated based on their traits and occurrence in the soil and litter (adaptation to the soil environment), vertical stratification by sampling at different depths in the field was not performed. These field samples are important in order to confirm that the morphological traits measured in the laboratory reflect stratification in the field. Christiansen (1964) reports that most of these animals are found in the 0.00-0.10 m profile, depending on the habitat type, although some species are uniformly distributed throughout the profile.

Relationships of soil properties with collembolan communities

Important environmental factors which determine soil fauna composition include vegetation type and biological, chemical, and physical soil properties. These factors affect soil processes in the Collembola communities and vary according to the land use system.

Their relatively large population size and potential influence in nutrient mobilization make Collembola an important component in site productivity and forest system processes (Eaton et al., 2004). In agricultural lands, the existence of a positive correlation between nitrogen and Collembola density was verified (Filser et al., 1999). Similarly, in this study, positive correlations were found between total nitrogen and hemiedaphic ($r = 0.72$, $p<0.001$, in NT) and epigeic ($r = 0.65$, $p<0.001$, in NT; and $r = 0.46$, $p<0.05$, in ICL) groups (Table 5). Likewise, positive correlations were found between potential nitrification groups and hemiedaphic ($r = 0.63$, $p<0.01$) and epigeic ($r = 0.39$, $p<0.05$) groups, both in NT. Nitrogen mobilization by Collembola might be important for many ecosystems, but is insignificant in a fertilized agricultural soil (Schröder, 2008).

In our study, positive correlations were found between TOC and POC and hemiedaphic (in NT) and epigeic (in NT and ICL) springtails (Table 5). According to Chamberlain et al. (2006), the activities of Collembola have been shown to translocate C from surface litter into the soil, and to enhance the quantity of C in litter available to the soil microbial community. This corroborated the results for the NT system, since the MBC showed positive correlations with semiedaphic ($r = 0.53$, $p<0.01$) and epigeic ($r = 0.51$, $p<0.05$)

groups. However, this did not occur for the ICL system, in which correlations occurred for Collembola ($r = 0.48$, $p<0.05$), edaphic ($r = 0.48$, $p<0.05$), and hemiedaphic groups ($r = 0.50$, $p<0.05$).

Our results showed relationships between Collembola and eco-morphological groups and exchangeable cations (Ca^{2+}, Mg^{2+}, K^+) (Table 5), as already reported in the literature (Cutz-Pool et al., 2007). Nevertheless, the direct action of these soil properties on collembolan species is difficult to show because ecological information on this relationship is still lacking, although, according to Cutz-Pool et al. (2007), they have a significant effect on the composition of Collembola populations.

Densities of springtails are correlated negatively with Bd and positively with macroporosity (Table 5). In most cases, high Bd decreases macroporosity, and this strongly determines the living conditions for Collembola, which inhabit mainly macropores and often show little to no ability to burrow through the mineral soil (Beylich et al., 2010). The absence of correlation between edaphic group and soil density may indicate that, in both systems, depths below 0.05 m were physically well structured for collembolan species (Table 5). Correlations were found in several studies between an increase in soil density and a decrease in the abundance and diversity of edaphic collembolan species (Heisler and Kaiser, 1995; Dittmer and Schrader, 2000). These studies show that soil structure and inhabitable pore space are key properties in the density of edaphic springtails (Larsen et al., 2004), promoting the highest density of soil organisms (Figure 2).

The life-strategy of Collembola (e.g., edaphic, hemiedaphic, and epigeic groups) is differently affected by the intensity of soil tillage, depending on particle size distribution that characterizes their habitat, in association with their ability or lack of ability to burrow (van Capelle et al., 2012). This study showed positive correlations with sand and negative with clay for hemiedaphic and epigeic groups in NT and epigeic in ICL (Table 5), manifesting greater adaptability to sandy soils than clay. However, it was expected that there would be correlation with the edaphic group, since they appear to be most influenced by mineral soil.

Microbial biomass C interacts with higher trophic levels of the soil, as well as collembolan populations. In fact, these interactions with springtails occurred significantly with hemiedaphic ($r = 0.53$, $p<0.01$) and epigeic ($r = 0.51$, $p<0.05$) groups in NT; and collembolan ($r = 0.48$, $p<0.05$), edaphic ($r = 0.48$, $p<0.05$), and hemiedaphic ($r = 0.50$, $p<0.05$) groups in ICL. In addition, qMic correlated positively with the edaphic ($r = 0.51$, $p<0.05$) and hemiedaphic ($r = 0.51$, $p<0.05$) groups since the MBC also correlated positively with these groups (Table 5). The existence of these correlations may indicate a greater influence over the groups that act in the soil profile (below the 5 cm depth) in microbial biomass, because qMic is an indicator of the efficiency of use of organic matter by soil microorganisms. Negative correlation of qMic ($r = -0.43$, $p<0.05$) and the absence of correlation between MBC and the epigeic group may indicate the lack of influence of this group.

The AMF-ML showed correlations with hemiedaphic ($r = 0.60$, $p<0.001$) and epigeic ($r = 0.70$, $p<0.01$) EM groups in NT (Table 5), although the values were significantly higher in ICL. The correlations suggest trophic niche differentiation, and distinct differences in feeding strategy were indicated (Sechi et al., 2014). The higher amount of organic matter present in the soil promoted growth of certain populations of Collembola, which has fungivorous habits (Scheu and Folger, 2004; Sawahata, 2006), and positive correlations were found for TOC with the same groups (Table 5). In contrast, considering the correlations between AMF-MIP with hemiedaphic ($r = 0.40$, $p<0.05$) and epigeic ($r = 0.52$, $p<0.01$) groups in NT and the epigeic group ($r = 0.61$, $p<0.001$) in ICL (Table 5), the presence of Collembola can facilitate the infection of plants by dispersing AMF inoculum. In summary, grazing by microarthropods (Collembola) can directly and indirectly modulate AMF performance, which, in turn, can impose infection potential from AMF propagules on the soil (Caravaca and Ruess, 2014). These results point to these important trophic interactions between collembolans and AMF in NT.

CONCLUSIONS

Not only the presence of certain Collembola species, but also the diversity of EM groups is important for soil processes, as soil fertility by feeding on soil microorganisms and dead organic matter.

Collembola EM groups are a better predictor for ecosystem functioning than Collembola density, since they are more easily associated with ecosystem services.

The richness of Collembola morphotypes was more effective in demonstrating differences between land use systems than density.

Variations in morphotypes show correlations with soil properties, whereas the mere presence of Collembola does not.

Even without using the taxonomy of collembolan species, this approach can distinguish differences between soil uses, reducing laboratory analysis time, and may help clarify relationships between collembolan and soil ecosystem services.

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