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Change of collembolan (Hexapoda: Collembola) community structure related to anthropic soil disturbance

Cambio de la estructura de la comunidad de colémbolos (Hexapoda: Collembola) en relación con el disturbio antrópico de los suelos

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Abstract

In order to evaluate the effects of the anthropic impact on the structure of de soil collembolan community, three different soil uses were researched: agricultural fields (AG) with 50 years of continuous farming, pastures entering the agricultural cycle (CG), and naturalized grasslands (NG). The study was carried out in fields of Chivilcoy (34°53'49 S, 60°01'09 W, elev. 60 m) and Navarro (34°51'30 S, 59°12'25 W, elev. 43 m), Buenos Aires Province, Argentina. For each of the three uses, three fields were selected as replicates, with three soil samples per replicate and sample date (10) for a total of 216 samples analyzed. Collembolans (Hexapoda: Collembola) were extracted and identified to family level. Five families were found: Hypogastruridae, Onychiuridae, Isotomidae, Entomobryidae, and Katiannidae. Soils were also characterized by means of physical and chemical analyses. The index of degree of change of collembolan diversity was calculated with the biological data. The results show that the biological index of degree of change can detect soil use effects on the collembolan community. Somewhat surprisingly, the index showed that the diversity of collembolans was higher in the high anthropic impact site AG, followed by CG and lowest in NG. The results also show that collembolan families respond differently to soil use. The families Hypogastruridae, Onychiuridae, and Isotomidae presented differences between systems. Therefore, collembolan community structure can be a useful tool to assess agricultural practices´ impacts on soil.

Keywords
soil use intensity • collembolans • anthropic impact

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RESUMEN

Con el objetivo de evaluar el efecto que produce el impacto antrópico sobre la estructura de la comunidad de colémbolos, tres usos diferentes del suelo fueron investigados: campos de agricultura (AG) con 50 años de agricultura continua, pasturas ingresando al ciclo agrícola (CG) y campos naturalizados (NG). El estudio fue llevado a cabo en campos de los partidos de Chivilcoy (34°53'49 S, 60°01'09 W, elev. 60 m) y Navarro de la provincia de Buenos Aires, Argentina. Para cada uno de los tres usos del suelo, tres campos fueron seleccionados como réplicas. Cada muestreo consistió en tres muestras de suelo por réplica y por fecha de muestreo (10) para un total de 216 muestras recolectadas y analizadas. Los colémbolos fueron extraídos de las muestras e identificados a nivel de familia. Se identificaron cinco familias: Hypogastruridae, Onychiuridae, Isotomidae, Entomobryidae y Katiannidae. Los suelos fueron además caracterizados mediante análisis físicos y químicos. Con los datos biológicos se calculó el índice de grado de cambio de la diversidad de colémbolos. Los resultados muestran que el índice biológico del grado de cambio puede detectar los efectos del uso del suelo sobre la comunidad de colémbolos. Sorpresivamente, el índice muestra que la diversidad de colémbolos medida a través del índice de grado de cambio es más alta en los sitios de mayor impacto antrópico (AG), seguido de CG y la menor diversidad en el sitio de menor impacto (NG). Los resultados muestran además que las familias de colémbolos responden de manera diferente al uso del suelo. Las familias Hypogastruridae, Onychiuridae e Isotomidae presentaron diferencias entre los usos. En consecuencia, la estructura de la comunidad de colémbolos puede ser una herramienta útil para evaluar el impacto en el suelo de las prácticas agrícolas.

Palabras clave
intensidad de uso del suelo • colémbolos • impacto antrópico

INTRODUCTION

It is increasingly recognized that community structure and composition may be used as ecological state indicators (11, 14, 18), and the use of biological information to assess ecological quality is currently an active field of research.

While several tools have been already adopted for the use of invertebrate community composition and structure as ecological state indicators in freshwater ecology in both Europe (20, 44, 52), and in the US (2, 3), the development of these tools is lagging behind for terrestrial ecosystems.

Several authors have proposed new methods to evaluate soil quality, based on invertebrate assemblages, particularly the arthropods (1, 8).

Some of these methods are based on the information provided by only one taxon (28), while others are based on a general evaluation of the presence and abundance of the soil arthropods (6, 11, 48, 53). Even though diversity is a characteristic that can be used to differentiate ecosystem structure, another important characteristic of a system is the fluctuation in the abundance of its components (13).

Soil invertebrates play a very significant role in the different processes that occur in the soil, influencing its formation, nutrient cycles, organic matter decomposition, porosity, aggregates' formation, and water retention capacity. Soil structure, can also be related to the edaphic biota, because they increase soil specific surface, which is in turn well correlated to water retention capacity (45). Earthworms in particular, contribute not only to soil structure but also to soil physical stability (22). In addition, each component of the edaphic communities has a specific role in its specific niche that can hardly be replaced by others present in the system (32).

Furthermore, soil invertebrate community composition and structure are strongly influenced by soil characteristics and thus, are useful for the development of tools for soil quality assessment (4, 17) and soil sustainability (48, 53).

The diverse ecosystem services that the edaphic fauna provide play a crucial role on soil sustainability, and it can have both direct and indirect impacts on soil sustainability. Direct impacts are those where specific organisms affect crop yield immediately. Indirect ones include those provided by soil organisms participating in carbon and nutrient cycles, soil structure modification, and food web interactions that generate ecosystem services that ultimately affect productivity.

Agriculture has been identified as one of the greatest contributors to the loss of biodiversity due to the large amount of land allocated to this practice. Agricultural activities such as tillage, drainage, crop rotation, grazing, and the intensive use of pesticides and fertilizers, have all strong effects on the flora and fauna species found in the soil (42). However, reduced or no-tillage systems can be useful in terms of maintaining native species populations (35).

Collembolans (Hexapoda: Collembola) are one of the most abundant and varied groups among soil organisms, playing a very significant role in nutrient cycling and soil microstructure (46). They also respond to a variety of environmental and ecological factors, such as changes in soil chemistry, microhabitat configuration, and forestry and agricultural practices (29). Is in this context that the use of collembolans as indicators of ecological state has been recommended by several authors (2, 53).

The response of the Collembola community to changes in the agricultural practices is wide ranging, but in general the agricultural soils are expected to have low species richness, including the disappearance of key functional groups (50). In this way, the reduction in biodiversity is usually associated with an increase of management intensity and a general reduction in the environmental heterogeneity (21). The index of degree of change developed by Cancela Da Fonseca and Sarkar (1996), integrates abundance analysis, richness and diversity in a way that provides an analysis of the structure of the community, and allows for comparisons between different communities.

This study was performed in the rolling pampas in the Argentine pampean ecoregion (54), one of the most extensive and productive agricultural regions in the world. Since the mid 1970s, this region has suffered an increase in agriculture intensification, characterized by the incorporation of new technology, increased production and changing the use of a large number of hectares from cattle grazing to agriculture (54).

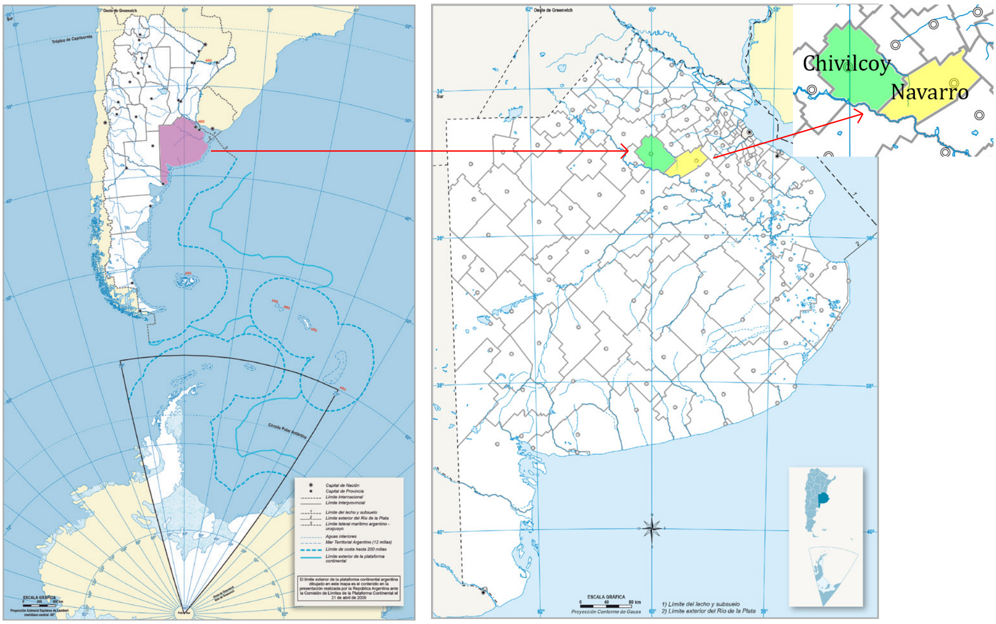
In this context, the objective of this work was to evaluate the degree of change in the structure of the soil collembolan community as an indicator of the degree of anthropic impact, under the hypothesis that the anthropic impact of different agricultural practices affects the structure of the collembolan community lowering diversity and structure when compared to naturalized grasslands.

MATERIAL AND METHODS

The study was carried out in fields of Chivilcoy (34°53'49 S, 60°01'09 W, 60 m a. s. l.) and Navarro (34°51'30 S, 59°12'25 W, 43 m a. s. l.), Buenos Aires Province, Argentina (figure 1). The soils of the sampling sites were all typical Argiudols, order Mollisols (52).

Three different management systems were evaluated: 1) A naturalized grassland system (NG), old and abandoned grasslands without anthropic influence for at least 50 years; 2) A cattle grazing system (CG), fields with mixed history of agriculture and livestock; and 3) An agricultural system (AG), fields under constant intensive agriculture for 50 years and under no-tillage agriculture during the last 16 years prior to the start of this work.

For each management system, 3 different sites were selected as replicates and in each replicate 3 random samples were taken each one of the eight sampling dates. Samplings were performed every three months over a 2 year period, in order to maximize the collembolan abundance and diversity of the samplings. Therefore, a total of 216 samples were collected and analyzed. This sample size is similar to the number of samples collected in similar studies in Argentina (7, 26, 28). Samples for the extraction of the collembolans were taken from to the first 0 to 5 cm of soil, following Bardgett *et al*. (1993), and Hutson and Veitch (1983) who found that in a range of upland grassland soils, 92 to 98% of Acari and collembolans were extracted from the upper 0 to 2 cm soil. From these top 5 centimetres, a pooled 150 c^3. of an undisturbed sample was collected per random sample.



Source: National Geographic Institute / Fuente: Instituto Geográfico Nacional - República Argentina

Figure 1. Map showing the location of the sampling sites.

Figura 1. Mapa con la localización de los sitios de muestreo.

Upon arrival to the laboratory, collembolans were extracted from the soil by flotation, since this method was more efficient for Collembola extraction than the Berlesse system (47) and later classified to family level (36).

With the data obtained, the index of the degree of change in the biodiversity, proposed by Cancela da Fonseca and Sarkar (1996) was calculated for each soil use, following Cortet *et al*. (2002), and Mazzoncini *et al*. (2010).

In order to characterize the studied soils, physical (bulk density, electric conductivity, and mechanical resistance), and chemical variables (organic matter content, phosphorus content, total nitrogen, and pH) were analyzed from samples taken at the same moment and from the same sampling places as the collembolans. Microbiological variables (soil respiration and nitrogen fixing bacteria activity) were measured as well.

Statistical analysis

Physical and chemical characterization

With the physical and chemical variables, a discriminant analysis was performed to determine how these variables characterize the different environments.

Index of degree of change of the diversity of ecological systems

For the calculation of the degree of change of the diversity (Δ) between sites, this formula was used following Cancela da Fonseca and Sarkar (1996), and Cortet *et al.* (2002):

$$\Delta = [V(\ )+V(S)+V(n)+V(Hx)+V(Hy)]\ \dot{x}$$

where:

$\dot{x}$ = mean abundance of the taxonomic group
S = number of taxonomic groups
n = number of sample-units
Hx= group index of diversity (γ)
Hy= Shannon index of diversity

For parameters S, n, Hx, and Hy, the variation (V) for any parameter (m) is calculated as:

$$Vm: (Em-Cm)/(Em+Cm)$$

where:

m = parameters $\dot{x}$, S, n, Hx, or Hy
Cm= value of parameter m of the system taken as a reference or control
Em= value of parameter m of the system to compare to

The index ranges from -1 to +1, being -1 when the evaluated environment shows lower diversity than the one it is compared to, and +1 when it is higher (15).

The behavior of this index was evaluated by its authors as well as Cortet *et al.* (2002) for taxonomic resolutions to order and higher. For this reason it was considered important to go a step further in this work, and use this index to collembolans and the families within, in the assumption that a lower taxonomic level could provide a better detail of the effects of anthropic activities on soil communities.

Abundance

A Kruskall-Wallis test was carried out for the abundance of each one of the collembolan families present between environments.

RESULTS

Physico-chemical characterization

Data on the physico-chemical variables measured are shown in table 1 (page 222). The discriminant analysis (figure 2, page 223) shows a clear separation between the two anthropized systems (CG and AG) and the natural environment (NG), given by a higher electric conductivity (EC), pH, mechanic resistance (MR), bulk density (BD), and microbiological acetylene reduction activity (ARA) in NG.

Table 1. Physical, chemical, and microbiological variables.

Tabla 1. Variables físicas, químicas y microbiológicas.

Parameter	Method	Sites		
		NG	CG	AG
P (ppm)	Kurtz y Bray	11 +/- 8.5 ac	15 +/- 12 b	14 +/- 12 bc
OM (%)	Walkey-Black	4 +/- 1.5 a	4 +/- 1.5 a	4 +/- 1.4 a
CE (dS/m)	Conductivimeter	1.5 +/- 1.3 a	0.8 +/- 0.5 b	0.7 +/- 0.5 c
Ph		7.5 +/- 1 a	6 +/- 0.6 b	6 +/- 0.5 b
Bulk density (gr/cm^3)	Porta	1.2 +/- 0.2 a	1.1 +/- 0.1 b	1.2 +/- 0.1 a
Hr (%)	calculation	0.2 +/- 0.1 a	0.3 +/- 0.1 b	0.2 +/- 0.1 a
N (%)	Kjeldahl	0.28 +/- 0.1 a	0.32 +/- 0.1 b	0.29 +/- 0.05 b
Nitrogenase activity (nanolitres of ethylene/g dry soil*incubation hour)	ARA	0.3 +/- 0.3 a	0.2 +/- 0.2 b	0.2 +/- 0.3 b
Respiration (mg de CO^2 produced/g dry soil per day)	Incubation in alkaline	0.09 +/- 0.06 a	0.07 +/- 0.05 b	0.05 +/- 0.05 c
MR 0-5 (Kg/cm^2)	Cone	10 +/- 6 a	2.5 +/- 3 b	5.5 +/- 4 c
MR 5=10 (Kg/cm^2)	Cone	13 +/- 7 a	5 +/- 5 b	8 +/- 5 c

Mean values and standard deviation of the different systems shown. NG: Naturalized grassland, CG: Cattle grazing, AG: Agricultural system. Values in the same row followed by the same letter are not significantly different from each other (Kruskal-Wallis p<0.05).

Se muestran valores de las medias y desviación estándar de los diferentes sistemas. NG: pastizal naturalizado, CG: sistema mixto, AG: sistema agrícola. Los valores con las mismas letras no presentan diferencias significativas unos de otros (Kruskal-Wallis p<0,05).

Between the two anthropogenic systems, the AG system presented higher phosphorus, humidity, and organic matter values, while the CG system presented higher nitrogen values. This analysis shows that Root 1 clearly separates the natural environment (NG) from the two anthropized environments.

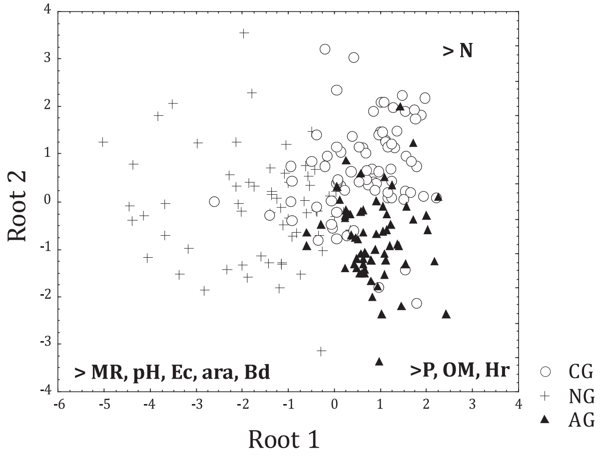
Index of degree of change of the diversity between systems

This procedure calls for the calculation to be made between the three soil uses by pairing them, thus obtaining three indexes of degree of change, according to the methodology proposed by Cortet *et al.* (2002).

The results of this analysis show that the index of degree of change between the NG and the CG environments is positive, which indicates that the biodiversity of soil collembolans community as measured by this index is higher in the CG environment (table 2a, page 223).

The index of degree of change between the CG and AG environments is also positive, which indicates that the biodiversity of soil collembolans community measured by this index is higher in the agricultural environment (table 2b, page 224).

Lastly, the index of degree of change between the grassland and agricultural environments is positive as well, which indicates that the biodiversity of soil collembolans community measured by this index is higher in the agricultural environment (table 2c, page 224).



NG: naturalized grassland, CG: cattle grazing, AG: agricultural system. Variables: bulk density (Bd), electric conductivity (Ec), mechanical resistance (MR), organic matter content (OM), Phosphorus content (P), total Nitrogen (N), pH, nitrogen fixing bacteria activity (ara).

NG: pastizal naturalizado, CG: sistema mixto, AG: sistema agrícola. Variables: densidad aparente (Bd), conductividad eléctrica (Ec), resistencia mecánica (MR), contenido de materia orgánica (OM), contenido de fósforo (P), Nitrógeno total (N), pH, actividad bacteriana fijadoras de nitrógeno (ara).

Figure 2. Discriminant analysis performed with the physical, chemical, and microbiological variables.

Figura 2. Análisis discriminante realizado con las variables físicas, químicas y microbiológicas.

Table 2a. Index of degree of change of the diversity between the naturalized grassland and the cattle grazing.

Tabla 2a. Índice de grado de cambio de la diversidad entre el pastizal naturalizado y el sistema mixto.

Cattle grazing-Naturalized grassland	V(ẋ)	V(S)	V(n)	V(Hx)	V(Hy)	Σ V	Δ
feb-09	0.0862	0.5	0	1	0.3944	1.8081	0.3616
may-09	0.5342	0.2	0.0588	0.7890	0.3160	1.8981	0.3796
aug-09	0.9782	0.2	0.6363	0.8198	0.7215	3.3559	0.6711
dec-09	0.6232	0	0	0.1761	0.0161	0.4631	0.0926
mar-10	0.4792	0.1428	0.0588	0.0866	0.0585	0.7084	0.1416
jun-10	0.7048	0	0.1428	0.1409	0.0815	1.0702	0.2140
sep-10	0.8406	0.1428	0.0588	0.3102	0.0977	1.4503	0.2900
dec-10	0.5107	-0.2	0	0.5915	0.2562	0.1370	0.0274
							0.2491

The sum of the last column being positive, indicates that the biodiversity measured by this index was greater in the CG environment. V: value of the degree of change of each parameter. ẋ: mean abundance of the taxonomic group, S: number of taxonomic groups, n: number of sample-unit, Hx: group index of diversity (γ), Hy: Shannon index of diversity.

La suma de la última columna es positiva, indicando que la diversidad medida por este índice fue mayor en el sistema CG. V: valor del grado de cambio de cada parámetro; ẋ: abundancia media del grupo taxonómico, S: número de grupos taxonómicos; n: número de unidades por muestra; Hx: índice de diversidad de grupo (γ); Hy: índice de diversidad de Shannon.

Table 2b. Index of degree of change of the diversity between the cattle grazing and the agricultural system.

Tabla 2b. Índice de grado de cambio de la diversidad entre el sistema mixto y el sistema agrícola.

Agricultural system-Cattle grazing	V(ẋ)	V(S)	V(n)	V(Hx)	V(Hy)	Σ V	Δ
feb-09	0.5835	-0.20	0.1667	-0.3372	-0.2676	-0.0547	-0.0109
may-09	0.1913	0	-0.1250	0.0276	-0.1551	-0.0612	-0.0122
aug-09	-0.6441	0	-0.0588	-0.4624	-0.1987	-1.3639	-0.2728
dec-09	0.3558	0	0.2308	-0.0640	0.1350	0.6576	0.1315
mar-10	0.2351	0	0.0588	0.2356	0.0619	0.5914	0.1183
jun-10	0.4792	0.1429	0.0588	0.3736	0.2128	1.2673	0.2535
sep-10	-0.3842	0.1111	0.0000	-0.1888	-0.0355	-0.4974	-0.0995
dec-10	0.4479	0.3333	0.0588	0.1816	0.1263	1.1480	0.2296
							0.0422

The sum of the last column being positive, indicates that the biodiversity measured by this index was greater in the AG environment. V: value of the degree of change of each parameter. ẋ: mean abundance of the taxonomic group, S: number of taxonomic groups, n: number of sample-unit, Hx: group index of diversity (γ), Hy: Shannon index of diversity.

La suma de la última columna es positiva, indicando que la diversidad medida por este índice fue mayor en el sistema AG. V: valor del grado de cambio de cada parámetro; ẋ: abundancia media del grupo taxonómico, S: número de grupos taxonómicos; n: número de unidades por muestra; Hx: índice de diversidad de grupo (γ); Hy: índice de diversidad de Shannon.

Table 2c. Index of degree of change of the diversity between the naturalized grassland and the agricultural system.

Tabla 2c. Índice de grado de cambio de la diversidad entre el pastizal naturalizado y el sistema agrícola.

Agricultural system - Naturalized grassland	V(ẋ)	V(S)	V(n)	V(Hx)	V(Hy)	Σ V	Δ
feb-09	0.5236	0.3333	0.1667	1	0.1418	2.1653	0.4331
may-09	0.6583	0.2000	-0.0667	0.7993	0.1693	1.7601	0.3520
aug-09	0.9036	0.2000	0.6000	0.5756	0.6103	2.8895	0.5779
dec-09	-0.3436	0.0000	0.2308	0.1135	0.1192	0.1198	0.0240
mar-10	0.6420	0.1429	0.0000	0.3158	0.1200	1.2207	0.2441
jun-10	0.8851	0.1429	0.2000	0.4888	0.2893	2.0062	0.4012
sep-10	0.6743	0.2500	0.0588	0.1290	0.0624	1.1745	0.2349
dec-10	-0.0814	0.1429	0.0588	0.6982	0.3705	1.1890	0.2378
							0.3131

The sum of the last column being positive, indicates that the biodiversity measured by this index was greater in the AG environment. V: value of the degree of change of each parameter. ẋ: mean abundance of the taxonomic group, S: number of taxonomic groups, n: number of sample-unit, Hx: group index of diversity (γ), Hy: Shannon index of diversity.

La suma de la última columna es positiva, indicando que la diversidad medida por este índice fue mayor en el sistema AG. V: valor del grado de cambio de cada parámetro; ẋ: abundancia media del grupo taxonómico, S: número de grupos taxonómicos; n: número de unidades por muestra; Hx: índice de diversidad de grupo (γ); Hy: índice de diversidad de Shannon.

The degree of change between AG and NG is higher than between AG *vs.* CG, therefore AG and NG are more separated between each other than AG and CG are. These results show that the diversity of soil collembolans community resulted in a range were AG > CG > NG.

Comparison of the abundances between systems

A total of 2028 individual collembolans were retrieved throughout the whole sampling period. As shown in figure 3 (page 226), collembolan families behaved differently when their abundances were compared between the studied systems.

The Entomobryidae and Katiannidae families were significantly different ($P<0.01$) between NG and AG. The three environments showed significant differences for the Hypogastruridae family, being higher in CG, followed by AG, and with NG having the lowest abundance.

The Onychiuridae was significantly different between AG and the other two systems, but no differences were found between NG and CG. Isotomidae showed differences between the natural system (NG) and the other two anthropized systems, which were not different from each other.

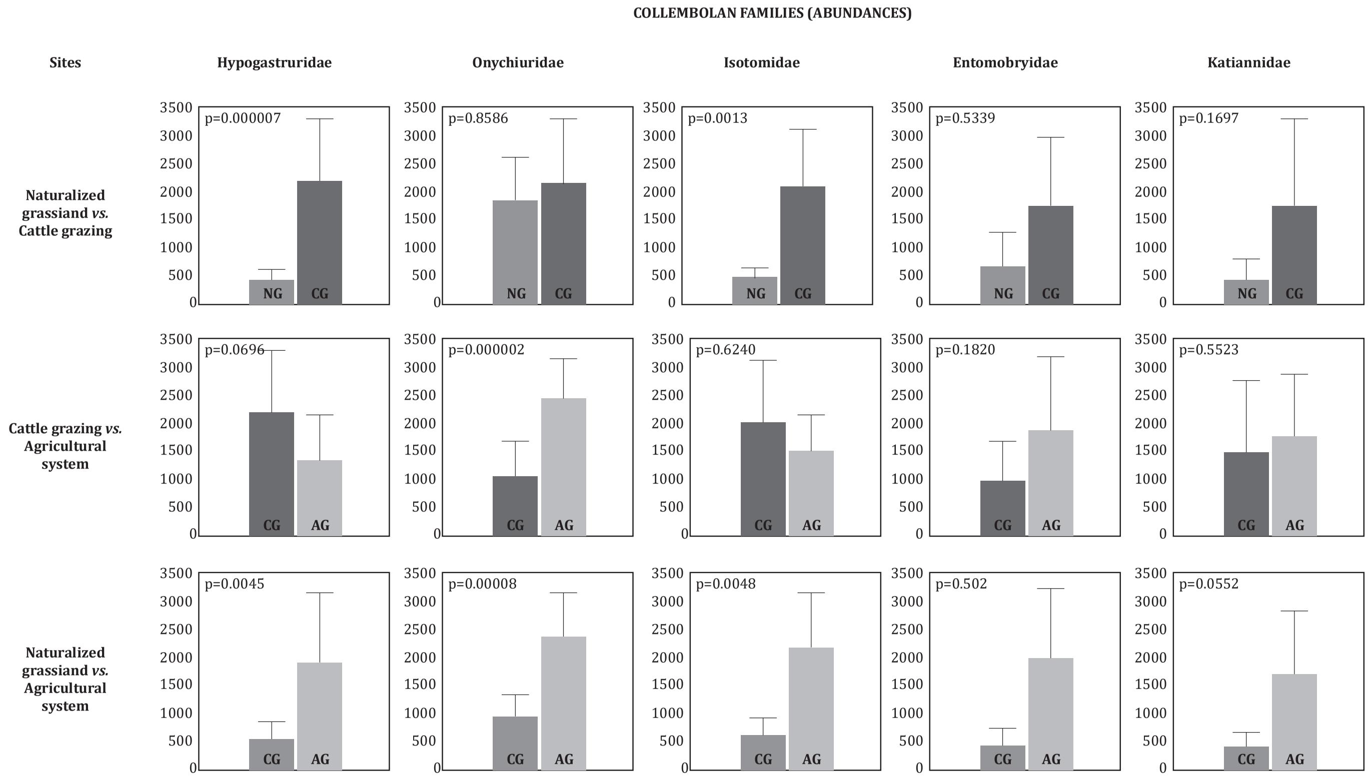
DISCUSSION AND CONCLUSIONS

The physical and chemical variables are important in the characterization of the edaphic environments. In this sense, the results presented here allow for a clear separation between the soil uses, which are related to management practices, determining changes in the edaphic environment that modulate the fauna's composition and abundance. The increase of nitrogen and phosphorus as a result of fertilization, the changes in the use of the soil water, and the changes in the quality and dynamics of litter inputs are all factors that affect the edaphic fauna and are responsible for the fluctuations in their populations (11, 38). In this way, changes introduced by agricultural practices determine changes in the amount of resources available to the soil organisms whose distribution and abundance are determined by the availability of food, the texture and porosity of the soil, water retention, and the existence of predators and parasites (40).

Disturbance or perturbation of soils is usually expected to depress microarthropod numbers. Tillage, fire, and pesticide applications typically reduce populations but recovery may be rapid and micro arthropod groups respond differently.

Regarding the abundance data gathered in this study, there are significant differences between the environments tested. Contrary to what was expected, and unlike what other authors have found (7, 11, 15, 26, 31), the results show higher collembolan diversity in the anthropized systems than in the naturalized grassland in a gradient were AG > CG > NG. Socorrás and Rodriguez (2005) found that undisturbed, fertile soils show high densities of collembolans and mites. The results presented here show that no-tillage agricultural practices with very low or null soil movements, with high levels of litter on the surface, high content of organic matter, and the indirect effect of nutrient enrichment through fertilization, can result in an increase of these groups, as shown in this study.

The analyses performed on collembolans at the family level, show that the response depends on the particular family. These results also show the need of further identifying key collembolan families that can be used as indicators of particular ecological states.



P values (Kruskal-Wallis p<0.1) as well as means and SD are shown. NG: Naturalized grassland; CG: Cattle grazing; AG: Agricultural system.

Se muestra el valor P (Kruskal-Wallis p<0,1) así como la media y el SD. NG: pastizal naturalizado, CG: sistema mixto, AG: sistema agrícola.

Figure 3. Analysis of the abundances (ind/m^2) of each of the collembola community families across the three systems.

Figura 3. Análisis de las abundancias (ind/m^2) de cada familia de la comunidad de colémbolos entre los tres sistemas de uso.

The biological indexes assess the soil global state in a simple way. Since they represent an integrated response of the soil fauna to conditions over an extended period of time, they have some clear advantages for ecological state assessment when compared to classical time-point physical and chemical analyses.

Therefore, the analysis of the structure of the edaphic community provides information on the effects of several factors (management practices, pesticide use, crop residuals) integrated over time. Furthermore, the biological indexes diminish the number of analysis and interventions demanded by other indicators, with the objective of obtaining a good representation of the quality of the soil (37, 41). Therefore, they are useful in agricultural systems, in which it would be hard to focus on one or a few impact factors such as pesticides, crop rotation, sowing, harvest, fertilization and other factors that are present in different combinations (10, 39).

The index of degree of change of the diversity calculated for the different soil uses in this work is a synthetic variable that reflects this integrated response of the biota to the environmental conditions, and allows for the comparison between systems with different soil uses and therefore different anthropic impact.

Work by several authors suggest that intensive agricultural practices tend to reduce collembolan densities (7, 16, 25, 33, 43). According with these authors, collembolan densities are generally lower in agricultural land than in natural sites (43, 25). Maraun *et al*. (2003) suggest that collembolans are particularly sensitive to mechanical disturbances, even more than Oribatids (Acari: Oribatida).

Results by Filser (2002) however, indicate that collembolans can maintain high population densities under intensive soil disturbances.

The results of the index of degree of change between the ecological systems analyzed in this study show that the agricultural system, under no-tillage management practices extended over several years have a positive effect on collembolan assemblages, when compared to the other two systems evaluated. The results differ from those by Cancela da Fonseca and Sarkar (1996), who found a negative index in their study, which implies a higher global diversity in the uncultivated system when compared to the cultivated one. The positive index of degree of change presented here indicates a higher ecological diversity in the no-tillage agricultural field in comparison to the other two systems.

The higher diversity found in the field that is supposed to be the most disturbed, also coincides with the higher abundance of some collembolan families in these fields. These, somewhat surprising results can be due to the fact that the no-tillage system usually leaves some 15% or more of the harvest residuals on the surface of the soil, diminishing erosion processes (51), preserving water, as well as adding organic matter to the system.

The thick layer of crop residues left on the surface and accumulated year after year, creates a mulch that provides a source of organic matter as food, keeps temperature variations low and soil humidity high, all conditions that favor the development of the soil collembolan communities.

The results of this work show that low impact agricultural practices, which include crop rotation, little use of pesticides, and a high organic matter input may have positive effects on the soil collembolans' community.

An increasing number of works provide growing evidence that soil fauna can be a reliable indicator of anthropic disturbances (7, 19, 23, 25, 27, 28, 53). Earthworms, Enchytraeids, Acari, and Collembolans are all groups being considered as candidates for the development of soil quality indexes (18, 23, 47). The results presented here support this view with a cautionary note. Even though the structure of the collembolan community can be used to assess anthropic impact in the soil ecosystem, not always does it in the expected direction. While most published works support the idea that anthropic impact simplifies the soil fauna, and lowers diversity and abundance, the results of this work go in a different direction. According to the structure of the collembolan communities tested in this work, an intensive soil use can lead to an increase in collembolan diversity.

Even though more information needs to be gathered on the biology and particular requirements by collembolans, what the results presented in this work clearly show is that the presence, abundance and diversity of collembolan families can be useful indicators to assess the degree of anthropic soil disturbance as more basic biology of these groups becomes available.

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