Environmental Earth Sciences (2018) 77:134
https://doi.org/10.1007/s12665-018-7313-x

ORIGINAL ARTICLE

Changes in the porosity induced by tillage in typical Argiudolls of southeastern Buenos Aires Province, Argentina, and its relationship with the living space of the mesofauna: a preliminary study

Maria Fernanda Alvarez[1,2,3] · **Margarita Osterrieth**[1,2] · **Miguel Cooper**[4]

Received: 13 November 2017 / Accepted: 29 January 2018

Abstract
The study of structure is essential to understand the effects of natural and anthropogenic degradation of the environment. Continuous tillage has negative effects on soil structure. The structural heterogeneity of the soil is a key element which makes it possible for several functional groups of organisms to coexist in the soil. Thus, the soil provides a habitat for a vast array of small and large organisms residing permanently or temporarily within it. The aim of our work is to analyze the effect of tillage in typical Argiudolls of Los Padres Pound, in the pores morphology, size and roughness, and its relationship with the potential available habitat space of the mesofauna. We worked on a cultivated plot, for over 40 years, and referencing a plot with non-farmed soils. Size, number, and roughness of pore were determined. For mesofauna, they were taken into account previous studies in these soils. The results of this study proved such influence of tillage on soil structure in the cultivated plot. The modifications of physical properties resulting from tillage are due to the decrease in total porosity and the modification in the type, size, and roughness of the pores. The decrease in total porosity might influence the abundance and diversity of mesofauna in these typical Argiudolls.

Keywords Land use · Pores of soil · Architecture of habitat

Introduction

Soil structure is the spatial arrangement or ordering of the aggregates and the spaces between them (Oades 1984). The porous system of the soil is directly related to the shape, size, and spatial arrangement of the individual particles and soil aggregates. Both the geometry of the pores and their interrelations control the behavior of water and air and provide a great deal of information on transfer processes and life in the soil (biopores) (Porta et al. 1999). Continuous tillage has negative effects on soil structure, causing a reduction in total porosity, due to the modification in the quantity, distribution, and continuity of pores, determining the flow of air and gases, and the development of soil organisms (Kay and Vanden Bigaart 2002; Iglesias et al. 2007; Alvarez et al. 2008; Alvarez 2009). In this pore system, "available habitat space" refers to the fraction of pore space that is accessible to soil organisms (Hassink et al. 1993).

The soil provides a habitat for a vast array of small and large organisms residing permanently or temporarily within it (Estrade et al. 2010). The modifications produced by tillage in the physical conditions (texture, porosity) influence this complexity (Kampichler 1999). As the complexity of a habitat increases, so does the diversity and abundance of organisms, as a result of the increase in the available habitat space (Morse et al. 1985). Soil is a highly complex three-dimensional habitat, and differences in structure that lead to differences in soil pore volume and surface area are likely to influence abundance of soil biota. Many studies recognize that structural complexity influences species richness and abundance in habitats (Downes et al. 1998; Mac Nally and

✉ Maria Fernanda Alvarez
mfer_alvarez@yahoo.com.ar

1 Instituto de Geología de Costas y del Cuaternario (CIC-UNMdP), Dean Funes 3350, CC722, 7600 Mar del Plata, Argentina

2 Instituto de Investigaciones Marinas y Costeras (CONICET-UNMdP), Mar del Plata, Argentina

3 Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Buenos Aires, Argentina

4 Departamento de Agricultura-ESALQ-Universidad Estadual de San Pablo-Brasil, Piracicaba, Brazil

Published online: 13 February 2018

Horrocks 2007) and the importance of high complexity has been discussed for soil faunal communities (e.g., Bardgett 2002). The relation between fauna and soil structure has been extensively studied in cultivated soils (Kladivko 2001) through the morphological analysis of cave systems or measuring porosity, hydraulic conductivity, and aggregate stability (Langmaack et al. 2002). However, studies relating soil organisms with pores as available habitat space are rare. There is a clear, positive relation between the number and size of pores and the type of animals inhabiting them (Kampichler and Hauser 1993; Hassink et al. 1993; Kampichler 1999; Duhour et al. 2009, Alvarez et al. 2013).

Mites (Arachnida: Acari) are the most diverse and abundant groups of the soil mesofauna. Within these, the oribatid mites play an important role in the decomposition and mineralization of soil organic matter, and its transport through the profile (Lal 1991). Their abundance depends on soil type and texture, as they use pore space for their life; the distribution of these organisms in the profile is related to the amount and distribution of organic matter, pH, and trophic relations, among other properties (Anderson 1988). Because of ecological function, these organisms are used as soil quality indicators and are sensitive to environmental changes (Behan-Pelletier 1999, Bedano et al. 2008).

The soils of the Pampean region show a high physical, chemical, and biological degradation (INTA 1989 in Orellana and Pilatti 1994; SAGyP-CFA 1995; Urricariet and Lavado 1999; Aparicio and Costa 2007). Typical Argiudolls, with wide distribution in southeastern Buenos Aires, with a high content of organic matter and nutrients, are considered the most fertile soils in the country; this is why they are used for traditional horticultural and agricultural production. They show a significant loss of structure, organic and inorganic colloidal fraction, and biological diversity (Osterrieth and Maggi 1996; Elissondo et al. 2001; Alvarez 2009; Alvarez et al. 2011, 2012). Horticultural and agricultural practices periodically modify the available habitat space of the organisms, affecting the diversity and density of soil mesofauna, even causing the elimination of some groups of organisms and the modification of certain parameters of the community (Fernández 1995; Bedano and Ruf 2007; Bernava et al. 2013). Accordingly, certain characteristics of soil fauna communities can be used as indicators of the loss or degradation of soil quality (Behan-Pelletier 1999; Bedano et al. 2008; Socarrás 2013). However, there are no studies linking porosity and the habitat of the organisms in the area.

Taking into account the abovementioned studies, we propose the following hypothesis: "soil tillage negatively influence on the porosity, by modifying shape, size and roughness of the pores, and thus conditioning the available habitat space of the mesofauna."

The aim of our work is to analyze the effect of tillage in typical Argiudolls of Los Padres Pound, in the pores morphology, size and roughness, and its relationship with the potential available habitat space of the mesofauna.

Materials and methods

Area description and soil characteristics

The site under study is located in the General Pueyrredon District, around the Los Padres Pond, Province of Buenos Aires (37°56′S and 57°44′W) (Fig. 1). According to Köpen climatic classification, the climate is oceanic temperate, the annual precipitation is 800 mm, the annual average temperature is 14 °C, the average minimum temperature is 4 °C in June, while the average maximum temperature reaches 22 °C in January (National Weather Service, according to the 1981–2010 record).

The Los Padres Pond site belongs to the geomorphological unit known as "Perinange eolian hills" (Martinez 2001), which comprises a relief of morphologically complex hills, with relative heights of up to 30 m and concave–convex profiles with intermediate straight patches and slopes between 6 and 8% (Osterrieth et al. 1998). In the area, predominant soils are typical Argiudolls, originated from eolian loessian sediments linked to the latest arid cycle of the late Pleistocene–Holocene. These natural soils have an A horizon over 30 cm thick and a B horizon of approx. 50 cm. The organic matter content is high, approximately 9.4% in the A horizon, 3% in the B horizon, and 1.5% in the parent material. The pH values are slightly acid (6–6.3) in the A horizon and close to neutrality (6.8–7) in the parent material. The soil texture is silt loam, with the silt (55–70%) and clay (20–30%) fractions being the most representative. Following the standards set by the Soil Survey Staff (1996), the soil temperature regime is mesic, and the moisture regime is of udic. In cultivated soils, these characteristics are modified negatively (< organic matter content, < pH, etc.).

Methodology and soil measurements

Plots from the same topographic position were selected, with the same soil type (Typical Argiudolls):

C (cultivated): subjected to crop during the last 40 years, with horticultural practices (carrot, potato, corn), with conventional tillage (includes those practices that involve the use of machinery such as plows of disks, which open and invert the soil completely).

N (natural) reference plot. It belongs to the "Reserva Integral de la Laguna de Los Padres." It is a reserve sector within a recreational area, with grass vegetation and some patches of *Acacia melanoxylon*, *Colletia parodoxa*, and *Rubus* sp., characterized by having non-farmed soils.

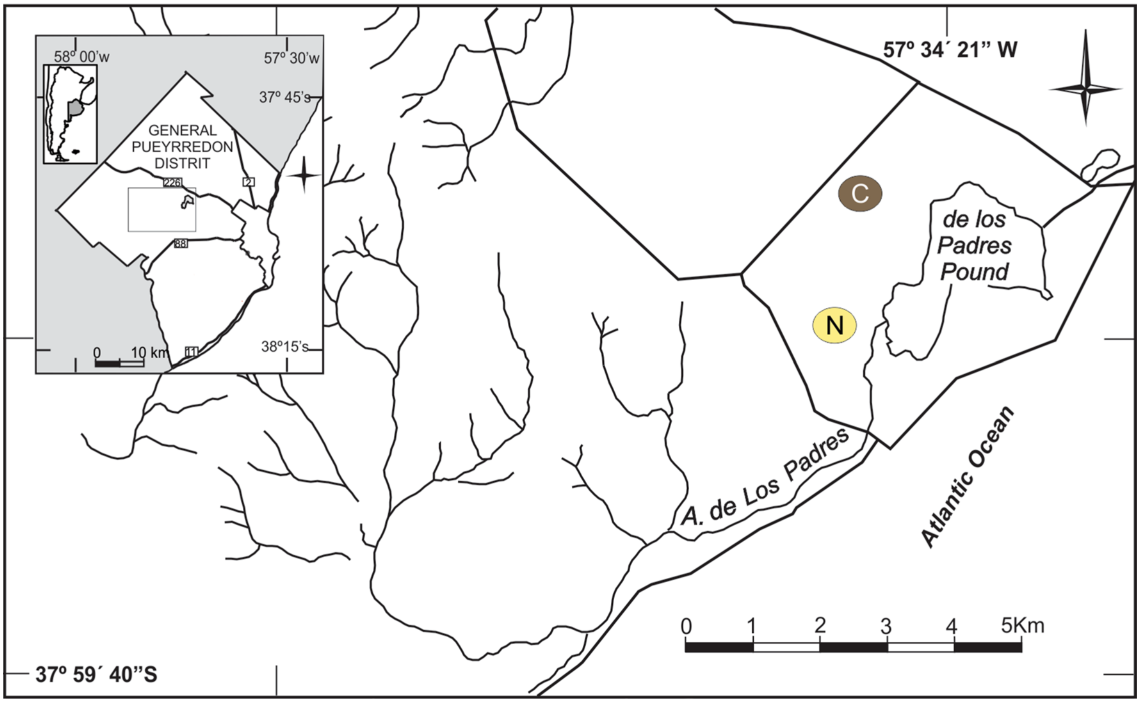

Fig. 1 Map of the location of the study area. N: Natural. C: Cultivated

The natural plot (N) is situated in a natural reserve in the region of the SE Buenos Aires Province, where typical Argiudolls soils in pristine situation are almost not found, due to their intense use for agricultural activities. On the other hand, cultivated plot (C) represents a typical soil with crops diverse, and it may represent the characteristics of a high fraction of the soils of the region. Besides this, we decided to obtain pseudo-replicates separated at a distance such that the samples can be considered independent, ensuring to show the heterogeneity of each site (Camus and Lima 1995).

In each plot, taking into account the porosity antecedents for the area, three undisturbed samples (pseudo-replicates) were taken from the upper levels of the mollic epipedon (0–5, 5–10 cm) and placed in 5 × 10 × 3 cm cardboard boxes. The samples were impregnated with polyester resin diluted in styrene monomer (Murphy 1986). A fluorescent pigment (Uvitex OB) was added to the solution to distinguish the pore space of the matrix with UV light. Blocks were extracted from the impregnated samples, in which 20 small areas (1.4 × 1.1 cm^2) were selected for image analysis and photographed under magnifying glass (Pires et al. 2008). These digitalized images were processed using the Noesis Visilog® program. From these images of areas selectioned, we determined total porosity (the sum of the areas of the types of pores/total area of the field), pore shape (rounded, irregular, elongate), and size type of the pores: 0–100, 100–200, 200–300, 300–400, 400–500, 500–1000, and > 1000 µm, characterized through two indexes and thresholds (Cooper et al. 2005).

Pore roughness was determined from the same images, following the methodology of intersection points proposed by Alvarez et al. (2008), in which the contour of the pore aggregates, obtained from their photographic images, is combined with polygons adapted to each shape, and the of intersection points (IP) between both lines are quantified, hence IP = roughness.

In order to relate total porosity to the potential habitat of the mesofauna, published studies were reviewed for natural and cultivated sites in southeastern Buenos Aires (Fernández 1995, Scampini 1998; Bernava et al. 2013). It was taken into account the abundance of organisms of the total mesofauna and the body size of the species of oribatid mites. Although the mesofauna and porosity data were obtained in different years of sampling, the oribatids mentioned in these studies are the representative ones of these Argiudolls. Therefore, it is interesting as an initial approach to the study of variations in porosity according to soil use, and its effect on mesofauna when it modifies its habitable space.

Statistical analysis

Multivariate analysis was used for pseudo-replicates of each plot. Non-metric multidimensional scaling (nMDS) was performed using Bray–Curtis similarity matrix (Underwood 1998; Clarke and Warwick 2001), taking into account the

variables pores morphology and size. In this analysis, the pores roughness was included as a factor. To determine if the differences in pore roughness between plots and in depth were significant, a Mann–Whitney test was performed. To elucidate if the pore morphology and size vary with depth, a one-way PERMANOVA (considering "Depth" as a factor and type I error) was performed based on Bray–Curtis similarity matrix (Underwood 1998; Anderson 2001). On the other hand, to determine if the variables pores morphology and size discriminate significantly to the N and C plots, a generalized discriminant analysis (GDA) based on Bray–Curtis distances was performed (Legendre and Legendre 1998; Anderson and Robinson 2003).

Results

Porosity

The results show that total porosity (TPA = percentage of total area occupied by the pores) decreases 10% in the cultivated plot (C) in comparison with the natural plot (N), the latter reaching a value close to 34.4% (Fig. 2a). In both plots, total porosity is composed mainly by large irregular pores, followed by the round and the elongate pores. For both depths, an approximate increase of 20% in rounded pores and a 40% decrease in irregular pores were observed in C with respect to N (Fig. 2a).

On the other hand, image analysis also revealed differences between the two plots. The N plot showed a microstructure crumbs, with more complex porosity caused by a more intricate pore network, with more tortuous pores which are more interconnected, while the C plot showed a subangular blocky microstructure, with more simple porosity, showing very small pores and large fissure pores (a consequence of tillage in the plots), which are less interconnected (Fig. 2b).

In the analysis of porosity according to the pore size, both depths showed a higher percentage of small rounded pores (< 100, 100–200, 200–300 μm) in the C plot in comparison with the N plot, while irregular pores, especially > 1000 μm pores, decreased 20% at a depth of 0–5 cm and 40% at 5–10 cm. On the other hand, in plot C, at a depth of 0–5 cm, the 300–400-μm rounded pores decreased, while the irregular 400–500-μm pores increased (Fig. 3a).

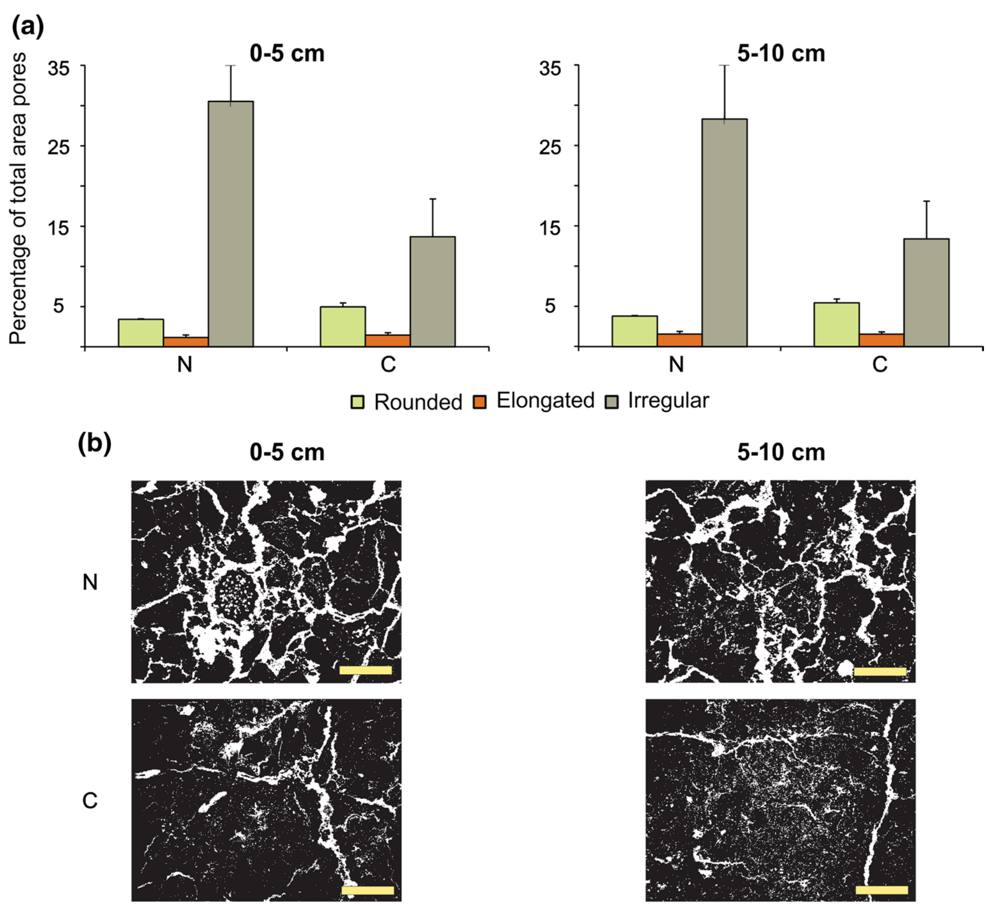

Fig. 2 **a** Distribution of total porosity according to the pores shape at 0–5 and 5–10 cm depth. Bars indicate the standard error. N: Natural. C: Cultivated. **b** Binary images corresponding to the plots studied; white areas indicate porosity and black areas mineral material. Scale = 5000 μm

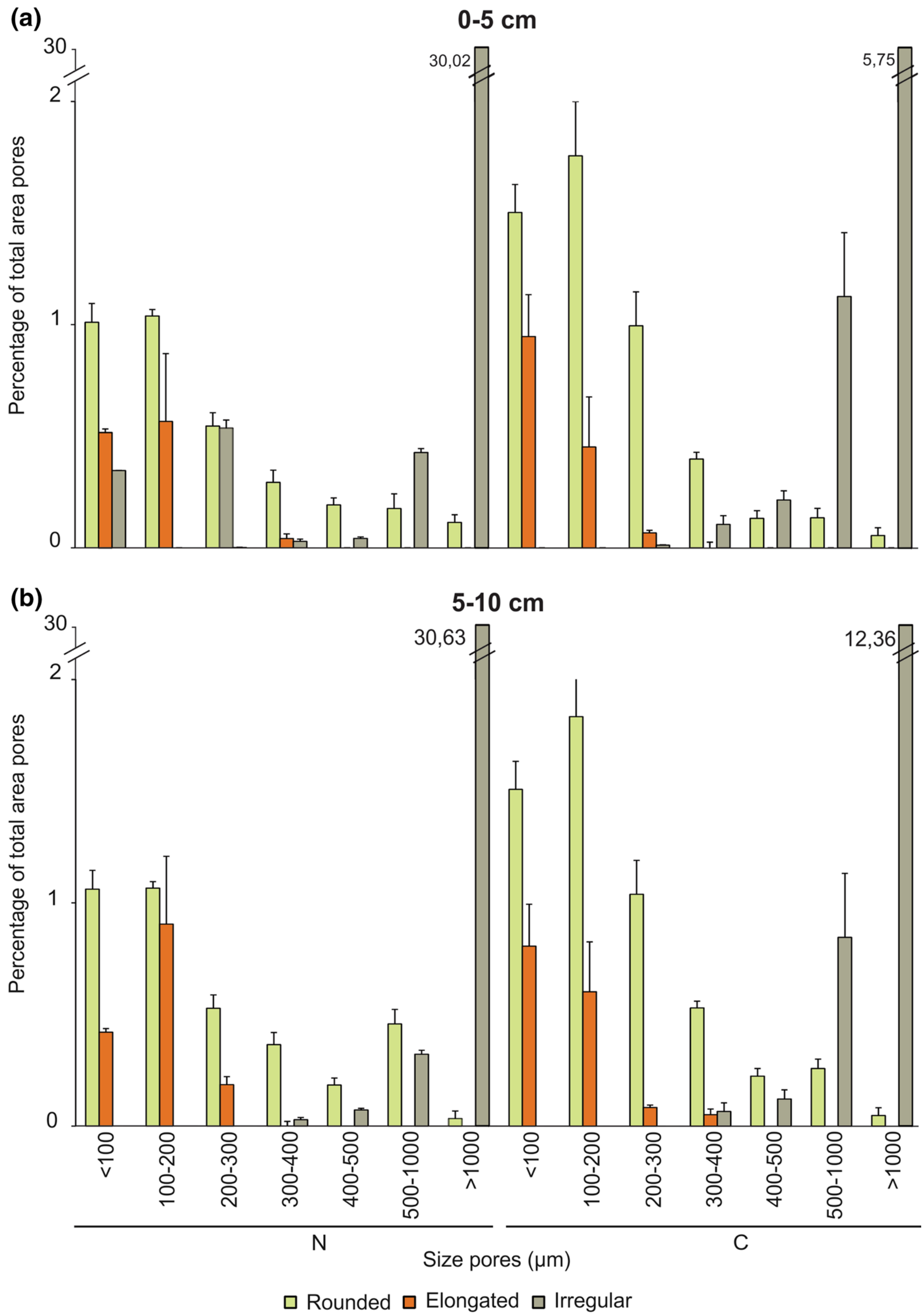

Fig. 3 Distribution of total porosity according to the pores shape and size at 0–5 and 5–10 cm depth. Bars indicate the standard error. N: Natural. C: Cultivated

Roughness

Results show a decrease in pore roughness in the cultivated plot compared with the natural plot. The values in the intersection points in C were significantly lower in the both depths ($p < 0.05$), decreasing approximately 50% with respect to N (Fig. 4a).

These differences in roughness are apparent also in the images, where C presents aggregates with a smoother surface, which translates into lower roughness in its pores (Fig. 4b, c), whereas in N, the aggregates are more rough.

Statistical analysis

A PERMANOVA analysis was used to determine the variations in the morphology and size of the pores in relation to depth. The results show that there are no significant

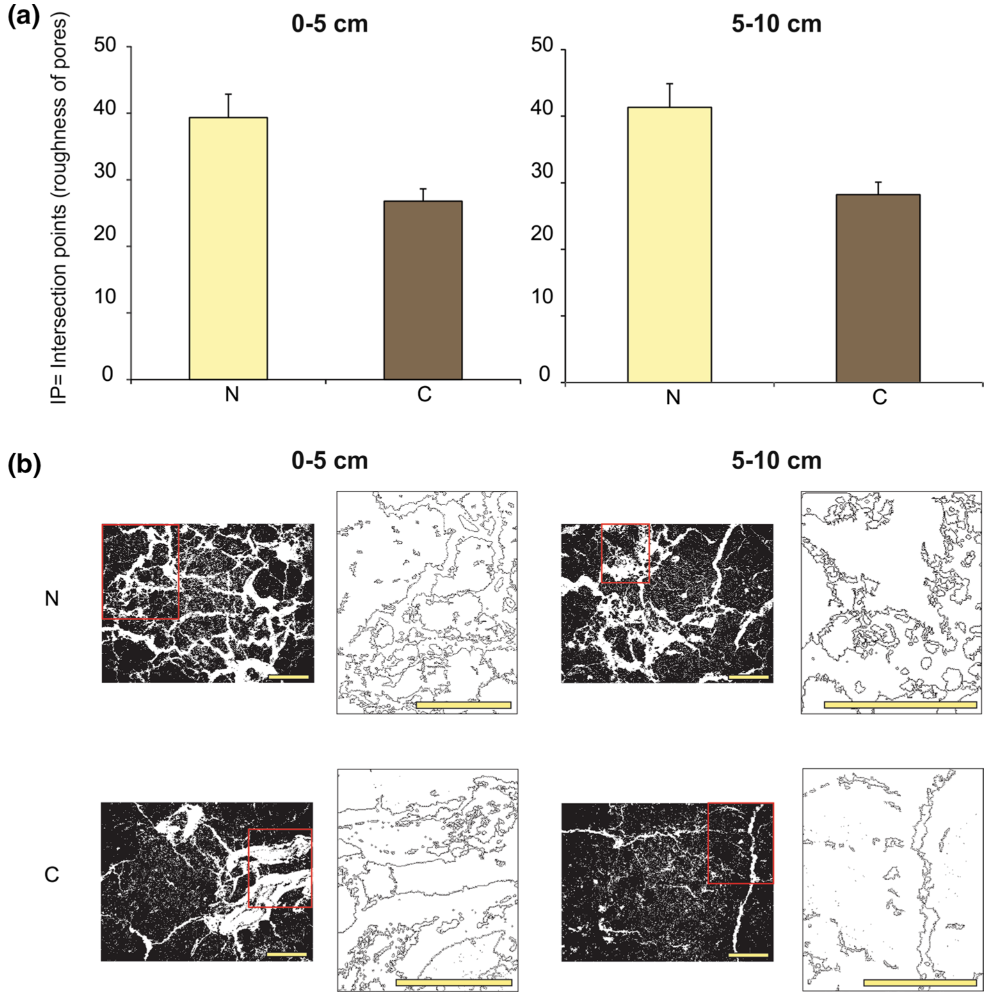

Fig. 4 **a** Pore roughness (IP: intersection points). Bars indicate the standard error. N: Natural. C: Cultivated. **b** Binary images corresponding to the plots studied; white areas indicate porosity and black areas mineral material. Scale = 2500 µm. c Detail of the pore roughness. Scale = 2500 µm

differences in the N plot and the C plot, $p = 0.3$ and $p = 0.9$, respectively.

An MDS analysis showed that the N plot samples are closer to each other, thus indicating a greater similarity in terms of the morphology and size of the pores than the C plot samples. On the other hand, the higher values of PI (> pore roughness) were associated to the N plot samples (Fig. 5).

The results of GDA indicate that the plots can be discriminated significantly. Through the "leave-one-out method" (Lachenbruch and Mickey 1968; Anderson and Robinson 2003), the classification error amounted to 0% (Fig. 6). The variables playing a major role in the discrimination were the < 100-µm elongated pores ($p = 0.92$), the 200–300-µm rounded pores ($p = 0.9$), the 100–200-µm rounded pores ($p = 0.88$), the < 100-µm rounded pores ($p = 0.81$), and the > 1000-µm irregular pores ($p = 0.84$).

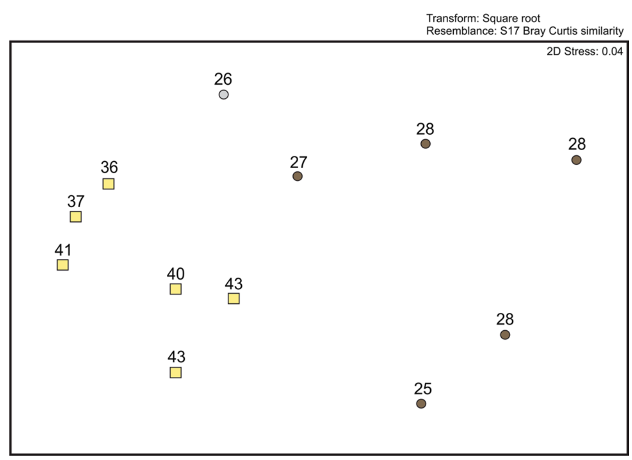

Fig. 5 MDS analysis considering the variables pores morphology and size, pore roughness was included as a factor. Yellow squares: natural plot (N). Brown circles: cultivated plot (C)

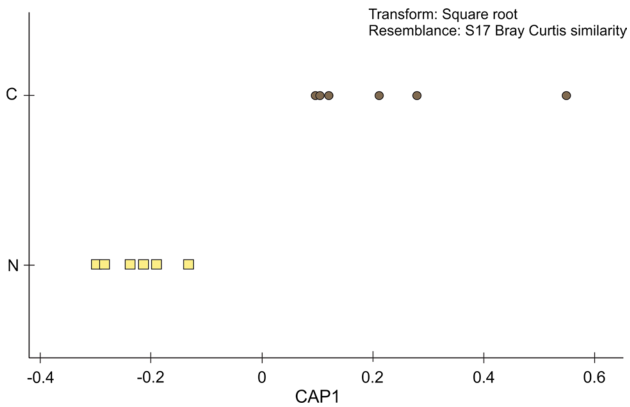

Fig. 6 GDA considering the variables pores morphology and size, pore roughness was included as a factor. Yellow squares: natural plot (N). Brown circles: cultivated plot (C)

Mesofauna

In order to establish a possible relation between the mesofauna of the soils studied and the porosity of the plots, several studies of these typical Argiudolls were taken into account, with special emphasis on the Oribatida group (Fernández 1995; Scampini 1998; Bernava et al. 2013). Abundance of organism and their respective sizes were considered. The body width of these organisms is relevant to study the size of the pore spaces within which these oribatids can move.

Broadly, in cultivated plots a decrease in the number of oribatids and the appearance and disappearance of some species was reported. Regarding the abundance of Oribatida according to their size, in all the cases approximately the same pattern was observed in the natural plot. High values were found, up to 400 µm, reaching a maximum in the number of individuals measuring 200–300 µm (Fig. 7). In the cultivated plot, the decrease in the number of individuals

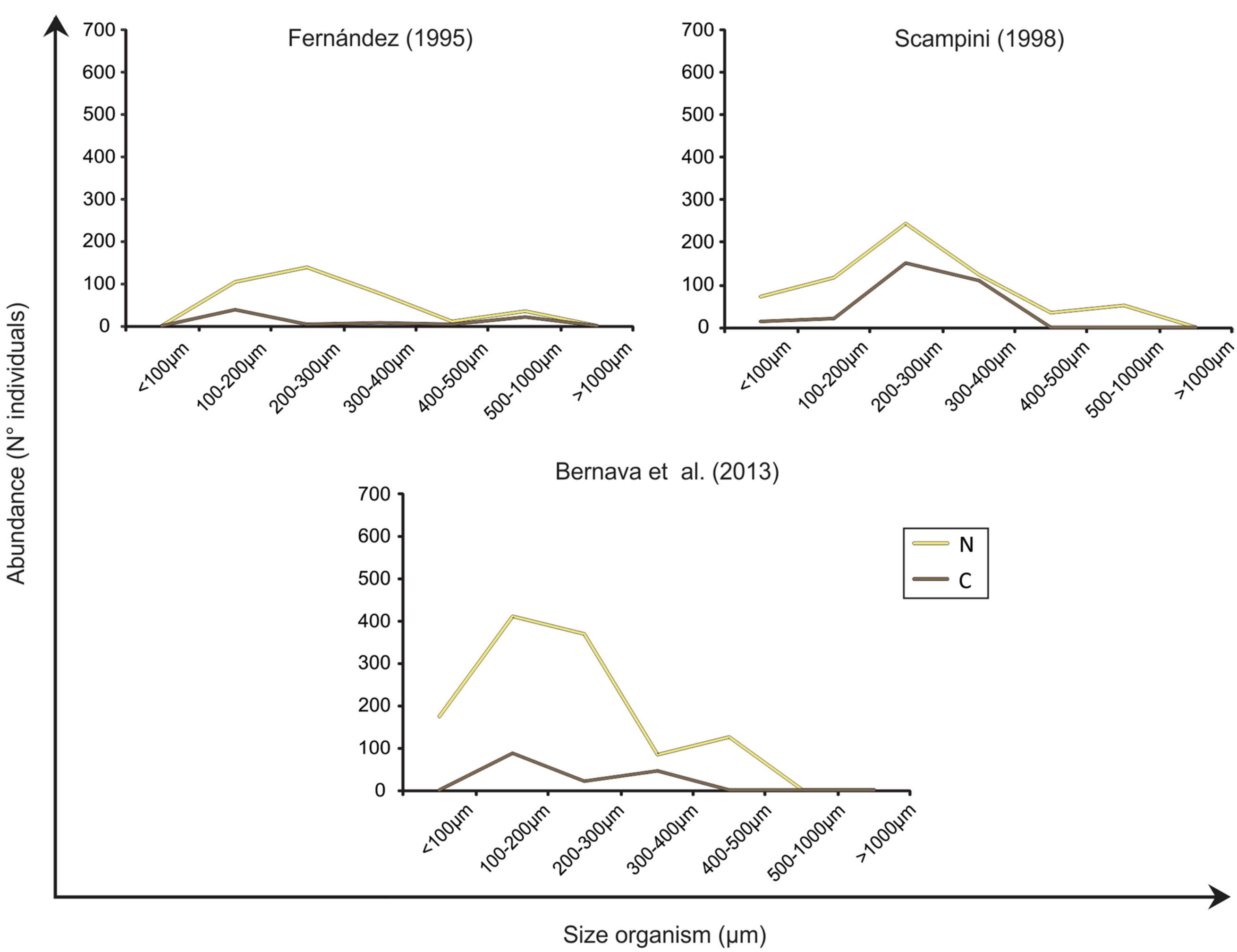

Fig. 7 Abundance of oribatid mites according to rank of body sizes in the natural (N) and cultivated (C) plots

Table 1 Oribatid mites present in the first 10 cm of soil profile and their body size (μm). N: Natural. C: Cultivated

	Body size (μm)	N	C
Fernández (1995)			
Microppia sp.	90	1	0
Ramusella sp.	135	2	0
Tenuelamellarea sp.	140	1	0
Xylobates sp.	170	6	3
Perxylobates sp.	175	1	36
Brachioppia sp.	200	91	0
Brachioppia sp.2	200	2	0
Brachioppia sp.3	200	85	1
Totobates sp.	220	28	0
Graptoppia sp.	240	15	2
Opiella sp.	250	0	1
Oxyopiella sp.	250	0	1
Lanceoppia sp.	275	8	0
Pulchropia sp.	300	1	0
Pysobates sp.	300	0	1
Epilohmannia sp.	310	1	1
Semischeloribates sp.	350	61	5
Reteremulus sp.	370	10	0
Carenella sp.	370	0	1
Brasilobates sp.	380	4	0
Nothrus sp.	400	1	0
Maculobates sp.1	450	4	0
Maculobates sp.2	450	4	2
Maculobates sp.3	450	0	1
Hemileius sp.	450	1	0
Jugatala sp.	470	1	0
Joshuella sp.	500	0	1
Galumna sp.	600	18	0
Humerobates sp.	600	16	21
Scampini (1998)			
Microppia minus	70	14	14
Sellnickochthonius folliatus	90	1	0
Sellnickochthonius rotundatus	90	2	0
Oxyoppia pilosa	100	54	0
Fosseremus sp.	120	32	0
Brachioppiella pepitensis	130	13	0
Ramusella sp.	135	5	5
Epilohmannia pallida americana	137	33	0
Opiella nova	150	10	10
Teratoppia brevipectinata	160	1	0
Gerloubia sp.	170	1	0
Xylobates capucinus capucinus	190	6	6
Tectocepheus sp.	190	13	0
Teratoppia sp.	195	1	0
Teratoppia regalis	200	1	0
Eremulus crispus	220	41	0
Hemileius suramericanus	230	39	0
Graptoppia sp.	240	1	0

Table 1 (continued)

	Body size (μm)	N	C
Totobates mollicoma	240	153	153
Lanceoppia sp.	275	8	0
Oribatella longisetosa	300	3	0
Oripoda cordobensis	350	1	0
Cryptozetes sp.	360	11	0
Erogalumna sp.	360	25	25
Urumbambates paraguayensis	380	87	87
Nothrus sp.	500	35	0
Galumna australis	525	6	0
Galumna sp.	650	6	0
Galumnidae	650	39	0
Bernava et al. (2013)			
Microppia minus	70	174	0
Oxyoppia suramericana	120	5	0
Ramusella sp.	135	12	0
Epilohmannia pallida	137	4	0
Berlesezetes brasilozetoides	145	7	0
Suctobelbella sp.	145	14	0
Tenuelamellarea argentinensis	150	0	1
Oppiella nova	150	0	1
Cultroribula zicsii	155	27	0
Oxyoppia affricanus taurus	155	1	0
Paraphauloppia sp.	172	0	4
Tectocepheus sp.	190	18	81
Lauroppia fallax	200	294	0
Brachioppia sp.	200	25	0
Eremulus crispus	220	57	0
Totobates sp.	220	48	0
Galumna flabellifera	225	175	0
Hemileius suramericanus	230	0	0
Scheloribates praenincisus acuticlava	235	61	7
Scheloribates sp.	300	25	0
Oripoda sp.	245	4	2
Physobates spinipes	250	9	0
Zygoribatula sp.	250	0	12
Oribatula sp.	255	20	28
Oribatella sp.	300	0	1
Porozetes sp.	350	17	11
Scheloribates sp.	350	21	0
Nothrus peruensis total	400	40	0
Nothrus sp.	400	0	0
Hemileius sp.	400	4	4
Eupelops sp.	400	0	3
Platynothrus sp.	500	124	0

compared to those in the natural parcel is significant, in all the sizes found (Fig. 7). Table 1 shows a list of the organisms present in the first 10 cm of soil profile, both in natural and cultivated plots. In the natural plot, the most abundant and

exclusive species were *Lauroppia fallax*, *Microppia minus*, *Totobates mollicoma*, *Brachioppia sp.*, *Eremulus crispus*, *Oxyoppia hairy*, *Hemileius suramericanus*, and *Epilohmannia pallida americana*. The body sizes of these species were all more than 300 µm. Other species with larger body sizes more than 600 µm, such as *Nothrus peruensis*, *Platynothrus* sp., and *Galumna* sp., were also abundant and exclusive in this plot. Some species with the body sizes less than 300 µm also were recorded in both plots (*Scheloribates acuticlava praencicisus*, *Xylobates* sp., and *Oripoda* sp.), but their abundance was lower in the cultivated plot. Here the most abundant species were *Tectocepheus* sp., *Perxylobates* sp., *Oribatula* sp., *Humerobates* sp., and *Eupelops* sp.; the following species were exclusive to that plot, *Zygoribatula sp.*, *Paraphauloppia* (Monoph.), *Opiella* sp., *Physobates* sp., *Karenella* sp., *Joshuella* sp., and *Oxyopiella* sp. All of them had small body sizes less than 300 µm (Table 1).

Discussion

The results show modifications in the structure of cultivated plot in comparison with the natural plot. Some of them include decrease in total porosity, and the modifications in type, size, and roughness of the pores. These variations in soil structure influence several processes and the space available for the mesofauna.

The porosity observed in both plots may be explained by two different mechanisms. As pointed out by Kay and Vanden Bygaart (2002), edaphic porosity may be caused by both abiotic factors (farming) and biologic activity. In the natural plot (N), part of the total porosity, represented by irregular and rounded pores, is surely caused by the effects of roots and macrofauna. On the contrary, in the cultivated plot (C), the elongated pores, especially fissural pores of vertical and horizontal orientation, may have been originated as a consequence of farming. Furthermore, in previous studies in these plots (Alvarez et al. 2012) high values of bulk density and mechanic resistance were recorded, possibly generated by the weight of machinery. About this, Pagliai et al. (2004) pointed out that compaction modifies the bulk density, the mechanic resistance, the geometry of the pore space, and the tortuosity and connectivity of the pores, and, thus, the space available for soil organisms (Beylich et al. 2010).

The abovementioned physical properties of the soil are directly linked to the structural stability and the organic carbon (OC). Tisdall and Oades (1982) pointed out that areas which are uncultivated and with higher OC content have a higher proportion of stable macroaggregates, whereas areas subjected to intensive cultivation show the opposite characteristics. Several authors (Osterrieth et al. 1998; Scampini et al. 2000; Borrelli 2001; Montti 2002; Alvarez et al. 2011) have studied the OC in these same plots (N and C), observing a decrease of approximately 3% in C with respect to N, with the subsequent decrease in structural stability. The loss of stability translates into a decrease in the total porosity which, in turn, modifies connectivity between pores.

The results of pore roughness are similar to those obtained by Alvarez et al. (2008) for aggregate roughness. These authors indicate the presence of aggregates with spherical morphology and aggregates with lower roughness in their walls in plots subjected to cultivation, and they attribute these characteristics to mutual friction as a result of soil tillage. In the cultivated plot (C), the aggregates display a smoother surface and fewer points of contact between them, which increases the speed of water entry during the moistening process of the aggregates. This causes slaking, thus reducing structure stability, the decrease in macropores and an increase in micropores (Baver et al. 1973), which offers space for the smaller organisms. On the other hand, this lower aggregate roughness translates into pores of lower tortuosity, which generates a lower complexity in the space available for organisms. On the contrary, the natural plot (N) displays pores of higher roughness which would allow a more complex habitat architecture, offering a higher number of habitable pore spaces for soil organisms.

For the organisms of the mesofauna, in all the cases analyzed, the lower abundance found in the cultivated plot was related directly with the tillage carried out in it. The consequences of the anthropic impact on the mesofauna in relation to the physical properties are associated with the reduction in habitable space, with the subsequent total or partial reduction in the microarthropod community (Altieri 1999; Battigelli et al. 2004; Larsen et al. 2004; Maraun et al. 2003). Soil tillage, in addition to the disturbances caused in the habitat, has a direct effect on the organisms, since they may harm them and even kill them, or expose them to the risk of predation. The organisms of the mesofauna with a body size of between 100 and 2000 µm live primarily in the macropores (Lavelle et al. 1997). That is why the pore size found in both plots (20–1000 µm) offers habitable spaces for these organisms.

There are scarce studies linking the mite abundance to pore size (Vreeken-Bruijs et al. 1998; Clapperton et al. 2002; Ducarme et al. 2004). However, with the porosity results and the representative mesofauna of these soils, some theoretical inferences could be made. The increase in small pores, specifically the increase in 200–300-µm rounded pores in the cultivated plot, might not be related to an increase in the number of organisms of the same size. These pores may offer space for other opportunistic organisms that can adapt quickly to anthropic disturbances. Such is the case of the genus *Tectocepheus* sp. (190 µm), organism cosmopolitan that has already been identified as an indicator of ecosystem degradation by anthropogenic activities (Gulvik 2007; Fujita and Fujiyama 2001). Its abundance, higher than that

of the natural plot mites, is due to the fact that they are generalist species, which can live in difficult conditions. After soil disturbance, they would be restricted to 100–300-μm micropores as a result of tillage. The same happens with *Perxylobates* sp. (175 μm), *Oribatula* sp. (255 μm), *Zygoribatula* sp. (250 μm), and *Opiella* sp. (250 μm). Berch et al. (2007) considered the latter as an indicator of disturbance in grasslands and agroecosystems, and as a pioneer in colonizing agricultural areas. Some of the other species found have been described in soils with other types of disturbances (Aoki 1979; Travé 1981; Bosch-Serra et al. 2014; among others).

In the studies analyzed, we observe a higher abundance of those ranging from 200 to 300 μm in the natural plot. Oribatida of all sizes decrease in number in cultivated soils. The abundance of oribatid mites is directly related to the content of organic carbon, pH, humidity, and the chemical products present in the soil (Anderson 1988; Larink 1997). The decrease in the number of mites in the cultivated plot (C) might be due to some of these factors.

On the other hand, the organisms of larger sizes (400–600 μm), such as *Platynothrus* sp., *Urumbambates paraguayensis, Semischeloribates* sp., *Nothrus peruensis, Scheloribates* sp., and *Galumna* sp. disappear in the cultivated plot, due to a reduction in macroporosity caused by soil tillage. These species can move in larger and more interconnected pores and are highly dependent on the content of organic matter in the soil; this is why they are absent in the cultivated plot.

Even though in both plots there are pores of type and size which are appropriate to offer habitable space to these organisms, few of these spaces seem to be available for the oribatids. Since the interconnection and continuity of pores in the cultivated plot are lower than in the natural plot, these organisms seem to be restricted to small pores. The habitat architecture in the natural plot is more complex, with a higher number of pores of all sizes, coarser pores, and with higher continuity between them. Hence, there is a broader "supply" of habitable space for the organisms. Consequently, the only organisms that will live in the pore spaces of the cultivated soil are those that are capable of living in them because of their smaller size and those that have survived the direct action of agricultural machinery or the indirect action of tillage (the reduction in macroporosity).

As previously mentioned, although the mesofauna and porosity data were obtained in different years of sampling, the oribatids mentioned in these studies are the representative ones of these Argiudolls. Therefore, it is interesting as an initial approach to the study of variations in porosity according to soil use, and its effect on mesofauna when it modifies its habitable space.

Taking into account the relationships which might be established between pores and soil organisms, it is essential to know, in addition, the behavior of these organisms, their diets and their feeding habits, and the ecological characteristics that determine their activities.

Conclusions

The results of this study prove the influence of tillage on the soil structure in the cultivated plot. The modifications in the physical properties resulting from soil use are due to the decrease in total porosity and the modification in the type, size, and roughness of the pores (decrease in the macropores and increase in the micropores, and decrease in the roughness).

These changes in porosity were not perceptible at different depths, so the size and morphology of the pores may be uniform in the first 10 cm of soil.

Taking into account the records of mesofauna organisms present in this type of soils and the pores properties, it was possible to make certain theoretical inferences. The decrease in total porosity might influence the abundance of mesofauna in these typical Argiudolls. The increase in microporosity and the variation of other properties of the soil might lead to the appearance of other species which easily adapt to abrupt environmental changes. On the other hand, the decrease in macropores might lead to the disappearance of some species of greater size.

Acknowledgements The authors thank the Projects ANPCyT (BID-PICT No 2010-2036 y BID-PICT No 2012-2694), Laboratory Department of Soils (ESALQ, University of Sao Paulo, Brazil), Group of Arthropods-Department of Biology (University National of Mar del Plata) and Dra. Verónica Taglioretti for statistical collaboration.

References

Altieri MA (1999) Dimensiones multifuncionales de la agricultura ecológica en América, Latina edn. PED-CLADES/CIED, Lima, Perú

Alvarez MF (2009) Efecto de las prácticas agrícolas y forestales sobre las fracciones coloidales en Argiudoles típicos del sudeste bonaerense. FCEyN, Universidad Nacional de Mar del Plata, Argentina, Tesis Doctoral

Alvarez MF, Osterrieth M, Bernava Laborde V, Montti L (2008) Estabilidad, morfología y rugosidad de agregados de Argiudoles típicos sometidos a distintos usos: su rol como indicadores de calidad física de suelos, Buenos Aires, Argentina. Ciencia del Suelo 26(2):115–129

Alvarez MF, Osterrieth M, del Río JL (2011) Organic matter fractionation in aggregates typical Argiudolls southeastern Buenos Aires and its relation to different soil uses. A preliminary study. Environ Earth Sci 65(2):505–515

Alvarez MF, Osterrieth M, del Río JL (2012) Changes on aggregates morphology and roughness of induced by different uses of typical Argiudolls, Buenos Aires province, Argentina. Soil Tillage Res 119:38–49

Alvarez MF, Osterrieth M, Cooper M (2013) Cambios de porosidad inducidos por la actividad hortícola en Argiudoles típicos de agroecosistemas del sudeste bonaerense y su relación con el hábitat de la mesofauna. Un estudio preliminar. Resúmenes III Congreso de Ecología y Biología de Suelos. Río Cuarto, Córdoba. 39p. Expandido en CD

Anderson JM (1988) Spatiotemporal effects of invertebrates on soil processes. Biol Fertil Soils 6:216–227

Anderson MJ (2001) Permutation tests for univariate or multivariate analysis of variance and regression. Can J Fish Aquat Sci 58:626–639

Anderson MJ, Robinson J (2003) Generalized discriminant analysis based on distances. Aust N Z J Stat 45:301–318

Aoki J (1979) Difference in sensitivities of oribatid families to environmental change by human impacts. Revue d'Ecologie et de Biologie du Sol 16(3):415

Aparicio V, Costa JL (2007) Soil quality indicators Ander continuous cropping systems in the Argentinean Pampas. Soil Tillage Res 96:155–165

Bardgett RD (2002) Causes and consequences of biological diversity in soil. Zoology 105:367–374

Battigelli J, Spencer R, Langor DW, Berch SM (2004) Shortterm impact of forest soil compaction and organic matter removal on soil mesofauna density and oribatid mite diversity. Can J For Res 34(5):1136–1149

Baver LD, Gardner WH, y Gardner WR (1973) Física de, suelos edn. Limusa, México

Bedano JC, Ruf A (2007) Soil predatory mite communities (Acari: Gamasina) in agroecosystems of central Argentina. USA. Appl Soil Ecol 36:22–31

Bedano JC, Arolfo R, Domínguez A (2008) La mesofauna edáfica como indicadora de la degradación del suelo. Resúmenes XXI Congreso Argentino de la Ciencia del Suelo, Expandido en CD

Behan-Pelletier VM (1999) Oribatid mite biodiversity in agroecosystems: role for bioindication. Agric Ecosyst Environ 74:411–423

Berch SM, Battigelli JP, Hope GD (2007) Responses of soil mesofauna communities and oribatid mite species to preparation treatments in high-elevation cutblocks in southern British Columbia. Pedobiología 51:23–32

Bernava Laborde V, Narciso EN, Alvarez MF, Martínez PA (2013) Evaluación de calidad de suelos a través de mesofauna y estabilidad estructural en huertas agroecológicas y convencionales del sudeste bonaerense. Resúmenes III Congreso de Ecología y Biología de Suelos. Río Cuarto, Córdoba. 17p. Expandido en CD

Beylich A, Oberholzer HR, Schrader S, Höper H, Wilke BM (2010) Evaluation of soil compaction effects on soil biota and soil biological processes in soils. Soil Tillage Res 109:133–143

Borrelli NL (2001) Minerales, biominerales y su relación con las propiedades físico-químicas de Argiudoles Típicos afectados por prácticas agrícolas en Laguna de Los Padres, Buenos Aires. FCEyN, Universidad Nacional de Mar del Plata, Tesis de grado

Bosch-Serra AD, Padró R, Boixadera-Bosch RR, Orobitg J, Yagüe MR (2014) Tillage and slurry over-fertilization affect oribatid mite communities in a semiarid Mediterranean environment. Appl Soil Ecol 84:124–139

Camus PA, Lima M (1995) El uso de la experimentación en ecología: supuestos, limitaciones, fuentes de error, y su status como herramienta explicativa. Revista Chilena de Historia Natural 68:19–42

Clapperton MJ, Kanashiro DA, Behan-Pelletier VM (2002) Changes in abundance and diversity of microarthropods associated with Fescue Prairie grazing regimes. Pedobiología 46:496–511

Clarke KR, Warwick RM (2001) Change in marine communities: an approach to statistical analysis and interpretation, 2nd edn. PRIMER-E, Plymouth, UK

Cooper M, VidalTorrado P, Chaplot V (2005) Origin of microaggregates in soils with ferralic horizons. Scientia Agricola (Piracicaba, Braz.) 62(3):256–263

Downes BJ, Lake PS, Schreiber ESG, Glaister A (1998) Habitat structure and regulation of local species diversity in a stony, upland stream. Ecol Monogr 68:237–257

Ducarme XD, Andre HM, Wauthy G, Lebrun P (2004) Are there real endogeic species in temperate forest mites? Pedobiologia 48:139–147

Duhour A, Costa C, Momo F, Falco L, Malacalza L (2009) Response of earthworm communities to soil disturbance: Fractal dimension of soil and species' rank-abundance curves. Appl Soil Ecol 43:83–88

Elissondo E, Costa JL, Suero E, Fabrizzi LP, Garcia F (2001) Evaluación de algunas propiedades físicas del suelo luego de la introducción de labranzas verticales en un suelo bajo siembra directa. Ciencia del Suelo 19(1):11

Estrade JR, Anger C, Bertrand M, Richard G (2010) Tillage and soil ecology: partners for sustainable agriculture. Soil Tillage Res 111:33–40

Fernández C (1995) Efecto de prácticas agrícolas sobre las propiedades físico-químicas y la distribución y composición faunística de los microartrópodos en un Argiudol típico de Laguna de los Padres. FCEyN, Universidad Nacional de Mar del Plata, Tesis de grado, p 28

Fujita M, Fujiyama S (2001) How can the minor species, Tectocepheus minor (Oribatida), dominate T. velatus in a no-tillage crop field? Pedobiología 45:36–45

Gulvik ME (2007) Mites (acari) as indicators of soil biodiversity and land use monitoring: a review. Polish J Ecol 55(3):415

Hassink J, Boijwman LA, Zwart KB, Brwsaard L (1993) Relationships between habitable pore space, soil biota and mineralization rates in grassland soils. Geoderma 57:105–128

Iglesias J, Galantini J, Santiago L (2007) Cambios en la distribución y orientación de diferentes tamaños de poros. Sistemas Productivos del S y SO bonaerense. RevistaTécnica de Siembra Directa, pp 24–27

INTA-EEA Rafaela (1989) Degradación de los suelos por intensificación de la agricultura. Informe del Taller organizado por CONICET. p 185

Kampichler C (1999) Fractal concepts in studies of fauna. Geoderma 88:283–300

Kampichler C, Hauser M (1993) Roughness of soil pore surface and its effect on available habitat space of microarthropods. Geoderma 56:223–232

Kay BD, Vanden Bygaart AJ (2002) Conservation tillage and depth stratification of porosity and soil organic matter. Soil Tillage Res 66:107–118

Kladivko EJ (2001) Tillage systems and soil ecology. Soil Tillage Res 61:61–76

Lachenbruch PA, Mickey MR (1968) Estimation of error rates in discriminant analysis. Technometrics 10:1–11

Lal R (1991) Soil structure and sustainability. J Sustain Agric I:67–92

Langmaack M, Schrader S, Rapp-Bernhardt U, Kotzke K (2002) Soil structure rehabilitation of arable soil degraded by compaction. Geoderma 105:141–152

Larink O (1997) Springtails and mites: important knoots in the food web of soils. In: Benckiser G (ed) Fauna in soil ecosystems: recycling processes, nutrient fluxes, and agricultural production. Books in Soils, Plants and the Enviroment. CRC Press, New York, p 400

Larsen T, Schjønning P, Axelsen J (2004) The impact of soil compaction on euedaphic Collembola. Appl Soil Ecol 26:273–281

Lavelle P, Bignell D, Lapege M, Wolters V, Roger P, Ineson P, Heal OW, Dhillion S (1997) Soil function in a changing world: the role of invertebrate ecosystem engineers. Eur J Soil Biol 33:159–193

Legendre P, Legendre L (1998) Numerical ecology, 2 English edn. Elsevier Science B.V., Amsterdam

Mac Nally R, Horrocks G (2007) Inducing whole-assemblage change by experimental manipulation of habitat structure. J Anim Ecol 76:643–650

Maraun M, Salamon JA, Schneider K, Schaefer M, Scheu S (2003) Oribatid mite and collembolan diversity, density and community structure in a moder beech forest (*Fagus sylvatica*): effects of mechanical perturbations. Soil Biol Biochem 35:1387–1394

Martinez GA (2001) La influencia de un paisaje heredado sobre el escurrimiento superficial en la Región Pampeana. In: Teruggi L (ed) Workshop Manejo Integral de Cuencas Hidrográficas y Planificación Territorial Necochea, Buenos Aires. pp 47–55

Montti LF (2002) Efecto de las plantaciones de pinos y eucaliptus sobre las propiedades morfológicas físicas y químicas de los Argiudoles típicos en Sierra de los Padres, Bs. As. Tesis de grado.Universidad Nacional de Mar del Plata. p 56

Morse DR, Lawton JH, Dodson MM, Williamson MH (1985) Fractal dimension of vegetation and the distribution of arthropod body lengths. Nature 314:731–733

Murphy CP (1986) Thin section preparation of soils and sediments. AB Academic Publishers, Rothamsted

Oades J (1984) Soil organic matter and structural stability, mechanism and implications for management. Plant Soil 76:319–337

Orellana J, Pilatti M (1994) La estabilidad de agregados como indicador edáfico de sostenibilidad. Ciencia del Suelo 12:75–80

Osterrieth M, Maggi J (1996) Variaciones cuali-cuantitativas de la fracción arcilla en Argiudoles afectados por prácticas agrícolas en Laguna de Los Padres. Buenos Aires. Resúmenes VI Reunión Argentina de Sedimentología, pp 337–342

Osterrieth M, Fernández C, Bilat Y, Martínez P, Martínez G, Trassens M (1998) Geoecología de Argiudoles típicos afectados por prácticas hortícolas en la Llanura Pampeana. Buenos Aires, Argentina. Resúmenes XVI Congreso Mundial de la Ciencia del Suelo. Montpellier, Francia. SIMP. 32. CD: 1–8

Pagliai M, Vignozzi N, Pellegrini S (2004) Soil structure and the effect of management practices. Soil Tillage Res 79:131–143

Pires LF, Cooper M, Cássaro FAM, Reichardt K, Bacchi OOS, Dias NMP (2008) Micromorphological analysis to characterize structure modifications of soil samples submitted to wetting and drying cycles. Catena 72(2):297–304

Porta J, López-Acevedo M, Roquero C (1999) Edafología. Para la agricultura y el medio ambiente. Ed. Mundi-Prensa. España

Scampini E (1998) Fauna edáfica y propiedades físicoquímicas del suelo en la bordura entre un área de reserva y un campo cultivado.Tesis de grado. FCEyN, Universidad Nacional de Mar del Plata. p 52

Scampini E, Osterrieth ML, Martinez P (2000) Relación entre propiedades físico-químicas y mesofauna asociada de una bordura en Argiudoles de la Llanura Pampeana. Neotropica 44(111–112):3–12

Secretaría de Agricultura, Ganadería y Pesca (SAGyP), y el Consejo Federal Agropecuario (CFA). (1995) El Deterioro de la Tierras en la República Argentina. Alerta Amarillo. p 287

Socarrás A (2013) Mesofauna edáfica: indicador biológico de la calidad del suelo. Pastos y Forrajes 36(1):5–13

Soil Survey Staff (1996) Keys to soil taxonomy, 7th edn. United States Department of Agriculture, Washington D.C

Tisdall JM, Oades JM (1982) Organic matter and water stable aggregates in soils. J Soil Sci 33:141–163

Travé J (1981) Les biocénoses halophiles d'acariens de l'archipel de Kerguelen. Comité National Français des Recherches Antarctiques (CNFRA) 48:149–158

Underwood AJ (1998) Experiments in ecology: their logical and interpretation using analysis of variance. Cambridge University Press, Cambridge

Urricariet S, Lavado RS (1999) Indicadores de deterioro en suelos de la Pampa Ondulada. Ciencia del Suelo 17:37–44

Vreeken-Bruijs MJ, Hassink J, Brussaard L (1998) Relationships of soil microarthropod biomass with organic matter and pore size distribution in soils under different land use. Soil Biol Biochem 30:97–106