Article

Diversity of soil spiders in land use and management systems in Santa Catarina, Brazil

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Abstract: The ability of spiders to spread over contiguous areas (Arachnida: Araneae) is directly related to soil management conditions. The objective of this work was to study the effect of land use system (LUS) on the abundance and diversity of soil spider families and their relationship with soil physical and chemical properties. The evaluated LUS were: native forest, eucalyptus reforestation, pasture, crop-livestock integration, and no-tillage crop. Samples were collected in three municipalities of Southern Plateau of Santa Catarina, considered as true replicates, during winter and summer. A total of 270 samples was taken in each area and season. The sampling points were arranged in a grid of 3×3 m, spaced by 30 m. We evaluated soil physical, chemical, and microbiological attributes and the abundance and diversity of spider families, collected by soil monolith and soil traps. A total of 448 spiders were captured, 152 in winter and 296 in summer, distributed in 24 families and 52 species/morphospecies. There was a seasonality effect related to the land use systems and the highest Shannon-Wiener diversity index was recorded in the native forest in both sampling periods. Most families of spiders have a direct dependence on soil physical and chemical properties, such as microporosity, exchangeable aluminum, calcium, magnesium, and potassium during the winter. Organic matter, nitrogen, pH in water, weighted average diameter, soil density, and microbial biomass carbon exhibited dependence during the summer. Vegetation type and soil management are the factors that seem to affect most the occurrence of spiders. The families Theridiidae and Nemesiidae are dependent on sites with low human intervention.
Keywords: Agriculture, Biodiversity, Soil Biology, Soil Ecology.

Diversidade de aranhas edáficas em sistemas de uso e manejo do solo em Santa Catarina, Brasil

Resumo: A capacidade de dispersão das aranhas em áreas contíguas (Arachnida, Araneae) está ligada diretamente às condições de manejo do solo. Objetivou-se com o presente trabalho estudar o efeito do sistema de uso do solo (SUS) sobre a abundância e diversidade das famílias de aranhas edáficas, bem como a relação dessas com os atributos físicos e químicos do solo. Os SUS avaliados foram: floresta nativa, reflorestamento de eucalipto, pastagem, integração lavoura-pecuária e lavoura com sistema plantio direto. As amostras foram coletadas em três munícipios do Planalto Sul-Catarinense, considerados réplicas verdadeiras, durante o inverno e o verão. Um total de 270 amostras foi coletado em cada área e estação do ano. Os pontos de amostragem foram dispostos em uma grade de amostragem de 3×3 distanciados 30 m entre si. Foram avaliados atributos físicos, químicos e microbiológicos do solo e abundância e diversidade de famílias de aranhas, coletadas pelo método de monólitos e armadilhas de solo. Ao todo foram capturados 448 indivíduos, sendo 152 no inverno e 296 no verão, distribuídos em 24 famílias, 52 espécies/morfoespécies. Houve efeito da sazonalidade entre os sistemas de uso e a maior diversidade de Shannon-Wiener foi registrada em floresta nativa em ambas as épocas de amostragem. A maior parte das famílias de aranhas possui dependência direta dos atributos físicos e químicos do solo, como: microporosidade e alumínio trocável, cálcio, magnésio e potássio durante o inverno. Matéria orgânica, nitrogênio, pH em água, diâmetro médio ponderado, densidade do solo e carbono da biomassa microbiana apresentaram dependência durante o verão. O tipo de vegetação e o manejo são fatores que mais afetam a ocorrência de aranhas. As famílias Theridiidae e Nemesiidae são dependentes de locais com baixa intervenção antrópica.
Palavras-chave: Agricultura, Biodiversidade, Biologia do Solo, Ecologia do Solo.

Introduction

Among the arthropods, spiders are one of the most well-known and diversified groups, occupying different niches and with a cosmopolitan distribution, a characteristic that is basically given by the capacity of exploration and adaptation to various ecological conditions (Mader *et al*. 2016). Spiders are active predators and directly help to control populations, maintaining the balance of the ecosystems. However, the effect of human action on the landscapes has led to increasing losses in biodiversity on many scales, both vegetal and animal (Kovács-Hostyánszki *et al*. 2013, Sas-Kovács *et al*. 2015).

Conventional agriculture is one of the main causes of decline of biodiversity, basically for reducing the vegetal cover and structural complexity of plant communities that are often associated with the low biodiversity of other taxonomic groups (Chen *et al*. 2011, Barsoum *et al*. 2014), because they are predators and dependent on the organizational heterogeneity of the soil fauna. Monoculture and the suppression of forest remnants represent a challenge in terms of management of agroecosystems, especially for reducing the diversity of the soil fauna, particularly of spider communities (Camara *et al*. 2012).

On the other hand, more-diversified managements such as no-tillage and crop-livestock integration can contribute to the sustainable production of food, which generates diverse plant biomass in amount and quality, attracting other organisms that serve as prey for spiders (Liu *et al*. 2015). The fragments of forests are pointed by some authors as buffer zones in areas impacted by the agricultural activity since they work as a temporary refuge for soil organisms (Moraes *et al*. 2015, Jesus *et al*. 2015).

Soil management leads to disturbances, irreversible in many cases, for the soil fauna, and the patches of native forest act as a conditional refuge for the establishment of spider populations (Mineo *et al*. 2010). Many studies have demonstrated that spiders can be an effective indicator of modified environments (Borchard *et al*. 2014, Haase & Balkenhol 2015, Mumme *et al*. 2015, Balkenhol *et al*. 2016). The presence of spiders is frequently associated with the structural quality of the ecosystems, due to their effect of biological control over soil animals. Despite this importance, little is known about the spider fauna in the state of Santa Catarina, especially in agricultural areas.

The present study aimed to evaluate the diversity of spider families in the southern Plateau of the state of Santa Catarina, under different land use and management systems, identifying variations in richness and abundance of these organisms related to an increasing gradient of land use.

Material and Methods

1. Characterization of the study site

The study was carried out in the Southern Plateau of Santa Catarina, encompassing land use systems (LUS) with increasing intensity of human intervention, namely: native forest (NF), eucalyptus reforestation (ER), pasture (PA), crop-livestock integration (CLI), and no-tillage crop (NT). The areas were selected according to the previously geographic characteristics, relief, altitude, and soils representative of the region in three municipalities: Campo Belo do Sul (50°39'W and 27°52'S; 1.016 m a.s.l.) and Lages (50°35'W and 27°47'S; 895 m a.s.l.), in Humic Kandiudox, and in Otacílio Costa (49°50'W and 27°35'S; 919 m a.s.l.), in Humic Dystrudept.

Soil classification follows USDA Soil Taxonomy (Soil Survey Staff 2014). Further information on the history of use of the areas, sampling scheme, coordinates and altitude by LUS can be obtained in Bartz *et al.* (2014) and Rosa *et al*. (2015).

2. Sampling methods

For the collection of the spider, a 1-ha area was delimited in each LUS, constituted of a 3 × 3 m sampling grid, spaced by 30 m with a border of 20 m, in a total of 270 points (winter + summer) for each method, totaling 540 sampling points. The sampling sites in each municipality were considered as true replicates of the LUS. The spiders were collected through the methods of soil monolith (Anderson & Ingram 1993) and soil traps, according to the methodology described by Baretta *et al.* (2007); with sampling during the winter of June and July of 2011 and during the summer, in Dec. 2011 and Jan. 2012, periods in which the conditions of temperature and rainfall are representative of the regional environment. The sampling area for the soil monolith method in each point was 0.25 × 0.25 m, excavating the soil up to 0.20 m depth. The collected soil was placed in plastic bags and taken to the laboratory for hand sorting, under artificial light. Soil traps with a diameter of 0.07 m were installed at the soil level, 0.3 m away from the collection points of the soil monolith method and left at the field for three days and then collected and taken to the laboratory, where they were separated using 0.125-mm-mesh sieves. All organisms found were fixed in 80% alcohol and sent for identification at the Instituto Butantan. All the material is deposited in the Arachnological Collection of the Laboratório Especial de Coleções Zoológicas in the Instituto Butantan (Curator: A.D. Brescovit).

3. Evaluation of the explicative environmental variables

Around the spider collection points, 15 soil subsamples were collected in the of 0.0-0.2 m layer and homogenized to form a composite sample. This sample was used for the evaluation of organic matter (OM), nitrogen (N), pH in water (pH), exchangeable aluminum (Al^{3+}), calcium (Ca^{3+}), magnesium (Mg^{2+}), and potassium (K^+), and sulfur (S), according to the methodologies of Tedesco *et al*. (1995).

Soil granulometry was determined through the pipette method in the same sample of the chemical analysis (Gee & Bauder 1986). Undistorted soil samples were also collected beside the points where the spiders were collected. A portion of clods was used to determine weighted average diameter (WAD), according to the wet sieving method of Kemper & Chepil (1965). Volumetric rings collected in these points were used to determine bulk density (Bd) and microporosity (Micro), as described in Embrapa (2011).

For microbiological analysis, samples were collected from a depth of 0.10 m, sieved (<0.002 m), and kept refrigerated (4 °C) for analyses. Determination of microbial biomass carbon (MBC) was performed with the fumigation-extraction method (Vance *et al*., 1987).

4. Metrics of diversity

The Shannon-Wiener index (H') was calculated according to Odum (1988), in order to verify how the environmental pressures (intensification of land use) might interfere with the distribution of spider families. Estimations of Shannon-Wiener index were performed using Vegan Community Ecology Package in R Core Team software, v. 2.12.2. The mean values of H' were compared point by point (n = 27) by Tukey test at 0.05 probability level, using Agricolae Package in R Core Team software, v. 2.12.2.

5. Statistical analyses

Since the objective of the present study was not to compare the collecting methods, the data of the total abundance of both methods was summed to minimize the limitations of the methods. The obtained values were used to determine the length of the gradient (DCA). The total abundance of the spider families and studied types of LUS were compared through the principal component analysis (PCA). Physical, chemical, and microbiological attributes were considered as explicative environmental variables, in which the collinear parameters were removed from the statistical model and later used to establish the correlation between them and the spider families in the redundancy analysis (RDA). Multivariate analyses were performed using CANOCO software, v. 4.5.

Results

In total, considering the collection methods and LUS, 448 spiders were captured, 152 in the winter and 296 in the summer, distributed into 24 families and 52 genus/species (Table 1). There were differences ($p < 0.05$) between the evaluated LUS. The highest diversity (H') was recorded in the NF, followed by PA > ER = CLI > NT during the winter. In the summer, the diversities followed the anthropization gradient NF > ER > PA > CLI > NT (Table 1).

The richness of the families obeyed the following order: NF, ER, and PA with 11 families, CLI with 8 families and NT with 6 families in the summer. During the winter, according to the use of intensity, the richness of the families increased for NF (12) and decreased in all remaining LUS, ER (9), PA (06), CLI (05), and NT (04), respectively, evidencing that, in general, the modification in the vegetal complexity reduces the biodiversity of soil spiders.

The principal component analysis explained 43% of the total variation, 37% by the principal component 1 (PC1) and 7% by the PC2 during the winter and 56% during the summer, in which the PC1 explained 37% and PC2 explained 19% (Figure 1). Among the land use systems, Nesticidae, Mecicobothriidae, Pholcidae, Amaurobiidae, Xenoctenidae, Lycosidae, and Nemesiidae were more associated with the NF. Theridiidae, Zodariidae, Hahniidae, Gnaphosidae, and Araneidae were associated with ER, while systems with a higher level of human intervention (PA, CLI, and NT) grouped the families Ctenidae, Palpimanidae, Tetragnathidae, Corinnidae, and Linyphiidae during the winter (Figure 1A).

During the summer, Oxyopidae, Linyphiidae, Mysmenidae, Lycosidae, Ctenidae, Prodidomidae, Theridiidae, Pholcidae, Salticidae, and Nesticidae were more associated with the NF. Filistatidae, Titanoecidae, and Amphinectidae were related to the PA system. Palpimanidae, Hahniidae, and Gnaphosidae were more associated with the systems NT, ER, and CLI (Figure 1B).

Among the soil physical and chemical attributes that showed correlation with the spider families during the winter, the following ones stood out: Micro, Al^{3+}, Ca^{3+}, Mg^{2+}, and K^+. Among them, the contents of Ca^{2+}, Mg^{2+}, and K^+ were correlated with the families Palpimanidae, Tetragnathidae, Araneidae, Hahniidae, Lycosidae, Gnaphosidae, and Salticidae, while the families Nesticidae, Amaurobiidae, Mecicobothriidae, Zodariidae, Ctenidae, Xenoctenidae, Pholcidae, Corinnidae, Nemesiidae, Theridiidae, and Linyphiidae showed correlation with Al^{3+} and microporosity (Figure 2A).

For the samplings made in the summer, the physical, chemical, and microbiological attributes that showed correlation with the spider families were: OM, N, pH, WAD, Bd, and MBC. From these variables, pH and Bd were correlated with the families Corinnidae and Palpimanidae, while WAD was strongly correlated with the abundance of Salticidae, Prodidomidae, Gnaphosidae, and Hahniidae. On the other hand, the N and OM favored the presence of the Mysmenidae, Linyphiidae, Theridiidae, Nesticidae, Amaurobiidae, Lycosidae, and Ctenidae, while MBC showed a direct correlation with Amphinectidae, Titanoecidae, Oxyopidae, and Filistatidae (Figure 2B).

Discussion

The richness of the spider families responded to the seasonality, especially because of the modifications in the vegetation structure of the evaluated land use and management systems. Similar results were obtained by Marín et al. (2015), who found differences between the sampling periods in the structure of spider communities in coffee plantations in Mexico. In the present study, the most abundant families were Linyphiidae (40%), Lycosidae (28%), and Theridiidae (8%), regardless of the LUS, corroborating the findings of Marín et al. (2015) and Lopes et al. (2009), who also found higher proportions of Linyphiidae and Lycosidae in areas with different types of vegetal cover.

The type of vegetation acts as a filter for spider families and this was also reported by Buchholz (2016), who studied spider families in peat areas with different flower compositions. He found that the occurrence of larger spiders is correlated with denser vegetation and of smaller spiders with areas where the predominant vegetation was formed by mosses. According to this author, Linyphiidae and Theridiidae occurred more frequently in the upper layers of the vegetation, corroborating the results of the present study, in which the native forest concentrated most individuals of from these families.

The changes in the distribution pattern between the sampling periods are probably due to the characteristic of each one of the land use types and to the complexity of the vegetal structure in each one of the ecosystems, which regulates the microclimate and soil moisture. Attention should be paid to this latter, because the positive correlation between the volume of micropores and certain families of spiders (Pholcidae, Theridiidae, Xenoctenidae, Zodariidae, and Nemesiidae) during the winter (Figure 2A) indicates the dependence of these families on soil moisture. It should be pointed out that this physical attribute (micropores) is responsible for water retention in the soil.

However, during the winter, the areas of native forest (NF) showed differences in terms of the composition of the spider families, compared with the anthropized systems (ER, PA, CLI, and NT). During the summer, this behavior was similar, but most families showed a positive correlation with NF, which sheltered a large portion of the individuals. In ER, NT, and CLI, only Gnaphosidae and Palpimanidae were more abundant, which suggests that these two families easily adapt to areas with high levels of human intervention. However, the lack of previous studies in this region of the state does not allow any type of comparison and discussion on this subject.

Table 1. Total abundance of spiders observed using two collection methods (soil monolith and soil traps) in systems of native forest (NF), eucalyptus reforestation (ER), pasture (PA), crop-livestock integration (CLI), and no-tillage (NT) in the winter and summer in the Southern Plateau of the state of Santa Catarina.

Family/Genus/Species	Winter					Summer				
	NF	ER	PA	CLI	NT	NF	ER	PA	CLI	NT
Amaurobiidae*	5	2	0	0	0	1	0	0	0	0
Amphinectidae**	0	0	0	0	0	0	0	1	0	0
Metaltella sp. 1	0	0	0	0	0	0	0	1	0	0
Araneidae*	0	1	0	0	0	0	0	0	0	0
Corinnidae**	1	2	1	0	0	0	4	2	1	0
NI***	1	2	0	0	0	0	3	2	1	0
Castianeira sp. 1	0	0	0	0	0	0	1	0	0	0
Corinna sp. 1	0	0	1	0	0	0	0	0	0	0
Ctenidae**	0	0	0	1	0	2	4	0	1	0
NI	0	0	0	0	0	1	4	0	1	0
Isoctenus ordinario Polotow & Brescovit, 2009	0	0	0	0	0	1	0	0	0	0
Isoctenus sp. 1	0	0	0	1	0	0	0	0	0	0
Filistatidae**	0	0	0	0	0	0	0	1	0	0
Misionella mendensis (Mello-Leitão 1920)	0	0	0	0	0	0	0	1	0	0
Gnaphosidae**	0	1	2	1	0	1	4	1	1	1
NI	0	1	2	1	0	0	3	0	0	0
Apopyllus sp. 1	0	0	0	0	0	1	0	1	0	0
Zimiromus sp. 1	0	0	0	0	0	0	1	0	1	1
Hahniidae**	0	2	1	0	1	4	4	3	4	9
NI	0	0	1	0	0	4	1	0	0	1
Neohahnia sp. 1	0	2	0	0	1	0	3	2	3	1
Neohahnia sp. 2	0	0	0	0	0	0	0	1	1	7
Linyphiidae**	11	7	11	25	4	51	18	12	19	18
NI	6	4	1	6	1	28	7	4	6	6
Agyneta sp. 1	1	0	1	2	2	3	7	3	2	2
Agyneta sp. 2	0	0	0	0	0	1	0	0	3	0
Erigone sp. 1	3	0	2	4	0	0	0	3	4	3
Erigone sp. 2	0	0	1	2	0	0	2	0	3	3
Exocora ribeiroi Lemos & Brescovit, 2013	0	0	0	0	0	0	1	0	0	0
Laminacauda sp. 1	0	0	0	1	0	0	0	0	0	0
Meioneta sp. 1	0	1	1	0	0	4	0	0	0	0
Mermessus sp. 1	1	0	4	2	0	6	0	0	1	0
Moyosi sp. 1	0	0	0	0	0	2	0	1	0	0
Neomaso sp. 1	0	1	0	0	0	0	0	1	0	0
Neomaso sp. 2	0	1	0	0	0	0	0	0	0	0
Ostearius sp. 1	0	0	1	8	1	0	1	0	0	4
Sphecozone novaeteutoniae (Baert, 1987)	0	0	0	0	0	7	0	0	0	0
Lycosidae**	12	3	4	10	7	27	9	16	23	12
NI	9	1	2	10	5	16	7	13	11	10
Allocosa sp. 1	0	0	0	0	0	0	0	1	9	0
Lobizon humilis (Mello-Leitão, 1944)	3	1	0	0	2	11	1	1	0	0

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Lycosa erythrognatha Lucas, 1836	0	0	0	0	0	0	0	0	1	0
Schizocosa sp. 1	0	0	0	0	0	0	0	1	0	0
Trochosa sp. 1	0	1	1	0	0	0	1	0	2	2
Trochosa sp. 2	0	0	1	0	0	0	0	0	0	0
Mecicobothriidae**	1	0	0	0	0	0	0	0	0	0
Mecicobothrium baccai Lucas, Indicatti, Brescovit & Francisco, 2006	1	0	0	0	0	0	0	0	0	0
Mysmenidae**	0	0	0	0	0	5	0	0	0	0
NI	0	0	0	0	0	1	0	0	0	0
Microdipoena sp. 1	0	0	0	0	0	4	0	0	0	0
Nemesiidae*	2	0	0	0	0	0	0	0	0	0
Nesticidae**	4	0	0	0	0	2	0	0	0	0
Nesticella sp. 1	4	0	0	0	0	2	0	0	0	0
Oxyopidae*	0	0	0	0	0	0	0	1	0	0
Palpimanidae*	0	1	0	0	0	0	1	0	0	0
Pholcidae**	3	0	0	0	0	1	1	1	0	0
NI	2	0	0	0	0	1	1	1	0	0
Mesabolivar aff. *difficilis*	1	0	0	0	0	0	0	0	0	0
Prodidomidae*	0	0	0	0	0	0	2	0	0	0
Salticidae**	1	0	0	0	0	1	1	0	1	1
Corythalia sp. 1	1	0	0	0	0	1	1	0	0	1
Corythalia sp. 2	0	0	0	0	0	0	0	0	1	0
Tetragnathidae**	0	0	0	1	2	0	0	0	0	0
Glenognatha australis (Keyserling, 1883)	0	0	0	1	2	0	0	0	0	0
Theridiidae**	6	4	4	0	0	12	4	4	2	2
NI	1	3	0	0	0	1	0	0	0	2
Dipoena pumicata (Keyserling, 1886)	0	0	2	0	0	0	0	1	0	0
Euryopis sp. 1	0	0	1	0	0	4	0	3	1	0
Guaraniella sp. 1	3	1	1	0	0	3	3	0	1	0
Stemmops sp. 1	0	0	0	0	0	1	0	0	0	0
Styposis selis Levi, 1964	1	0	0	0	0	2	0	0	0	0
Styposis sp. 1	1	0	0	0	0	1	0	0	0	0
Thymoites sp. 1	0	0	0	0	0	0	1	0	0	0
Titanoecidae**	0	0	0	0	0	0	0	1	0	0
Goeldia sp. 1	0	0	0	0	0	0	0	1	0	0
Xenoctenidae**	6	0	0	0	0	0	0	0	0	0
Odo aff. *blumenauensis*	1	0	0	0	0	0	0	0	0	0
Odo sp. 1	5	0	0	0	0	0	0	0	0	0
Zodariidae*	1	0	0	0	0	0	0	0	0	0
Total	53	23	23	38	14	107	52	43	52	43
Diversity index (H')	0.44a	0.17b	0.18b	0.17b	0.03b	0.63a	0.41ab	0.31ab	0.30ab	0.22ab

* Unidentified specimens on any level below family. ** The number of individuals in families corresponds to the sum of the number of individuals of genus and/or species.
*** NI: Unidentified specimens on any level below family.
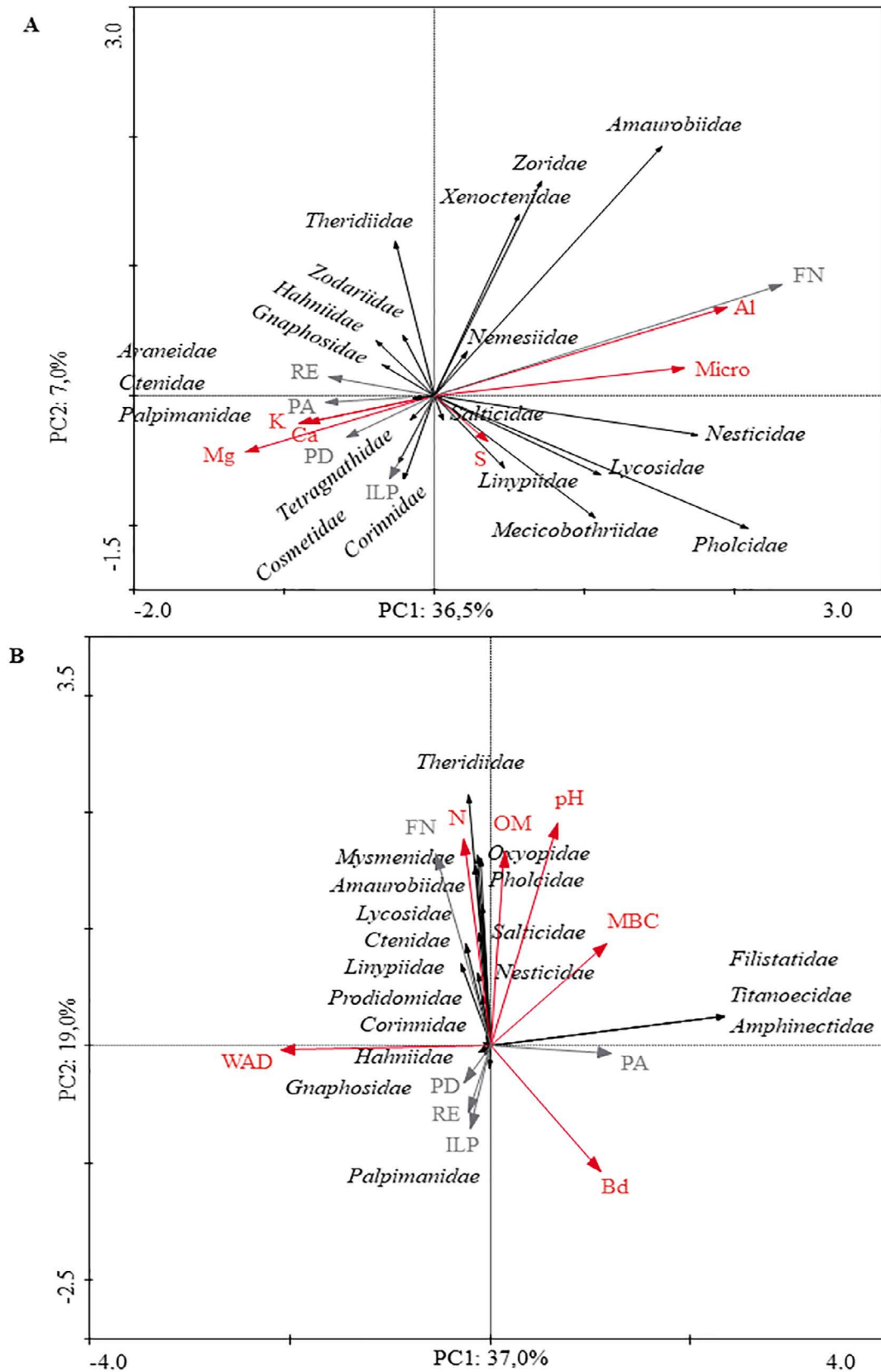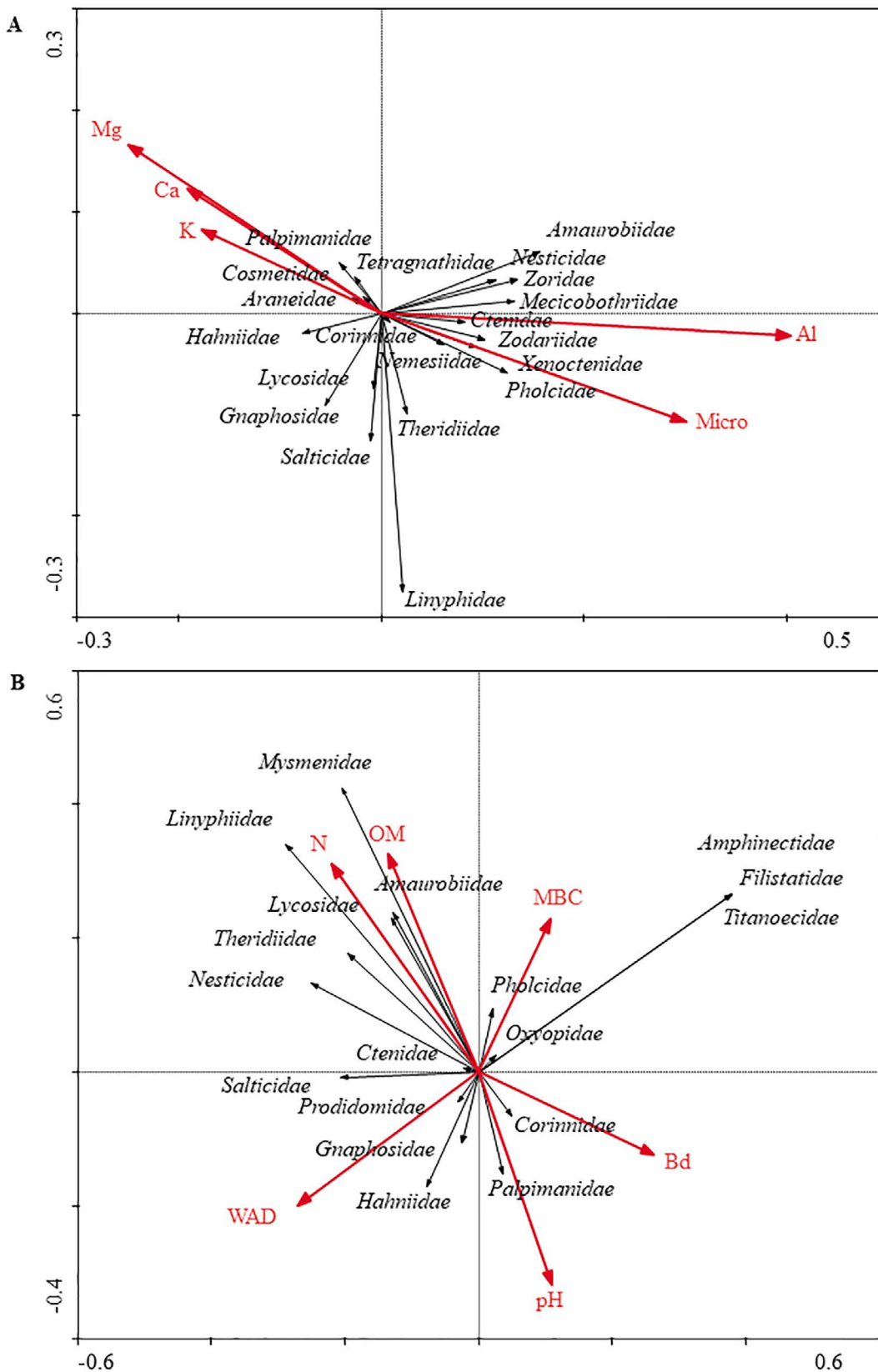
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Figure 1. Principal component analysis (PCA) (a = winter, b = summer), for soil spider families in the Southern Plateau of the state of Santa Catarina (n = 27) in each land use system: native forest (NF), eucalyptus reforestation (ER), pasture (PA), crop-livestock integration (CLI), and no-tillage (NT). Environmental properties: Organic matter (OM), Nitrogen (N), Microbial biomass carbon (MBC), Bulk density (Bd), pH in water (pH), Weighted average diameter (WAD), Magnesium (Mg), Calcium (Ca), Potassium (K), Aluminum (Al), Microporosity (Micro), and Sulfur (S).

Soil spiders in land use systems

Figure 2. Redundancy analysis (RDA) (a = winter, b = summer), for soil spider families in the Southern Plateau of the state of Santa Catarina (n = 27) in each land use system: native forest (NF), eucalyptus reforestation (ER), pasture (PA), crop-livestock integration (CLI), and no-tillage (NT). Environmental properties: Organic matter (OM), Nitrogen (N), Microbial biomass carbon (MBC), Bulk density (Bd), pH in water (pH), Weighted average diameter (WAD), Magnesium (Mg), Calcium (Ca), Potassium (K), Aluminum (Al), Microporosity (Micro), and Sulfur (S).

In a study conducted by Richman *et al*. (2011) in the Chihuahan desert, in Mexico, Gnaphosidae and Salticidae were more abundant in at least one period of the year. Although the desert is an inhospitable environment for many species, for these two families the reduction of resources does not seem to substantially affect their distribution, because they can forage in many environments and cover long distances searching for food and shelter.

The low relationship between the spider families and the agricultural areas may be explained by the use of agrochemicals in these sites, which can kill the spiders or reduce populations of other arthropods, and this compromise foraging in the entire food chain, affecting spiders, which are mostly secondary predators. Marliac *et al*. (2016) demonstrated that the continuous application of insecticides in apple orchards in southeast France negatively influenced the spider fauna, compared with the organic production of apple. Similar results were obtained by Mansour and Nentwig (1988) and Lefebvre *et al*. (2016), who also found a direct relationship between environments contaminated with chemical compounds and reduction in the biodiversity of spiders. The lack of information on the diversity of spiders in land use systems in the southern states of Brazil, especially Santa Catarina, compromises comparisons and more detailed discussions.

Besides the intrinsic conditions of the anthropized environment, i.e., entry of chemical compounds and reduction in the fluctuation of the population of other organisms, the composition of plants, their architecture and the microclimate formed in the different forms of land use system can affect the distribution of spiders (Peres *et al*. 2010, Bizuet-Flores *et al*. 2015, Rivera-Quiroz *et al*. 2016). These aspects tend to be more simplified in the cultivation areas, in relation to the native vegetation.

Spider families that are largely associated to the soil or vegetation, such as Theridiidae and Nemesiidae, are strongly affected by the movement of animals and/or machines, which can be an explanation for the reduction of these families in agricultural areas or areas used also by farm animals. Comparing the observed correlation of spider diversity with attributes such as Bd and WAD (Figure 2B) with the literature, we found that Downie *et al*. (2000) demonstrate that cattle grazing intensity drastically reduces the populations of spiders. The entry of sheep and cattle in pasture areas causes soil compaction and negatively interferes with the diversity and abundance of spiders (Dennis *et al.* 2015). Baretta *et al*. (2007) also report that the entry of production animals in pasture areas can be an aggravating factor for the reduction in spider fauna biodiversity as well as the effect of burning the vegetation.

The families Palpimanidae, Tetragnathidae, Araneidae, Hahniidae, Lycosidae, Gnaphosidae, and Salticidae showed direct correlation with the contents of Ca^{2+}, Mg^{2+}, and K^+. Those chemical attributes are commonly altered by management conditions, such as liming to correct acidity in agricultural areas, thus suggesting that these families easily adapt to land use and management conditions.

The correlation of Al^{3+} contents with Nesticidae, Amaurobiidae, Xenoctenidae, Dipluridae, Zodariidae, Ctenidae, Pholcidae, Corinnidae, Nemesiidae, Theridiidae, and Linyphiidae indicates adaptation to natural areas and acidic soils that have not been limed, differing from many soil organisms, which respond to the use of limestone (Baretta *et al*. 2011).

During the summer, besides physical and chemical attributes, a positive correlation was also found to at least one microbiological attribute, indicating interdependence between the carbon from the microbial biomass and the spider families. Thus, it should be pointed out that the higher the biological diversity of the soil, the greater the occurrence of secondary predators, with stabilization of the food chain and of the processes of maintenance of terrestrial ecosystems.

The content of organic matter is directly related to the litter decomposition rate, and these conditions are associated with some families of spiders, attracting primary decomposers and detrital fauna, and consequently favoring the appearance of predators, such as spiders. This mechanism was also described by Liu *et al*. (2015), who found positive relationships between litter decomposition rates and the abundance of spiders in native forest areas, reinforcing the results obtained in the present study.

Soil physical attributes such as Bd and WAD have a positive correlation with some families of spiders, which may be related to the effect of management on soil structure. The relationship between physical and chemical attributes and the diversity of spider families is proportional to the intensification of land use, so that the more managed and altered the environment, the greater the effects on the decrease in the diversity of spiders and, eventually, on possible losses in physical and chemical processes of the soil. Araújo *et al*. (2015), studying the relationship between soil degradation and key groups of soil organisms, observed that Araneae are strongly affected by the intensity of degradation of landscapes. Thus, a more adequate soil management in agricultural production areas can favor essential processes such as the biological control of pests and maintenance of energy flows in the soil (Haase & Balkenhol 2015, Brunbjerg *et al.* 2015).

Conclusions

Spider families are affected by the type of land use and management and by the seasonality in systems in the region of the Southern Plateau of Santa Catarina. The families Theridiidae and Nemesiidae are dependent on sites with low human intervention, being more abundant in the NF. The type of vegetation and management are the factors that most affect the spider families. Most spider families have a direct dependence on soil physical and chemical attributes, especially pH, soil density, weighted average diameter, organic matter, nitrogen, exchangeable aluminum, calcium, magnesium, potassium, and microporosity.

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Author Contributions

Marcio Gonçalves da Rosa: Responsible for sampling of soil spiders and for data collection, contributed to manuscript preparation, critical revision, and adding intellectual content.

Antonio Domingos Brescovit: Contribution to taxonomic identification of soil spiders, critical revision, adding intellectual content.

Carolina Riviera Duarte Maluche Baretta: Contribution for data collection, contribution to critical revision, adding intellectual content.

Júlio Cesar Pires Santos: Contribution to critical revision, adding intellectual content.

Luís Carlos Iuñes de Oliveira Filho: Contribution to critical revision, adding intellectual content.

Dilmar Baretta: Substantial contribution in the concept and design of the study, contribution to data analysis and interpretation, contribution to manuscript preparation, contribution to critical revision, adding intellectual content.

Conflicts of interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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