Mesofauna as an indicator of agroecosystem stability: degree of artificialization effect on land uses in Azul district, Argentina

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Abstract

Chronic anthropogenic stress agents include the different tillage systems, which usually influence the population metrics of cryptofauna communities. Among them, the edaphic mesofauna is sensitive to natural and anthropogenic disturbances of the environment, producing changes in its specific composition and abundance. This allows us to select it as an indicator of disturbances generated in the stability of the ecosystem by land use. Taking these into consideration, the objective of this work was to study the effect of the degree of artificialization in land use on the stability of the agroecosystem through mesofauna. The study area was located in an environment of peripheral hills of the district of Azul. Four sites were selected in similar geoenvironments, with different degrees of artificialization of land use. Edaphic parameters were analysed in each site, and mesofauna individuals were identified through keys for population analysis. Mesofauna population metrics were analysed. Biological indicators were applied. Through mesofauna it was possible to differentiate sites with different degrees of artificialization by land use. Biological indicators allowed us to determine the stability of agroecosystems.

Keywords *Acari* · *Collembola* · Biological indicators · Land use history · emergent property

1 Introduction

In recent years, there has been growing concern about the types of use and management of the edaphic ecosystem that contribute to human well-being. Although soil quality is conceptualized as the main link between strategies for management practices and the execution of the main objectives for achieving sustainable agriculture, it should not be overlooked in terms of optimal soil functioning in the ecosystem [12]. Researchers in soil conservation and management have made great progress in describing and understanding the complex biological, biophysical and biochemical interactions of soil [8, 9]. These interactions provide the soil as habitat for the food webs of edaphic cryptofauna and vegetation. In agricultural ecosystems,

the different tillage systems are considered as chronic stress agents which affect the population metrics of the soil fauna communities [23].

The use of agricultural ecosystems should be analysed in the context of their environmental fragility. It affects the sustained harvesting of the ecosystem, driving it to non-optimal states from the human point of view, in a destructive trend known as ecosystem disease [18]. The landscape is altered by anthropogenic activities and at the same time affects the quality of life. Physical processes (meteorization, adsorption, desorption, water and air exchange, etc.), chemical processes (ion exchange, dissolution, precipitation, etc.) and biological processes (bioturbation decomposition, root growth, etc.) all take place at characteristic spatial and temporal scales and sometimes involve a

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certain range of scales with certain invariant qualities in all of them. The edaphic ecosystem is a historical result, and one could say that it is an evolutive result. In this sense, it can be assumed that it has been submitted to a selective process ("sensu lato") that has produced systems with a high efficiency in the processing and dissipation of the external energy they receive. In this way, anthropogenic energy such as different tillage systems is considered artificialization in land use. Taking into account these considerations, stability is an emerging property of each system, which would indicate in summarized form what condition it is in relation to the external anthropic energy (artificialization) it receives and its capacity to metabolize it, maintain control over its condition and persist [19].

Traditionally, agricultural production systems have been evaluated through the concept of quality, where chemical, physical and biological indicators have been used. In the Mesofauna, mite subclasses (Acari) and the springtail subclass (Collembola) are the most important biological indicators of ecosystem condition [25] and soil quality [2, 3]. Furthermore, the spatial distribution of mesofauna organisms is closely related to the increasing pressure on agroecosystems, as a result of which some of the edaphic parameters, such as organic matter [13–15], promote spatial heterogeneity and the activity of mesofauna organisms at different scales [8].

In the 1990s, an advance was observed in the evaluation of ecosystems based on the edaphic mesofauna. Andrés [1] and Behan-Pelletier [5] highlighted the role of the *Oribatid* (Mites) as biological indicators of moisture and organic matter content in forest ecosystems, as well as in forest plantations and agroecosystems. At the same time, the growing knowledge of edaphic cryptofauna allowed the

development of biological indicators that use mesofauna as an indicator of soil quality [2, 3]. Andrés [1] proposed the relationship between Mites: *Oribatid/Prostigmata* and Mateos [20] presented the relationship *Acari/Colembola*, to determine the degree of stability in different land use systems.

1.1 Objectives

Taking into consideration previous statements, the general objective of this work was: study the effect of the degree of artificialization in the land use on the stability of the agroecosystem through mesofauna in hilly environments of the district of Azul, Province of Buenos Aires, Argentina.

The specific objectives were:

Analyse different soil organic fractions to characterize the sites under study.

Describe and compare the mesofauna in the sites under study.

Apply biological indicators to estimate stability in the sites under study.

2 Materials and methods

2.1 Selection and characterization of study sites

The district of Azul is located in the middle of the Province of Buenos Aires, in the Pampas Serrana region (36.13°37.27'S and 59.08°60.12'W) (Fig. 1). According to the classification of Köppen, the district of Azul has a humid temperate climate with oceanic influence, mild

Fig. 1 Location of the study area within the hilly environment in the district of Azul (Province of Buenos Aires)

winters, short and cool summers and has all wet seasons. It has an average of 915 mm of precipitation and average temperatures of 21.8 °C for the month of January and 7 °C for the month of July and an annual average of 14 °C [24].

The study area was located in the hilly environment of Azul district and corresponded to 3760–22-2, soil map of the Argentine Republic [15].

We proceeded to select four study sites in a transect corresponding to the same level curve at 240 of altitude.

The selected sites are listed below (Table 1).

The sites represent an increasing gradient in the artificialization degree associated with different tillage systems used over the past 25 years, from non-agricultural site “Closure” (less artificialized) to site 4 with different types of tillage (the most artificialized). The soil present in the study sites was Mar Del Plata serie, Tipic Argiudol (Soil Taxonomy 2006) [15].

2.2 Particulate organic matter (POM), organic carbon (OC) and loss of ignition (LOI)

The field correlations of the series described for the environment of peripheral hills were carried out with soil auger sampling at a depth of 0.8 m.

In the field-selected sites, soil samples were collected of five random subsamples at a depth of 0–10 cm. These were conditioned and transported to the laboratory, where they were air-dried and then sieved using a 2-mm-diameter mesh and stored in plastic bags for further analysis. Sampling took place in May 2017, January and September 2018.

Organic matter was characterized through different fractions: particulate organic matter (%POM > 50 μ), organic carbon (%OC) and loss of ignition (%LOI).

The parameters of the soil samples studied were determined by standardized methods [7, 21, 22] which are detailed below:

- Particulate organic matter (%POM > 50 μ) allows to discretize different management practices in shorter time spaces [13, 14];
- Organic carbon (%OC), LECO model CR12. It is a very reliable method, and it allows to separate different sites against different management practices [13];

- Loss of ignition (%LOI): organic matter by calcination. It allows to separate different sites against different management practices [15].

2.3 Mesofauna and biological indicators

In order to identify and classify the mesofauna in the experimental sites, two random samples were taken from each selected site, with 5-cm-diameter and 7-cm-deep punch with the accompanying stubble [17]. Sampling was carried out during January, March, September and December of 2018.

The samples were separated from the different components of the fauna using modified Berlese funnels [6]. The specimens were fixed in 70% alcohol for their conservation and later identified by keys [11] up to the suborder level, and the count of individuals was carried out. Then, with the aim of determining the agroecosystem stability we used the following biological indicators:

- The *Oribatid/Prostigmata* relationship [1] (values ≥ 1 are stable agroecosystems, values < 1 unstable agroecosystems).
- The *Acari/Colembolla* relationship [20] (values ≤ 1 are stable agroecosystems, values > 1 are unstable agroecosystems).

2.4 Statistical processing of information

For the analysis of %POM, %OC and %LOI for the four sites under study, mixed models were used. When significant differences were found, the LSD Fisher test was applied for mean comparison ($p \leq 0.05$).

Responses of mesofauna suborders to sites were evaluated by discriminant multivariate analysis [17]. Differences between the densities of the suborders and the different treatments were calculated using Kruskal–Wallis test.

The statistical analyses and discriminant analysis graphs were performed using the Infostat® software interface with R [10]. The graphs of individual m^{-2} were made using GraphPad Prism® software.

Table 1 The different sites selected and the characteristics of the history of land use of each one

Site	Characteristic
Non-agriculture site	Closure of 25 years. Closed for research, where animal access and sowing were prevented. It has a naturalized prairie
2	No-tillage agriculture for 25 years
3	Tillage with moldboard plough for 10 years and then No-tillage agriculture until today, 15 years
4	Different types of tillage from 25 years ago to the present day (moldboard plough, disc plough and no-tillage)

3 Results

3.1 Particulate organic matter (POM), organic carbon (OC) and loss of ignition (LOI)

There were statistically significant differences of the variable %POM in non-agricultural site and site 2 with respect to sites 3 and 4. They presented the highest and lowest values found for the variable, respectively. Non-agricultural site and site 2 did not differ from each other, neither did sites 3 and 4. The %OC variable was effective in separating between sites. Non-agricultural site had the highest %OC values, differing significantly from the rest. It is followed by site 2, site 3 and site 4, respectively, in decreasing values. All the sites showed significant differences between them. The %LOI variable also separated different sites. Non-agricultural site presented the highest %LOI values, differing statistically from the rest. Site 2 followed in decreasing value to non-agricultural site, differing statistically from the rest. Sites 3 and 4 presented the lowest values and both differed from the rest, but not between them (Table 2).

3.2 Mesofauna and biological indicators analysis

Non-agricultural site presented the highest values of mites and springtails per m^{-2} . No significant differences were found for *acar* variable (Fig. 2a), and a trend was observed where non-agricultural site presented the highest values, followed by site 4, and then, by sites 2 and 3 with similar

values. In *collembola*, on the other hand, significant differences were found. Non-agricultural site differed significantly of individual m^{-2} from the rest of the sites (2, 3 and 4). Sites 2, 3 and 4 presented similar values and were not statistically different (Fig. 2b).

In the analysis of the number of individuals of each sub-order between the different sites, it was observed that *Oribatid* (Fig. 3a) presented the highest number of individuals in non-agricultural site, being statistically different from the rest. Sites 2 and 3 presented the lowest values, being statistically equal between them. Site 4 presented intermediate values, being statistically equal to non-agricultural site as well as to sites 2 and 3.

For *Astigmata*, no significant differences between sites were found, but a trend of higher individual m^{-2} was observed at non-agricultural site (Fig. 3b). In *Prostigmata*, no differences between sites were observed, but a trend of higher values was observed in sites 3 and 4 (Fig. 3c). In *Mesostigmata*, no significant differences were found between the sites. In all cases, very low values of individual m^{-2} were observed (Fig. 3d).

Only significant differences were found for the suborder *Symphyleona* (Fig. 4c). Non-agricultural site showed the highest value and significant differences with the rest. Sites 2 and 3 presented intermediate values between sites 1 and 4, not differing significantly from both. Site 4 had the lowest values, differing significantly from non-agricultural site.

Figure 4 indicates that no significant differences were found between sites in relation to the suborders

Table 2 %POM (particulate organic matter), %OC (organic carbon), %LOI (loss of ignition) for the four sites analysed. The different letters indicate significant differences between the sites ($p \leq 0.05$)

Site	%POM	SE	Significant difference	%OC	SE	Significant difference	%LOI	SE	Significant difference
1	2.1	0.37	a	4.93	0.08	a	10.92	0.31	a
2	1.69	0.37	a	3.71	0.08	b	9.25	0.31	b
3	0.92	0.37	b	3.34	0.08	c	8.39	0.31	c
4	0.41	0.37	b	2.64	0.08	d	7.63	0.31	c

Fig. 2 Number of individual m^{-2} present at each site. **a** *acar*, **b** *collembola*. The different letters indicate significant differences ($p \leq 0.05$)

Fig. 3 Number of individual m^{-2} of each *acar* suborder present at each site. *Oribatid* (a), *Astigmata* (b), *Prostigmata* (c) and *Mesostigmata* (d). The different letters indicate significant differences ($p \leq 0.05$)

Fig. 4 Individual m^{-2} of each suborder of *collembola* present at each site. *Poduromorph* (a), *Entonomorph* (b) and *Symphyleone* (c). The different letters indicate significant differences ($p \leq 0.05$)

Poduromorpha and *Entonomorpha*. A trend of higher values of individual m^{-2} was observed in non-agricultural site.

In order to discriminate the effect of sites on mesofauna, a discriminant analysis was carried out using the different mesofauna suborders presented at each site (Fig. 5).

This analysis gave significant statistical differences. Axes 1 and 2 explained 99% of the variation found (77% axis 1 and 22% axis 2). It is clearly observed that the points corresponding to non-agricultural site, the lowest level of artificialization, were distributed to the right of line 0

Fig. 5 discriminant mesofauna analysis for the sites under study. Being 1 closure, 2, 3 and 4 sites with increasing level of artificialization

of canonical axis 1 (the one that explained most) and the points corresponding to the other sites, to the left of line 0. This indicated that the non-agricultural site was indeed different from the rest of the agricultural sites.

On the other hand, sites 2 and 3 had a very similar distribution, and their points were located above axis 0 of canonical axis 2, separating them from the points corresponding to site 4. Within agricultural sites, sites 2 and 3 resembled each other and were separated from site 4. In canonical axis 1, the suborders *oribatid*, *prostigmata* and *entonomorpha* were the components of the axis that most explained it. In turn, in canonical axis 2, *symphypleona*, *astigmata* and *mesostigmata* were the suborders that most explained it.

This analysis was congruent with those analysed for the density of individual m^{-2} where non-agricultural site differed from the rest of the agricultural sites. Agricultural sites 2 and 3 were similar, and site 4 was different. Therefore, canonical axis 1 mainly separated non-agricultural site, the closure, from the rest of the agricultural sites, and the axis 2 separated the agricultural sites from each other.

To identify the agroecosystem stability, biological indicators were applied. The *Oribatid/Prostigmata* indicator (Fig. 6a) showed that non-agricultural site reached values greater than “1,” the rest of the (agricultural) sites had values below “1.” The indicator *acari/collembola* (Fig. 6b) showed that agricultural sites 2, 3 and 4 reached values of “3,” and non-agricultural site a value slightly higher than 1.

4 Discussion

In this study, only the soil parameter %OC was the best to differentiate and accurately indicated contrasts between sites, confirming a gradient of artificialization by land use, from non-agricultural site to site 4. In addition, similar results were obtained for Eyherabide et al. [15], for the same region. However, the same author affirmed that %LOI

Fig. 6 stability indicators for each study site. **a** *oribatid/prostigmata* and **b** *acari/collembola*

was also effective as %OC. This is not consistent with our results, but %LOI was effective in separating non-agricultural sites from agricultural sites. Results for %POM were different to %OC and %LOI. This parameter only separates the non-agricultural site and the less artificialized

site from the sites 3 and site 4 both with higher degree of artificialization. Close results were found by Eiza et al. [14] where %POM was effective to separate different soil management practices in the first few centimetres for typic argiudol in Pampa Serrana region. Furthermore, we found that %POM and %OC were lower in agricultural soils than closure. These results were similar to those obtained by Duval et al. [13]

In concordance with a gradient of artificialization by land use confirmed by %OC analysis, the results of mesofauna population metrics revealed differences in sensitivity to human disturbances between sites, in agreement with Pankhurst et al. [23] and Cassani et al. [8]. We found large differences between non-agriculture site and agricultural sites (2, 3 and 4). Bedano et al. [4], in west Pampa Húmeda region, Argentina, found differences in mite's population metrics between non-agriculture sites and anthropized sites. These results were in accordance with ours. Actually, according to Behan-Pelletier [5], *oribatid* mites are the most susceptible to management practices; therefore, their relative abundance in less anthropized sites is greater, and these statements were observed in the non-agriculture site. Furthermore, Sousa et al. [29] in Portugal observed for *colembolla*, differences in population metric in sites with higher degrees of artificialization by land use, showing that land use influences the metric populations of springtails. Alike results were found in our investigation, where there were more individuals of *colembolla* in non-agriculture site vs. agricultural sites. Moreover, the abundance of *symphypleona* in non-agriculture site was the most abundant of all sites, being less abundant in sites 3 and 4, both with the highest degree of artificialization by land use, in concordance as reported by Sousa et al. [29]. In addition, Socarrás and Izquierdo [27] claimed that grassland areas are distinguished by a high dominance of microarthropods responsible for the decomposition of organic matter (stability indicators) and a sharp drop in the abundance of the rest of the groups (disturbance indicators) of the soil environment. It is therefore suggested that *oribatids* and *colembolla* are groups that effectively indicate stability in the system. Besides, according to Socarrás [28], springtails and *mesostigmata* (cohort *gamasina*) are the most affected groups by agronomical management practices in grasslands in Cuba.

In line with Socarrás and Izquierdo [27], and Socarrás [28], mites (especially *oribatids* and *mesostigmata*) and *colembolla* (principally *symphypleona*) are considerate good indicators of soil stability and fertility.

Not to mention, the discriminant analysis gave information that complemented to the density of individual m^{-2} . This analysis confirmed many of the differences found between the suborders of mites and springtails respect to the sites under study, which in this case would be the

treatments of this experiment. It was possible to discriminate between non-agricultural site from the rest of the experimental sites. Same results found by Bedano et al. [3] in their study was that a canonical analysis separated the natural environment (non-agricultural site with a closure of 30 years) from the rest of the agricultural sites, in the centre, east of Cordoba province and north of Buenos Aires province.

The application of biological indicators of stability resulted in a great difference of non-agricultural site with the rest of the sites. In both indicators used, this difference was observed. In *acar/colembolla* indicator, the agriculture sites were in a state of imbalance or greater disturbance, being unstable systems, in contrast to non-agricultural site (stable systems). Similar results were found by Socarrás and Rodríguez [26], for disturbed sites, where in agroecosystems recultivated with *pinus cubensis*, in a former mining zone, they had a very high *Acar/Collembola* ratio, even after 16 years of reforestation. The indicator *Oribatida/Prostigmata* showed same results than *Acar/Collembola* indicator. There was a dominance of *Prostigmata* in agricultural sites, an indicator group of oligotrophy and aridity, where the degree of imbalance of the communities is irreversible, therefore, unstable sites. In contrast, the non-agriculture site was stable. Same results were obtained by Bedano et al. [4], where they found values of great balance (stable system) in a 40-year closure and in cattle sites. Likewise, Socarrás and Izquierdo [25] found similar results, where in pasture sites the values were "stable," and in agricultural sites, "unstable."

Stability of the agroecosystem is the result of the landscape components interaction. This study gave us information to monitor artificialization in land use. Moreover, stability variable can be incorporated into the building of more sustainable land management models.

5 Conclusions

The different fractions of organic matter analysed (%POM, %OC, %LOI) were useful to indicate differences between sites, but it was %OC that allowed to accurately indicated contrasts between sites, confirming a gradient of artificialization by land use, from non-agricultural site to site 4.

The stability of an agroecosystem considers the interaction of all the components of the landscape and allowed the study of the interfaces that compose it. For that reason, stability is an emerging property that is specific to each agroecosystem, where going to more stable systems would be the optimal in terms of energy. According to results, biological indicators allowed us to determine the stability of agroecosystems. In stable systems, with a low degree of artificialization, the populations of *oribatid* and

collembola increase, suborders that contribute to the stability. In the other hand, in unstable systems, which receive more external energy from artificialization, the mesofauna was less. At the same time, the suborders of *astigmata* and *prostigmata* proliferated, indicating disturbances, aridity and oligotrophy.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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