The degree of change of collembolan community structure related to anthropic soil disturbance

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ABSTRACT

Edaphic fauna play a crucial role in soil processes such as organic matter incorporation and cycling, nutrient content, soil structure, and stability. Collembolans in particular, play a very significant role in nutrient cycling and soil structure. The structure and functioning of the soil fauna can in turn be affected by soil use, leading to changes in soil characteristics and its sustainability. Therefore, the responses of soil fauna to different soil management practices, can be used as ecological indicators. 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). For each soil use, three fields were selected. Each sampling consisted of three soil samples per replicate. Collembolans were extracted from the samples 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 diversity, was calculated. 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 is higher in the high anthropic impact site AG, followed by CG and being lower in lower impact sites, 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.

Key words: soil use intensity; collembola community; anthropic impact.

1. INTRODUCTION

It is increasingly recognized that community structure and composition may be used as ecological state indicators (Cairns and Pratt, 1993; Dickens and Graham, 1998; Carlisle et al, 2007), and the use of biological information to assess ecological quality is currently an active field of research. The development of biologically-based indices of ecological state has become a standard for the assessment of water quality in European countries. The European Water Framework Directive, for instance, requires all surface waters in Europe to have biologically-based water quality indexes in place by 2015 (European Parliament, 2000). 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 (Quintana et al, 2006), and in the US (Barboud et al, 1991, 1999), 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 (Blocksom and Johnson, 2009; Baldigo et al., 2009). Some of these methods are based on the information provided by only one taxon (Graham et al., 2009), while others are based on a general evaluation of the presence and abundance of the soil arthropods (Bardgett and Cook, 1998; Büchs et al., 2003). 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 (Cancela da Fonseca and Sarkar, 1998).

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. 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 (Lavelle et al., 1997). 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 (Bardgett, 2005; Decaëns T, 2010).

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 effects 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 (Barrios, 2007).

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 (McLaughlin and Mineau, 1995). Agricultural activities such as tillage, drainage, crop rotation, grazing, and the intensive use of pesticides and fertilizers, have strong effects on the flora and fauna species found in the soil. However, reduced or no-tillage systems can be useful in terms of maintaining native species populations (McLaughlin and Mineau, 1995).

Collembolans are one of the most abundant and varied groups among soil organisms, playing a very significant role in nutrient cycling and soil microstructure (Rusek, 1998). They also respond to a variety of environmental and ecological factors, such as changes in soil chemistry, microhabitat configuration, and forestry and agricultural practices (Hopkin, 1997). Is in this context, that the use of collembolans as indicators of ecological state has been recommended by several authors (Frampton 1997, Kopeszki 1997, Van Stralen and Verhoef, 1997).

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 (Swift and Anderson, 1993). In this way, the reduction in biodiversity is usually associated with an increase of management intensity and a general reduction in the environmental heterogeneity (Erwin, 1996).

This study was performed in the rolling pampas in the Argentine pampean ecoregion (Viglizzo et al., 2004), 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 development of new forms of changing the use of large numbers of hectares from cattle grazing to agriculture (Viglizzo et al., 2004).

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.

2. MATERIAL AND METHODS

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. (Fig.1). The soils of the sampling sites were all typical Argiudols, order Mollisols, (USDA, 2010). Three different management systems were evaluated: 1) A naturalized grassland (NG), an old and abandoned grassland 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), under constant intensive agriculture for 50 years and under no-tillage 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 per sample date. Sampling was performed every three months over a 2 year period.

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 cc sample was collected per random sample.

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 (Sandler et al., 2010) and later classified to family level (Momo and Falco, 2010)

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 (Table 1). Microbiological variables (edaphic respiration and nitrogen fixing bacteria activity) were measured as well.

2.1. Statistical analysis

2.1.1. Physical and chemical characterization

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

2.1.2. 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):

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

Where, $\dot{x}$: 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.

For parameters $\dot{x}$, S, n, Hx, and Hy, the variation (V) for any parameter (m) is calculated as:

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

Where m: parameter $\dot{x}$, S, n, Hx, or Hy.

and

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 (See Cortet et al, 2002)

2.1.3. Abundance

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

3. RESULTS

3.1. Physico-chemical characterization

The discriminant analysis (Fig. 2) 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. 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 from the two anthropized environments. The dispersion of the data in the NG system reflects the heterogeneity of the soil, differentiating this soil environment from the other two which appear grouped showing a lesser dispersion.

3.2. 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 measured by this index is higher in the CG environment. (Table 2a).

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). 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).

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. These results show that the diversity of soil collembolans community resulted in a range were AG > CG > NG.

3.3. Comparison of the abundances between systems

As shown in Fig. 3, 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.

4. 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 (Burges and Raw, 1971; Pankhurst et al., 1998). In this way, the 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 (Paoletti et al., 1998).

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 it was expected, and unlike what other authors have found (Cortet et al., 2002; Brennan et al., 2006; Kautz et al., 2006), 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) indicate that undisturbed, fertile soils show high densities of collembolans and mites. The results presented here show that no-tillage management 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 (N y P), can result in an increase of these groups, as shown in this study.

The analyses performed on collembolans at the family level, shows that the response depends on the particular family. This information will be useful in further identifying key collembolan families that can be used as indicators of particular ecological states.

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 (Muller et al., 2000; Parisi et al., 2005). 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 (Paoletti, 1999; Büchs, 2003).

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 (Culik, et al, 2002; Maraun, et al, 2002; Petersen, 2002). According with these authors, collembolan densities are generally lower in agricultural land than in natural sites (Petersen, 2002). Maraun et al. (2002) suggest that collembolans are particularly sensitive to mechanical disturbances, even more than Oribatids. Results by Filser (2002) however, indicates 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. Our results do not agree with those found 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 the 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 (Unger, 1994), preserving water, as well as adding organic matter to the system. The thick layer of crop residues left on the surface year after year, creates a mulch that keeps temperature variations low and soil humidity high, conditions that favour the development of the soil collembolans 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.

One possible explanation for this higher abundance of some collembolan families in the anthropized environment when compared with less disturbed ones, could be that some particular families are better adapted to high disturbance regimes. For collembolans, however, the generalized lack of biological information on the behavior of particular families to different disturbance levels, currently prevents us to reach this conclusion with a high degree of certainty. Therefore, more information needs to be gathered on the biology and particular requirements by collembolans in order to better explain these results.

However, what the results presented in this work clearly show is that the presence, abundance and diversity of collembolan families are useful indicators to assess the degree of anthropic soil disturbance.

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Fig.1

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

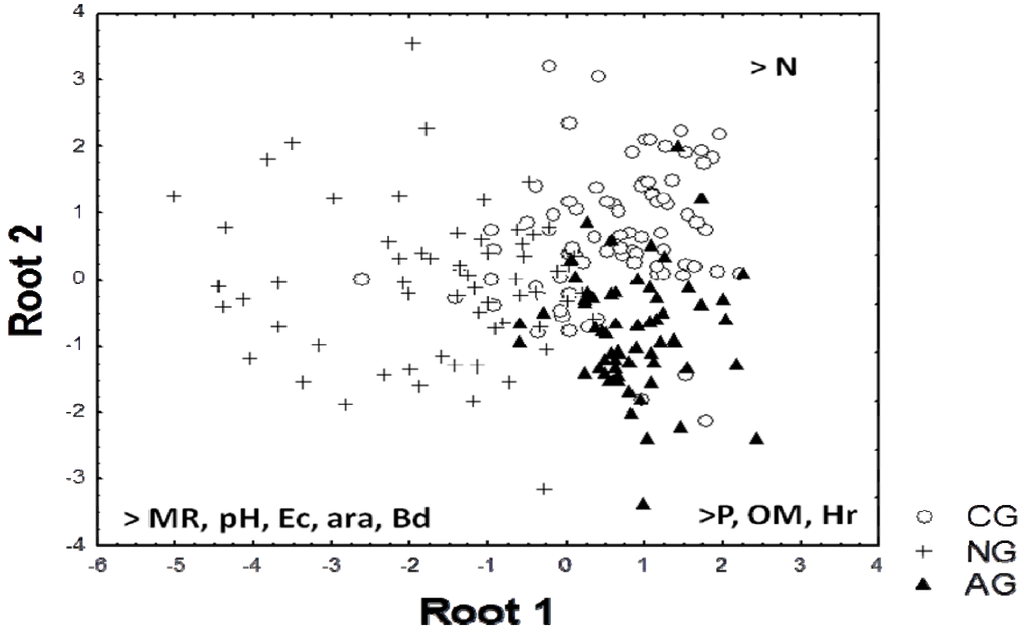

Figure 2: Discriminant analysis performed with the physical, chemical, and microbiological variables. NG: naturalized grassland, CG: cattle grazing, AG: agricultural system. Variables: bulk density (Bd), electric conductivity (Ec), mechanical resistance (MR), organic matter content (OM), Phosphorus content (P), total Nitrogen (N), pH, nitrogen fixing bacteria activity (ara).

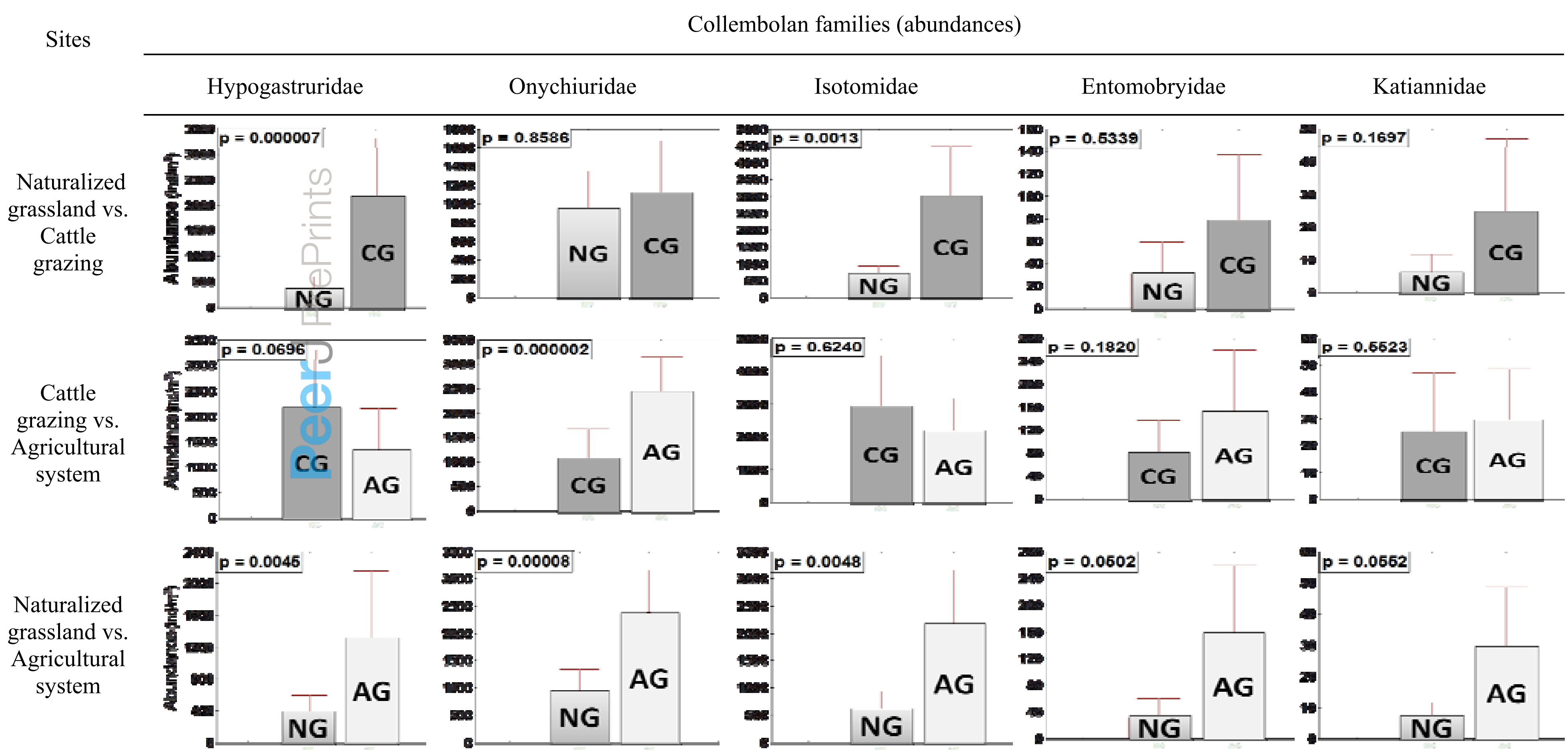

Figure 3: Analysis of the abundances (ind/m^2) of each of the collembola community families across the three soil uses. P values (Kruskal-Wallis p<0.1) as well as means and SD are shown.

Parameter	Method	Sites: NG	Sites: CG	Sites: 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/cm3)	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/ gr dry soi*incubation hour)	ARA	0.3 +/- 0.3 a	0.2 +/- 0.2 b	0.2 +/- 0.3 b
Respiration (mg de CO2 produced/gr 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/cm2)	cone	10 +/- 6 a	2.5 +/- 3 b	5.5 +/- 4 c
MR 5=10 (Kg/cm2)	cone	13 +/- 7 a	5 +/- 5 b	8 +/- 5 c

Table 1: Physical, chemical, and microbiological variables. Mean values and standard deviation of the different soil uses 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 $p<0.05$).

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

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

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

Table 2b: Index of degree of change of the diversity between the cattle grazing and the agricultural system. 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: cenotic index of diversity(α).

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

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