

Edaphic variables conditioning the habitat of oribatid mites in Luvic Phaeozems under forest plantations (Buenos Aires, Argentina)

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Variabls edáficas que condicionan el hábitat de ácaros oribatidos en Phaeozems Lúvicos bajo plantaciones forestales (Buenos Aires, Argentina)

Variáveis edáficas que condicionam o habitat de ácaros oribatídeos em Phaeozems Lúvicos sob plantações florestais (Buenos Aires, Argentina)

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ABSTRACT

The soil is a complex three-dimensional habitat and any changes in its structure and porosity are likely to affect the type and abundance of soil biota. Oribatid mites play an important role in the decomposition and mineralization of soil organic matter and their abundance depends on diverse soil parameters, including soil texture, organic matter content, pH, moisture, and the pore system. The aim of the present work is to analyze some of the edaphic variables that condition the habitat of oribatid mites in Luvic Phaeozems under *Pinus radiata* (site P) and *Eucalyptus globulus* (site E) plantations, in the Southeast of Buenos Aires, Argentina. Bulk density, penetration resistance, pH, moisture, pore system parameters, and oribatid abundance and species composition were analyzed. Site E had a greater total porosity than site P. The high tortuosity of the pores in both sites generates a complex habitat architecture for the development of oribatid mites. In both sites, oribatids of 70–400 μm in size predominated and were more abundant in site E. A positive correlation between the abundance of oribatids and the pore size in both sites was observed. In site E this correlation was lower for 70–600 μm ($R = 0.13$) or negative for 70–400 μm ($R = -0.78$). Therefore, the oribatid abundance could be explained by a greater complexity of the structure of the organic horizon, lower bulk density and lower penetration resistance. These conditions favor the mineralization of organic matter, and therefore food availability. On the other hand, in site P, oribatid abundance is mainly influenced by the porous system, which conditions the access to food, competition between organisms and refuge from predators. Two new species were registered for Argentina: *Mesotritia elegantula* and *Acrogalumna longipluma*.

RESUMEN

El suelo es un hábitat tridimensional altamente complejo. Los cambios en su estructura y porosidad pueden afectar el tipo y la abundancia de la biota del suelo. Los ácaros oribatidos juegan un papel fundamental en la descomposición y mineralización de la materia orgánica del suelo, y su abundancia depende de la textura, la materia orgánica, el pH, la humedad, el sistema poroso, entre otros. El objetivo del presente trabajo es analizar algunas de las variables edáficas que condicionan el hábitat de los ácaros oribatidos en Phaeozems Lúvicos bajo plantaciones de Pinus radiata (P) y Eucalyptus globulus (E), en el sudeste de la provincia de Buenos Aires, Argentina. Se analizaron la densidad aparente, la resistencia a la penetración, el pH, la humedad, los parámetros del sistema poroso y la abundancia de

oribátidos. Ambos sitios presentaron suelos bien estructurados con propiedades edáficas similares. La porosidad total fue mayor en el sitio E con respecto al sitio P. En ambos sitios la tortuosidad de los poros fue alta, lo que genera un hábitat de arquitectura compleja para el desarrollo de los ácaros oribátidos. Tanto en el sitio E como en el P predominaron oribátidos de 70–400 μm de tamaño y, en general, fueron más abundantes en el sitio E. Se observó una correlación positiva entre la abundancia de oribátidos y el tamaño de poros en ambos sitios. En el sitio E, esta correlación fue menor (70–600 μm) o negativa (70–400 μm). Por lo tanto, la abundancia de oribátidos podría explicarse por una mayor complejidad de la estructura del horizonte orgánico, menor densidad aparente y menor resistencia a la penetración. Estas condiciones favorecen la mineralización de la materia orgánica y, por lo tanto, la disponibilidad de alimento. Mientras, en el sitio P, la abundancia de oribátidos está influenciada principalmente por el sistema poroso, que condiciona el acceso al alimento, la competencia entre organismos y el refugio ante predadores. Se registraron dos nuevas especies en Argentina, Mesotritia elegantula y Acrogalumna longipluma.

RESUMIO

O solo é um habitat tridimensional altamente complexo. As mudanças na estrutura e na porosidade podem afetar o tipo e quantidade da biota do solo. Os ácaros oribatídeos têm um papel fundamental na decomposição e mineralização da matéria orgânica do solo, e a sua abundância depende da textura, teor de matéria orgânica, pH, humidade, sistema poroso, entre outros parâmetros do solo. O objetivo do presente trabalho é analisar algumas das variáveis edáficas que condicionam o habitat dos ácaros oribatídeos em Phaeozems Luviscos com plantações de Pinus radiata (P) e Eucalyptus globulus (E) no sudeste da província de Buenos Aires, Argentina. Foram analisados no solo a densidade aparente, resistência à penetração, pH, humidade, parâmetros do sistema poroso e a abundância e espécies dos ácaros oribatídeos. Ambos os sítios apresentaram solos bem estruturados e com propriedades edáficas semelhantes. A porosidade total foi maior no sítio E quando comparado com o sítio P. Em ambos os sítios a tortuosidade dos poros foi alta, o que propicia um habitat de arquitetura complexa para o desenvolvimento dos ácaros oribatídeos. Tanto em E como em P predominaram ácaros oribatídeos com 70–400 μm de tamanho e, em geral, foram mais abundantes em E. Foi observada uma correlação positiva entre a abundância de oribatídeos e o tamanho dos poros em ambos os sítios. Em E, esta correlação foi menor (70–600 μm) ou negativa (70–400 μm). Portanto, a abundância de oribatídeos poderia ser explicada pela maior complexidade da estrutura do horizonte orgânico, menor densidade do solo e menor resistência à penetração. Estas condições favorecem a mineralização da matéria orgânica e, conseqüentemente, a disponibilidade de alimento. Por outro lado, em P a abundância de oribatídeos é principalmente influenciada pelo sistema poroso que condiciona o acesso a alimento, a competição entre organismos e refúgio de predadores. Registaram-se duas novas espécies na Argentina, Mesotritia elegantula y Acrogalumna longipluma.

KEY WORDS

Pores, oribatid abundance, body size.

PALABRAS

CLAVE

Poros, abundancia de oribátidos, tamaño corporal.

PALAVRAS-

CHAVE

Poros, abundância de oribatídeos, tamanho corporal.

1. Introduction

Soil structure is defined as the arrangement of particles and pores of the soil (Oades 1993). The shape, size and spatial distribution of pores control the behavior of water and air, and provide information on transfer processes and life in the soil (Porta et al. 1999).

Soil management has negative effects on total porosity, quantity, distribution, and continuity of pores. This, in turn, causes changes in the flow of air, gases and water inside the pores, affecting the development of soil organisms (Kay and VandenBygaart 2002; Iglesias et al. 2007; Alvarez et al. 2008).

Soil is a complex system and provides space for the development of organisms of different sizes (Estrade et al. 2010). The concept of 'habitable pore space' suggests that there is a

relation between the size of organisms and the zones of soils they are physically able to inhabit (Young and Ritz 2000). Furthermore, there is a strong relationship between habitat complexity and the diversity and abundance of organisms (Downes et al. 1998; Bardgett 2002; Mac Nally and Horrocks 2007). As the complexity increases, available habitat space for organisms increases (Morse et al. 1985).

The relation between fauna and soil structure has been extensively studied in natural, cultivated and forested soils. Morphological burrow characteristics have been analyzed in relation to porosity, hydraulic conductivity and aggregate stability, amongst others (Jégou et al. 2001; Kladvko 2001; Langmaack et al. 2002). However, studies relating soil organisms with porosity as available habitat space are rare (Durcarme et al. 2004), although there is a clear, positive relation between the number and size of pores and the type of animals inhabiting them (Kamplicher and Hauser 1993; Hassink et al. 1993; Kamplicher 1999; Duhour et al. 2009; Alvarez et al. 2008, 2013).

Mites are the most diverse and abundant organisms in the soil because of their size range (0.1-2 mm) they belong to the mesofauna group. The oribatid mites play an important role in the decomposition and mineralization of soil organic matter, and its transport through the profile (Lal 1991). Due to this ecological function and to the fact that they are sensitive to environmental changes, these organisms are used as soil quality indicators (Behan-Pelletier 1999; Bedano et al. 2008). The oribatids live within the pore spaces and their abundance depends on soil type, texture, amount and distribution of organic matter, pH and trophic relations, among other properties (Anderson 1988). Some studies (Anderson 1975; Noti et al. 1996; Hansen and Coleman 1998; Hansen 2000) have specifically investigated the relationships between the diversity of oribatid mites and microhabitats (presence of leaf fragments, roots, faeces, micro-organism clumps, etc.) (Martínez et al. 1999; Fredes 2013).

The soil uses in the southeast of Buenos Aires Province are mainly devoted to agriculture and pastures, besides some recreational-touristic areas. Some sectors in the basin de Los

Padres Lagoon are ecologically suitable for the cultivation of *Eucalyptus globulus* and *Pinus radiata* and these plantations were installed more than 60 years ago with recreational purpose. The introduction of exotic forest species in these soils produces modifications in the structure of the soils, particularly in the moisture and organic carbon content, in the bulk density, penetration resistance and pH (Delgado et al. 2006; Gaitán et al. 2007; Jobbágy et al. 2006; O'Brien et al. 2003; Paruelo et al. 2006; Poore and Fries 1987).

There are precedents in the study of oribatid communities in cultivated soils (Osterrieth et al. 1998; Martínez et al. 1999; Scampini et al. 2000; Bernava et al. 2013) and forested soils (Levy et al. 2017); however, there are no studies linking the porosity and the habitat of the organisms in this area of Buenos Aires Province.

The aim of the present work is to analyze some of the edaphic variables that condition the habitat of oribatid mites in Luvic Phaeozems under tree cover of pines and eucalyptus, in the southeast of Buenos Aires. We propose the following hypothesis: "the abundance of oribatid mites in these soils is mainly influenced by the porosity characteristics".

2. Materials and Methods

2.1. Area description and soil characteristics

The study area is located in General Pueyrredón District, around de Los Padres Lagoon, Buenos Aires Province (37°56' S and 57°44' W) (Figure 1). The climate is oceanic temperate, with an annual precipitation of 800 mm and annual average temperatures of 14 °C (National Weather Service, according to the 1981-2010 records). According to Martínez (2001), the de Los Padres Lagoon belongs to the geomorphological unit "Perinange aeolian hills", which comprises a relief of morphologically complex hills, with heights of up to 30 m and slopes between 6 and 8% (Osterrieth et al. 1998). The predominant soils in the area are Luvic Phaeozems (IUSS

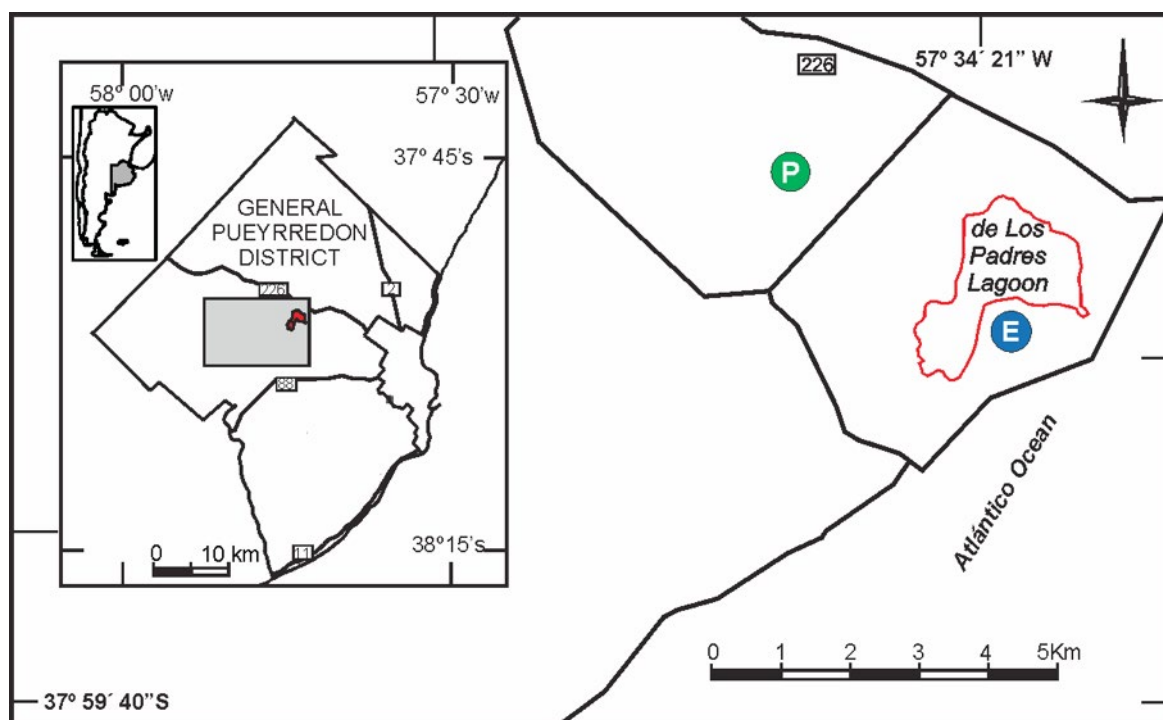


Figure 1. Map of the location of the study area. E: forested with *Eucalyptus globulus*. P: forested with *Pinus radiata*.

Working Group WRB 2015), formed on aeolian loess sediments linked to the latest arid cycle of the late Pleistocene-Holocene (Osterrieth and Cionchi 1985). These soils have an A horizon of 30 cm and a B horizon 50 cm thick approximately, with a silt loam texture. The organic matter content is high, approximately 9% in the A horizon decreasing with depth (INTA-EEA Rafaela 1989). The pH is slightly acid (6-6.3) in the A horizon, and close to neutrality (6.8-7) in the parent material. The soil temperature regime is mesic, and the soil moisture regime is udic (IUSS Working Group WRB 2015). In forested soils these characteristics are modified, the organic matter content and the pH are decreased (Delgado et al. 2006).

2.2. Soil measurements

The study was carried out in sites in the same topographic position, with the same soil type (Luvic Phaeozems): E): 60-year-old *Eucalyptus globulus* forest plantation, with recreational-touristic use; P): 40-year-old *Pinus radiata* forest plantation, with ant insecticides use only, periodic turnover and mulch removal until 2002.

Previous to the plantation of pines the site was used for traditional agriculture.

Sampling was carried out in winter 2014. In each site, random readings were carried out at ten points corresponding to penetration resistance; extraction of samples was performed with cylinders to determine bulk density and moisture content. Bulk density (BD) was measured by the cylinder method (100 cm³) (Blake and Hartge 1986) and penetration resistance (PR) was measured in the field with a cone penetrometer (Bradford 1986). The cone used follows the ASAE guidelines, with an angle of 30° and 14 mm basal diameter. The moisture was measured by the gravimetric method (Cassel and Nielsen 1986). To calculate PR, a correction with the moisture content was calculated according to the exponential regression model $IC = a.W^b$, where IC is the cone index, W is the moisture content, a and b are empirical parameters (Busscher et al. 1997). The pH was measured in a soil paste (1:1) using an electrode. These measurements were performed at 5 cm depth.

For the micro-morphological analysis of porosity, three undisturbed samples were taken from the

upper levels of the mollic epipedon and placed in 5 x 7 x 5 cm cardboard boxes. The samples were sprayed with polyester resin diluted in styrene monomer (Murphy 1986) and a fluorescent pigment (Uvitex OB). From each impregnated block one vertical thin section was obtained. These were scanned in transmitted light. For the quantification of porosity, areas of 3.5 cm x 4.5 cm were analyzed, according to previous studies (Poch 2005; Yagüe et al. 2016; Bosch-Serra et al. 2017).

The image was converted into a binary image using ImageJ® (Rasband 2014). The analysis was carried on pores larger than 70 µm to avoid interference with noise and also because this is the body size of the smallest oribatid mite, *Micropoppia minus*, found in these soils. The pore parameters were analyzed using the ImageJ® software. The solidity parameter (area divided by convex area for each pore) and the pore area fraction were obtained from pore images excluding pore edges. High values of solidity correspond to smooth pores, and low values to rough contours. Furthermore, the pore shape was assessed using a shape factor $I = [\text{Area}/\text{Perimeter}^2]$ proposed by Bouma et al. (1977), where a factor $I < 0.015$ corresponds to elongated pores, a factor I between 0.015-0.04 is attributed to irregular pores and a factor $I > 0.04$ to rounded pores. The pore size distribution was calculated using an opening algorithm inserting circles of increasing diameters in the pores, provided by the Quantim4 library (Vogel 2008).

2.3. Analysis of oribatid mites

On each site, ten undisturbed soil cores (5 cm in depth and 10 cm in diameter) were extracted along with the samples for physical determinations in winter 2014. Extraction of soil mites was carried out using modified Berlese-Tullgren funnels (Southwood 1980). Mites were extracted and fixed simultaneously in a 70% ethanol collector tube placed beneath the funnels during a three week period after which, they were saved for posterior determination.

The determination of oribatid mites species was carried out under stereoscopic and optical microscopes after clarifying the specimens

with warm lactic acid, and following the keys of Balogh and Balogh (1988, 1990, 1992).

For the analysis of oribatid mites, abundance (number of individuals) and body size (microns) was measured using a graduated eyepiece in the optical microscope, and corroborated with bibliographic data.

2.4. Statistical analysis

Soils and biological data were analyzed by means of a T-test ($p < 0.05$) for mean comparison (Statistica®). In order to study interdependence relationships between the community of oribatid mites and the variables studied, a Canonical Correspondence Analysis was performed (Past®). This tool allows us to relate the species of a community with the environment where it lives (Ter Braak and Prentice 1988).

3. Results

3.1. Soil properties

The forested *Pinus radiata* site (P) presented significantly higher bulk density values (0.93 g/cm³) ($p < 0.05$) than the *Eucalyptus globulus* (E) site (0.74 g/cm³). Site P also had higher pH values and penetration resistance, although these were not significant (Table 1). The moisture content was significantly lower in site P (Table 1).

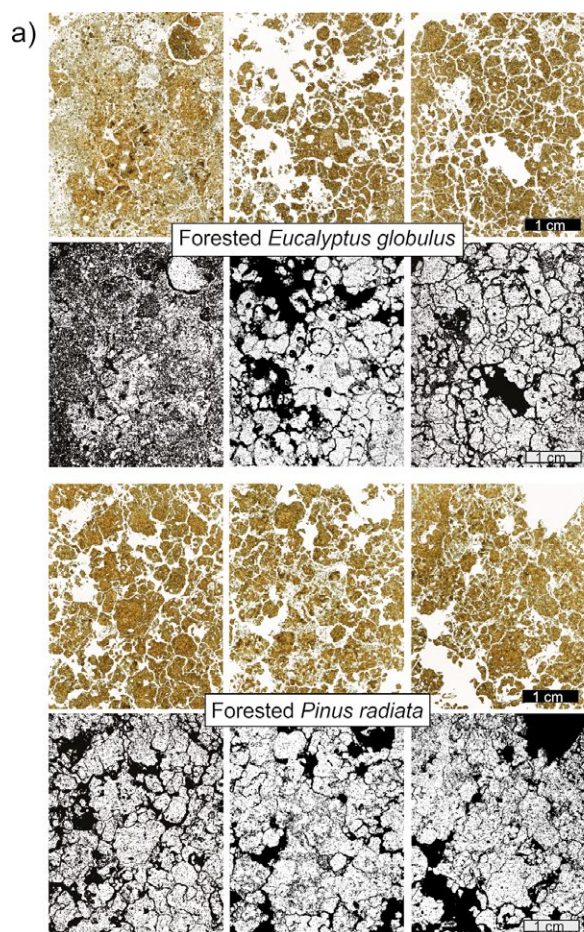
Table 1. Average values of some soil properties in the studied sites. E: forested with *Eucalyptus globulus*. P: forested with *Pinus radiata*. Different letters in the same row indicate significant differences between forested sites ($p < 0.05$)

	E	P
Bulk density (g/cm ³)	0.74 a	0.93 b
Penetration resistance (MPa)	366.67 a	418.12 a
Moisture (%)	33.29 a	23.88 b
pH	4.81 a	4.59 a

The structure and porosity parameters in the thin section images did not show any significant difference between the studied sites. Both soils presented a granular microstructure with rough, interconnected compound packing pores. Frequent plant residues were also observed (Figure 2a).

The total porosity was slightly higher in site E (47.85%) in comparison with site P (41.46%) (Figure 2b). Similarly, the pores of both sites showed high values of solidity, indicating a high pore roughness (Figure 2b).

In both sites, total porosity was composed mainly of elongated pores ($I < 0.015$), followed by irregular (I between 0.015-0.04) and rounded pores ($I > 0.04$), (Figures 2b, 2c). And the pore size distribution showed higher percentage of the pore diameter classes 70-100 μm , 100-200 μm and 200-300 μm (Figure 3). Although differences were not significant, pores of 70-100 μm and $> 1000 \mu\text{m}$ were more abundant in site E (Figure 3).



b)

	E	P
Pore area fraction (%)	47.85	41.46
Solidity	0.81	0.82
Elongated pores (%)	34.51	26.52
Irregular pores (%)	9.80	11.14
Rounded pores (%)	3.54	3.81

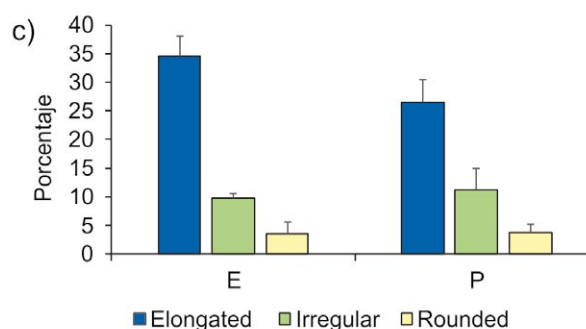


Figure 2. a) Transmitted light and binary images of the studied sites. Image size: 3.50 cm x 4.50 cm. b) Average values of some parameters of the pore system in the studied sites. c) Distribution of the percentage of pores according to morphology. E: forested with *Eucalyptus globulus*. P: forested with *Pinus radiata*.

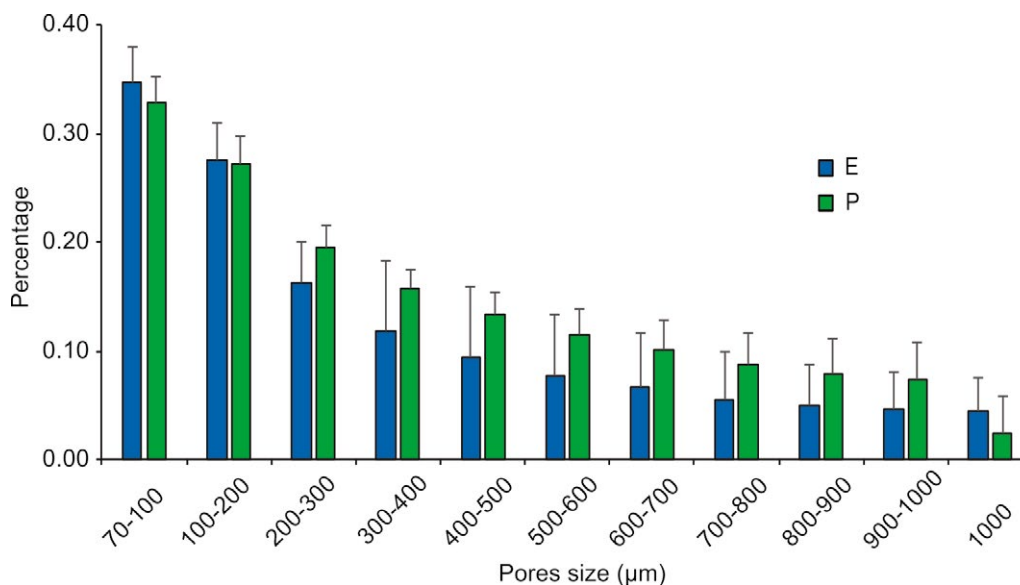


Figure 3. Percentages of pore diameter classes (µm) in the studied sites. E: forested with *Eucalyptus globulus*. P: forested with *Pinus radiata*.

3.2. Analysis of oribatid mites

Oribatid mite abundance was higher in site E with 141 individuals, while in the P site 73 individuals were found (Table 2). A predominance of organisms with size ranges of 70-400 µm and 500-600 µm was observed in both sites. Within these ranges, the most abundant organisms in site E showed sizes of 200-300 µm and 300-400 µm, while in site P the organisms of 70-100 µm predominated (Figure 4). No organisms larger than 600 µm were observed (Figure 4).

Twenty and sixteen species of oribatid mites were observed in E and P respectively. Five species were common to both sites: *Carinogallumna clericata*, *Micropoppia minus*, *Oppiella nova*, *Suctobelbella variabilis*, *Totobates discifer* (Table 2). Species exclusive to site E have a greater size range (200-400 µm) than the exclusive species of site P (< 100 µm).

It should be noted that three of the species found represented new cites for Argentina: *Mesotritia elegantula*, *Acrogalumna longipluma* and *Oxyoppia (Dzarogneta) taurus* (Levy 2017, not published).

3.3. Relation between variables

The relation between the pore size distribution and the abundance of oribatids in both sites was analyzed. For the 70-600 µm pore size, a positive correlation was observed between both variables in site P ($R = 0.77$) but it was very low in site E ($R = 0.13$). Moreover, for the 70-400 µm pore size, a positive correlation was observed in P ($R = 0.83$), but it was negative in E ($R = -0.78$) indicating that the abundance of oribatids in site E could be influenced by other variables besides porosity.

Considering all edaphic variables and the abundance of oribatid species, a Canonical Correspondence Analysis (CCA) was performed. In the first analysis with only physical-chemical variables, the first 2 axes explained almost 86% of the variation. A strong relation was observed between *Schelorbitates elegans*, *Xenolohmannia sp.*, *Micropoppia minus*, *Ramusella (Insculptoppia) merimna* and *Oxyoppia (Oxyoppiella) suramericana* species and pH and moisture. Furthermore, *Cultroribula lata*, *Suctobelbella variabilis*, *Totobates discifer*, *Oppiella (Oppiella) nova*, *Acrogalumna longipluma* and *Paraphauloppia (Monophauloppia) planissima* were associated with bulk density and penetration resistance (Figure 5a).

Table 2. Abundance (number of individuals) and body size (μm) of oribatid mites in the studied sites. E: forested with *Eucalyptus globulus*. P: forested with *Pinus radiata*

Oribatid mites species	Acronym	Abundance	Size (μm)	E	P
<i>Berlesezetes brazilozetoides</i>	Bbr	3	145		
<i>Brachioppiella (Gressittoppia) incisa</i>	Bin	1	130		
<i>Epilohmannia cylindrica</i>	Ecy	1	140		
<i>Epilohmannia pallida</i>	Epa	1	137		
<i>Eremulus crispus</i>	Ecr	1	220		
<i>Lanceoppia (Lancelalmoppia) nodosa</i>	Lno	4	275		
<i>Oxyoppia (Oxyoppiella) suramericana</i>	Osu	7	120		
<i>Oxyoppia (Dzarogneta) taurus</i>	Ota	4	110		
<i>Physobates spinipes</i>	Psp	35	250		
<i>Ramusella (Insculptoppia) merimna</i>	Rme	10	135		
<i>Rostrozetes ovulum</i>	Rov	1	250		
<i>Schelorbates elegans</i>	Sel	41	330		
<i>Trypochthonius tectorum</i>	Tte	1	330		
<i>Xenolohmannia sp.</i>	Xsp	2	500		
<i>Zygoribatula bonairensis</i>	Zbo	1	250		
<i>Microppia minus</i>	Mmi	13	70		
<i>Oppiella (Oppiella) nova</i>	Ono	23	150		
<i>Carinogallumna clericata</i>	Ccl	5	500		
<i>Totobates discifer</i>	Tdi	12	230		
<i>Suctobelbella variabilis</i>	Sva	16	145		
<i>Mesotritia elegantula</i>	Mel	1	550		
<i>Paraphauloppia (Monophauloppia) planissima</i>	Ppl	3	172		
<i>Zeasuctobelba diceros</i>	Zdi	1	185		
<i>Sellnickochthonius aff. S. foliatus</i>	Sfo	1	90		
<i>Quadroppia circumita</i>	Qci	4	113		
<i>Sellnickochthonius elsosneadensis</i>	Ses	5	90		
<i>Suctobelbella loksai</i>	Slk	4	145		
<i>Tectocephus minor</i>	Tmi	4	165		
<i>Machuella ventrisetosa</i>	Mve	3	106		
<i>Cultroribula lata</i>	Cla	3	135		
<i>Acrogalumna longipluma</i>	Alo	3	530		
Total species		214		141	73

In a second CCA taking into account the porosity variables, the first 2 axes explained 56% of the variation. *Carinogallumna clericata*, *Cultroribula lata* and *Oppiella (Oppiella) nova* were associated with rounded pores, while *Acrogalumna longipluma*, *Tectocephus minor*, *Suctobelbella variabilis* were related to solidity. Furthermore, *Schelorbates elegans*, *Xenolohmannia sp.*

are associated with pores A and B (70-100 μm and 100-200 μm) and *Oxyoppia (Oxyoppiella) suramericana* with elongated pores (**Figure 5b**).

In a third CCA considering all variables, the first 2 axes explained 42% of the variation and some associations were corroborated (**Figure 5c**): some species were directly related to the

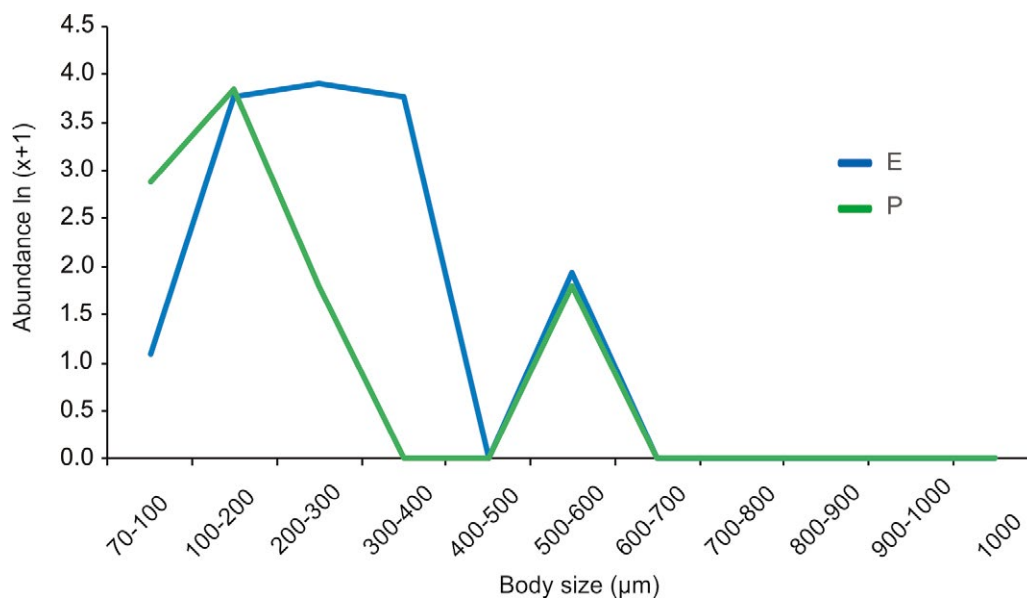


Figure 4. Distribution of the Oribatid mite abundance according to the body size (μm). E: forested with *Eucalyptus globulus*. P: forested with *Pinus radiata*.

porous system while others were influenced by physical-chemical variables.

In site E, *Oxyoppia (Oxyoppiella) suramericana*, *Xenolohmannia sp.*, *Micropoppia minus*, *Schelorbates elegans* and *Ramusella (Insculptoppia) merimna* were related to pH, moisture, elongated pores, pore area and pores A and B (70-100 μm and 100-200 μm).

In site P, *Cultroribula lata*, *Trypochthonius tectorum*, *Machuella ventrisetososa*, *Suctobelbella variabilis*, *Quadroppia circumita* were principally associated with bulk density and solidity, although penetration resistance and rounded pores also influenced these species abundance (Figure 5c).

4. Discussion

The physical soil variables showed a behavior similar to that observed by other authors in these sites (Alvarez et al. 2012; Levy et al. 2015; 2017). Bulk density values are related to the higher content of organic carbon. As mentioned

by some authors (Borrelli 2001; Montti 2002; Alvarez et al. 2011), the organic carbon content under these plantations was high, E = 7-11% and P = 5-9%. This favors aggregation of particles, increasing the porosity (Lamas and Moreno 2000) and the oribatid mites abundance, which is higher in site E.

Although pH was slightly more acidic in P, differences were not significant between sites. However, in E some species were associated with pH (Figure 5). The slightly acidic pH generated by the composition of the leaves from the mulch in both sites regulates the activity of microorganisms that act in the decomposition of organic matter (Oades 1993).

Moisture is also an important factor for the presence of organisms in the soil. The organic horizon present in E and P reduces evaporation and increases the organic matter in the soil, which in turn allows it to retain more water. This condition is more noticeable in E since a higher moisture content and a more developed organic horizon were observed when compared to P. At the same time, plant residues on the soil surface provide abundant food and regulate soil temperature. Also the structure and composition of the litter layer in E could explain the higher abundance of oribatids. Eucalyptus leaves

generate a more complex three-dimensional structure that offers a more heterogeneous habitat and, as a result, a greater density of oribatids; this could be reflected below ground (Hansen 2000).

The higher total porosity of site E could be indeed related to higher values of bulk density and organic carbon (Kay and VandenBygaart 2002). In both sites, elongated pores (channels, fissures) predominate, followed by irregular (compound packing pores) and rounded pores (channels, chambers): part of this total porosity is probably caused by the effects of roots and macrofauna. The solidity parameter gives information about the irregularity, tortuosity and roughness of pores. This roughness would reflect a complex habitat architecture that offers a higher number of habitable pore spaces for soil organisms (Alvarez et al. 2018). Similar solidity values were observed for both sites, so other properties could influence in oribatid mites abundance.

Some studies indicate that the abundance and density of microarthropods are related to soil porosity (Vreeken-Buijs et al. 1998; Ducarme et al. 2004; Nielsen et al. 2008; Alvarez et al. 2018), bulk density, moisture and pH (Bedano et al. 2006; Socarrás 2013). In cultivated Luvic Phaeozems some authors (Osterrieth, et al. 1998; Martínez et al. 1999; Scampini et al. 2000) indicated changes in organic matter content, structural stability, pH and fauna abundance in the soil. Repeated anthropogenic disturbances produce modifications in the micro- and meso-habitats of organisms. This reduces the period of stability for reproduction and growth of the edaphic fauna, directly affecting its abundance. Therefore, it is possible that the oribatid abundance in these forested sites is related with the studied soil properties, bulk density and porosity in particular. Furthermore, site E is located in a recreational area, so it is subject to periodic anthropic impact such as surface compaction. Oribatids can respond in various ways to disturbances, in some cases they can disappear if the disturbance is strong and constant. They can also develop strategies to deal with unfavorable environmental conditions. Some species, such as *Opiella nova*, abundant in site E, are parthenogenetic, and they develop reproductive strategies against changes in the environment (Norton and Palmer 1991).

In both sites mites of 70-400 μm predominated, with a positive correlation between the abundance and the pore size in site P and negative in site E. In site P, some characteristics of the porous system conditioned the abundance of some oribatids, as it was also found by Vreeken-Buijs et al. (1998) who related biomass of mites and pore size. Conversely in site E, the pH and moisture variables were more important. In this sense, Vreeken-Buijs et al. (1998), found a positive relationship between biomass of mites and pore size: oribatid mites were correlated to pores of 1.2-90 μm . In temperate forests, Ducarme et al. (2004) observed that the pores > 200 μm are a measure of the space available for soil microarthropods and this was correlated to their density and richness. Also, Nielsen et al. (2008) found a positive effect of increasing pore volume (60-300 μm) on mite abundance within two different habitats. Alvarez et al. (2018) conducted studies comparing cultivated and natural soils and observed the same relationship between mite abundance and pore size.

In these sites the relationship between abundance and pore size could be explained by the habitat selection of the organisms according to the availability of food. The oribatids are mainly saprophagous, but can feed on live plants, fungi and algae, some are nematode predators, and these occupy the small pores. Furthermore, larger species cannot invade small pores where fungi are more abundant (Elliott et al. 1980; Vreeken-Buijs et al. 1998). On the other hand, with the physical limitation of available space, competition decreases between functional groups. Also, the pores of this size would constitute refuges from predation. The organisms residing in pores of appropriate size could be protected from predation by larger organisms since the latter are denied physical access to their prey (Young and Ritz 2000). This in turn, could explain the absence of mites in pores larger than 600 μm .

All these conditions directly influence the humification and mineralization processes of organic matter, promoting differences among the communities of soil organisms. Therefore, because the soil is a complex system, one or more variables could explain the abundance of oribatids in these soils.

It should be noted that the results obtained for these edaphic properties differ from those from other authors who indicate high soil degradation due to the implantation of forest species (Delgado et al. 2006; Gaitán et al. 2007; O'Brien et al. 2003; Paruelo et al. 2006).

In the sites we have studied, despite the impact produced by the plantation of pine and eucalyptus, there is a tendency to recover the soil properties that were lost by its management, since these sites were agricultural prior to being forested.

5. Conclusions

The forested sites in the South of Buenos Aires (Argentina) studied here, have well-structured soils with similar edaphic properties. However, the site of *Eucalyptus globulus* had a greater total porosity than that of *Pinus radiata*. The high tortuosity (solidity) of the pores in both sites reflects a complex architecture habitat for the development of oribatid mites.

Although the number of mites was low, the oribatid abundance in the forested *Eucalyptus globulus* site could be explained by a greater complexity of the organic horizon, higher pH and moisture, and small pores (70-200 µm). These conditions favor the mineralization of organic matter, and therefore the availability of food. Conversely, the oribatid abundance in the forested *Pinus radiata* site is mainly influenced by the higher bulk density and penetration resistance which conditions porosity and access to food, competition between organisms and refuge from predators.

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