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Spiders (*Arachnida: Araneae*) in Agricultural Land Use Systems in Subtropical Environments

Marcio Gonçalves da Rosa[(1)*], Júlio Cesar Pires Santos[(2)], Antônio Domingos Brescovit[(3)], Álvaro Luiz Mafra[(2)] and Dilmar Baretta[(4)]

[(1)] Universidade do Estado de Santa Catarina, Departamento de Solos e Recursos Naturais do Centro de Ciências Agroveterinárias, Programa de Pós-Graduação em Ciência do Solo, Lages, Santa Catarina, Brasil.
[(2)] Universidade do Estado de Santa Catarina, Departamento de Solos e Recursos Naturais do Centro de Ciências Agroveterinárias, Lages, Santa Catarina, Brasil.
[(3)] Instituto Butantan, Laboratório de Artrópodes Peçonhentos, São Paulo, São Paulo, Brasil.
[(4)] Universidade do Estado de Santa Catarina, Departamento de Zootecnia do Centro de Educação Superior Oeste, Chapecó, Santa Catarina, Brasil.

ABSTRACT: Changes in land use management in agricultural areas can affect the biodiversity of spider families. This study aimed to evaluate spider diversity in different land use systems with capture by two sampling methods, and to identify soil properties that can modulate the occurrence of spiders. Five land use systems, representative of traditional agricultural areas, were evaluated in the west of Santa Catarina, Brazil, to establish a scale of land use intensity: native forest, eucalyptus reforestation areas, pastures, crop-livestock integration areas, and annual crops under no-tillage. The collection methods were manual from soil monoliths and soil traps. Altogether 479 individuals were captured, which were distributed among 20 families, 40 genera, and 8 species. Principal component analysis separated the land use systems and showed an association of spider families with land use in the two sampling methods. There was reduction in spider diversity as the intensity of land use increased. The manual collection method was more efficient for families of soil spiders, whereas traps were more efficient for epigeic spiders. The Lycosidae family was more resistant to environmental pressures, while Oonopidae and Amaurobiidae were more sensitive to environmental modifications. The differences in the spider communities were explained by the following soil properties: organic matter, mean weight-diameter of soil aggregates, and resistance to penetration, which were associated with the degree of anthropic intervention in the land use systems.

Keywords: Araneofauna, land management, soil biodiversity.

*** Corresponding author:**
E-mail: mgrmarcio@hotmail.com

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INTRODUCTION

Soil is home to a significant portion of total spider biodiversity. Agricultural management practices invariably limit the communities of these animals. Limiting factors include application of agrochemicals, soil compaction, and lack of floral diversity (Lo-Man-Hung et al., 2011). Spiders occurring in soils can be used as indicators of the sustainability and adequate management of agricultural landscapes (Jung et al., 2008) due to the functional diversity of spiders, which are specialized in preying on pests (Chatterjee et al., 2009). However, little is known about spider communities in natural and anthropogenic areas (Borges and Wunderlich, 2008).

Agricultural management practices have been reported by several authors as one of the factors responsible to reduce soil biodiversity (Castro and Wise, 2010; Teague et al., 2011; Velásquez et al., 2012; Lafage and Pétillon, 2014; Kernecker et al., 2015; Lefebvre et al., 2016; Polchaninova et al., 2016; Michalko et al., 2017). This is especially so for spiders, as these animals are dependent on balanced trophic structures for foraging. The occurrence of spiders may vary according to the time of year, which affects the distribution of other soil organisms that are trapped by spiders (De Lange et al., 2013). In addition, changes in forest vegetation and cultivated areas may influence spider populations.

Knowledge of spider diversity in the South of Brazil relies on only a few specific studies, including those of Indicatti et al. (2008), Ott (2003), Poeta et al. (2010), and Preuss and Lucas (2012), which are nevertheless limited and lack a systemic perspective. Furthermore, these studies do not include environmental variables, which are of paramount importance for understanding the ecological mechanisms of distribution and establishment of spider populations.

Another difficulty in evaluating the effects of soil use on spider biodiversity is the limitation imposed by sampling methods, which may underestimate the abundance and richness of these organisms (Baretta et al., 2007) or may be complicated due to costs, time, periodicity, and human error. For subtropical conditions in Brazil, only one study was found that evaluated sampling methods for spiders (Baretta et al., 2007). Therefore, it is necessary to expand knowledge concerning this subject.

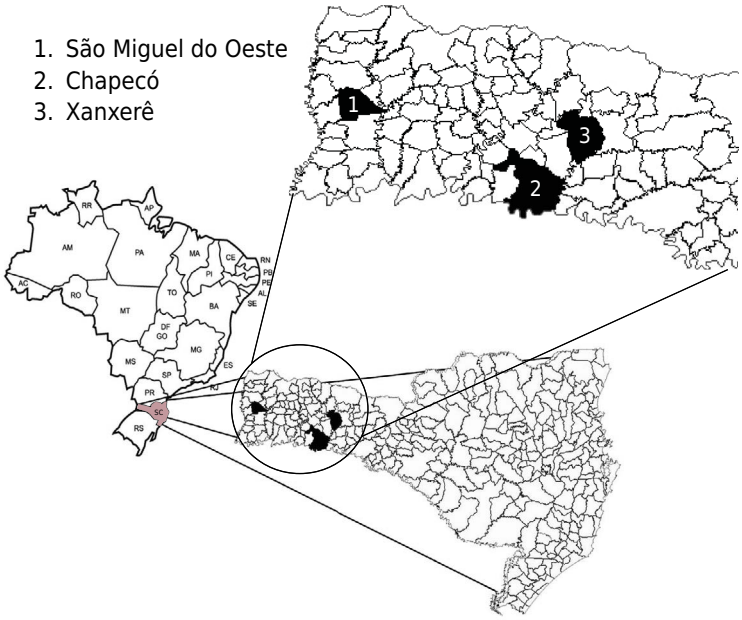
Two hypotheses guided this study. First, soil management can affect spider communities, reducing spider diversity and density according to the intensity of use. Second, soil properties may explain the distribution of spider families according to a scale of land use intensity.

This study aimed to evaluate the intensity of anthropic intervention in traditional agricultural areas in a subtropical environment and its effects on the diversity of spiders.

MATERIALS AND METHODS

Study areas

The study was carried out in the western part of the state of Santa Catarina in land use systems with increasing intensity of anthropic intervention, namely, native forest (NF), eucalyptus reforestation (ER), pasture (PA), crop-livestock integration (CLI), and annual crops using the no-tillage system (NT). The sites were selected according to previously evaluated characteristics of topography, altitude, and representative soil (*Latossolo* vermelho - Typic Hapludox), in three municipalities: Xanxerê, Chapecó, and São Miguel do Oeste (Figure 1). The areas evaluated in each municipality were adjacent or were separated by less than 1,500 m, in order to minimize environmental variations. Information regarding the history of use of the areas and the sampling scheme can be obtained in Bartz et al. (2014a,b) and in table 1. The sampling sites in each municipality were considered true representatives of the land use systems (Figure 1).



Municipalities	LUS	Latitude	Longitude	Altitude
				m
São Miguel do Oeste	NF	26° 44' 18.87" S	53° 32' 4.93" O	648
	ER	26° 43' 58.39" S	53° 32' 6.07" O	659
	PA	26° 44' 0.08" S	53° 32' 1.63" O	660
	CLI	26° 44' 38.88" S	53° 32' 43.30" O	641
	NT	26° 44' 40.32" S	53° 32' 39.70" O	642
Chapecó	NF	27° 2' 4.43" S	52° 41' 48.53" O	623
	ER	27° 1' 42.76" S	52° 41' 34.56" O	653
	PA	27° 5' 17.53" S	52° 38' 42.21" O	642
	CLI	27° 3' 3.68" S	52° 43' 9.86" O	593
	NT	27° 0' 48.90" S	52° 41' 22.90" O	679
Xanxerê	NF	26° 50' 1.21" S	52° 27' 11.96" O	714
	ER	26° 47' 3.27" S	52° 27' 36.72" O	709
	PA	26° 49' 40.68" S	52° 28' 11.35" O	723
	CLI	26° 49' 43.80" S	52° 28' 16.10" O	714
	NT	26° 50' 18.64" S	52° 28' 33.72" O	746

Figure 1. Geographic location and mean altitude of the land use system (LUS) of native forest (NF), eucalyptus reforestation (ER), pasture (PA), crop and livestock integration (CLI), and no-tillage (NT) in the municipalities of São Miguel do Oeste, Chapecó, and Xanxerê, in the western region of Santa Catarina.

Spider samples were obtained by hand-sorting methods in soil monoliths (Anderson and Ingram, 1993) and pitfall traps (Baretta et al., 2007). Sampling was carried out in the months of June and July 2011 (winter) and December 2011 and January 2012 (summer). During these periods, the temperature and rainfall conditions were representative of the regional environment (Santa Catarina, 1986). Spider samples were taken in a 3 × 3, sample grid, with nine points per land use system in each municipality, for a total of 27 points per land use system. Spacing between each point was 30 m, respecting a distance of 20 m from the border, with a total of 270 points for each of the methods (winter + summer) and total area of 1 ha in each of the land use systems.

At each point, the soil was excavated in 0.25 × 0.25 m monoliths, with a depth of 0.20 m. The collected soil was packed in plastic bags and taken to the laboratory, where manual sorting was performed with the aid of artificial lighting, collecting the spiders with tweezers. The individuals collected were stored in 80 % alcohol solution, in plastic bottles, and were sent to the Butantan Institute.

The traps were set up approximately 0.30 m from the collection points of the monoliths and consisted of 0.13 × 0.06 m glass containers (height × diameter) containing 200 mL of water with a few drops of detergent. The open part of the trap was installed at ground level, opening in a hole with a Dutch auger. The traps remained in the field for three days, were collected, and then taken to the laboratory, where the collected organisms were separated with the aid of 0.125 mm sieves. All the organisms found were stored in 80 % alcohol in plastic bottles and sent to the Butantan Institute. All material was deposited in the Arachnida and Myriapoda collection of the Special Laboratory of Zoological Collections (LECZ) of the Butantan Institute (A.D. Brescovit, curator).

The total abundance of the spider families from each collection method was used to obtain the gradient length by Detrended Correspondence Analysis (DCA), as proposed by ter Braak and Smilauer (1998). The comparison of the abundance of the spider families and the land use systems was made by Principal Component Analysis (PCA), considering each collection method and the combination of sampling methods.

The Shannon Wiener index (H') was calculated to verify how environmental pressures (intensification of land use) might interfere with the distribution of spider families; H' was

Table 1. History of use of the evaluated areas in the western region of Santa Catarina

Municipality	Parameter	Native forest	Eucalyptus reforestation	Pasture	Crop-livestock integration	No-tillage
Xanxerê	Area (ha)	1	6	4.2	1.9	6.2
	Duration of management (year)	>50	4	12	8	18
	Vegetation and management	Transition from rainforest and semideciduous seasonal forest. Secondary forest.	Formerly native pasture	Grazing introduced (*Axonopus affinis*). Treatment with animal waste.	Minimal tillage with crop rotation (soybean and corn for grains, oats and ryegrass for grazing). Entry of milk cows. Use of herbicides, insecticides, and fungicides.	No-tillage (soybean, corn, and wheat). Use of herbicides, insecticides, and fungicides.
São Miguel do Oeste	Area (ha)	10.4	2.6	1.9	1.8	3.2
	Duration of management (year)	>50	7	50	18	4
	Vegetation and management	Transition from rainforest and semidecidual seasonal forest. Secondary forest with people entering by trails.	Formerly native pasture	Mix of introduced pasture with native pasture. Accidental fire in 2007.	Minimum tillage with crop rotation (soybean and corn for grains, oats, and ryegrass for pasture). Entry of milk cows. Use of herbicides, insecticides, and fungicides.	No tillage with crop rotation (soybean, corn, oats, and ryegrass). In the last two years without application of herbicides, insecticides, and fungicides.
Chapecó	Area (ha)	7.6	3.5	5.4	5.1	2.2
	Duration of management (year)	>50	15	50	10	10
	Vegetation and management	Transition from rainforest and semidecidual seasonal forest. Secondary forest with people entering by trails.	Formerly native pasture. Application of animal waste. Accidental fire in 2006.	Native pasture.	Direct planting with crop rotation (soybean and corn for grains, oats, and ryegrass for pasture). Entry of milk cows. Use of herbicides, insecticides, and fungicides.	No tillage (soybean, corn, oats, and ryegrass). Use of herbicides, insecticides and fungicides.

calculated as proposed by Odum (1983) through the Vegan package (Oksanen, 2009) in the R statistical software (R Development Core Team, 2011). The mean values of H' were calculated point by point (n = 27) by the Tukey test at 5 % probability, with the R statistical program (R Development Core Team, 2011). For determination of average family richness, the number of individuals from each family in each sample unit was added up and divided by the number of sample units (n = 27) for each of the land use systems evaluated. To obtain the total richness of families, the number of individuals from each family was added up for all sample units (n = 27).

Soil properties

A total of 15 soil samples were collected using a Dutch auger in the 0.00-0.20 m layer around the spider collection points. The samples were homogenized to form a composite sample for determination of carbon (C), nitrogen (N), sulfur (S), and hydrogen (H) by dry combustion (Elementar Vario EL Cube® with 99 % sensitivity). We also measured pH in water at a ratio of 1:1 v/v, potential acidity (SMP index), phosphorus (P), potassium (K), organic matter (OM), exchangeable aluminum (Al^{3+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), potential acidity (H+Al), and cation exchange capacity (CEC) at pH 7.0, according to Tedesco et al. (1995) (Table 2).

Undisturbed soil samples were taken next to each excavated site to collect spiders from a 0.20 × 0.20 m pit with a depth of 0.10 m. A 25-g portion of 4.75-8.88 mm aggregates was manually removed from samples of undisturbed soil cores and kept in closed plastic pots to avoid drying until the stability of the aggregates was determined by the wet sieving method of Kemper and Chepil (1965). Volumetric rings, 0.05 m in height, removed from the 0.025-0.075 m layer, were used to determine soil bulk density (Bd, biopore volume (Bio), microporosity (Micro), macroporosity (Macro), and total porosity (TP), as described in Claessen (1997). Resistance to penetration (RP) was measured with a Marconi® bench penetrometer, model MA-933, in the central portion of the soil samples contained in the volumetric rings, with a stable moisture content of 6 kPa (Table 2).

Table 2. Soil properties (0.00-0.20 m) under native forest (NF), eucalyptus reforestation (ER), pasture (PA), crop and livestock integration (CLI), and no-tillage (NT) in Xanxerê (Xan), São Miguel do Oeste (SMO), and Chapecó (Cha)

Soil property	Xanxerê					São Miguel do Oeste					Chapecó				
	NF	ER	PA	CLI	NT	NF	ER	PA	CLI	NT	NF	ER	PA	CLI	NT
TOC (g kg^{-1})	46.9	32.0	44.3	31.9	33.4	53.5	33.1	45.0	29.4	28.9	48.4	28.1	34.8	33.8	31.4
N (g kg^{-1})	3.9	2.5	3.4	2.3	2.4	4.6	2.6	3.3	2.3	2.4	3.7	2.1	2.5	2.8	2.6
pH(H_2O)	4.5	5.0	4.5	5.2	5.4	4.3	4.7	5.2	5.6	6.2	4.0	4.7	5.4	5.0	5.3
SMP	5.0	5.4	5.2	5.7	5.9	4.9	5.1	5.9	6.0	6.5	4.4	5.3	5.7	5.6	5.9
P (mg dm^{-3})	5.0	4.8	4.3	8.9	15.9	5.8	5.1	3.5	8.9	17.1	5.0	5.5	6.2	18.1	11.7
K (mg dm^{-3})	75.4	178.0	259.1	85.4	102.4	99.6	60.7	87.6	150.5	316.2	72.2	78.3	88.4	298.4	366.9
OM (g kg^{-1})	4.8	4.1	5.1	3.8	3.9	5.2	4.0	4.8	3.6	3.7	4.8	4.1	4.6	4.5	4.6
Al^{3+} ($cmol_c$ dm^{-3})	2.0	1.3	2.1	1.1	0.3	3.9	3.0	0.6	0.2	0.0	4.5	2.4	0.3	1.1	0.7
m (%)	38.5	22.1	36.9	13.2	2.6	59.9	43.5	8.7	2.5	0.0	72.2	35.5	4.4	14.6	7.7
Ca^{2+} ($cmol_c$ dm^{-3})	2.2	3.5	2.0	5.4	7.6	2.0	2.5	4.9	6.4	8.1	1.2	3.0	4.0	4.0	5.9
Mg^{2+} ($cmol_c$ dm^{-3})	1.0	1.0	1.0	2.2	2.8	0.8	1.2	1.9	2.9	3.8	0.3	1.5	2.6	1.8	1.7
H+Al ($cmol_c$ dm^{-3})	14.4	8.8	11.0	6.2	5.0	16.1	13.2	5.2	4.3	2.7	28.2	10.0	5.9	6.8	4.9
CEC pH 7.0 ($cmol_c$ dm^{-3})	17.8	13.8	14.7	14.1	15.7	19.1	17.1	12.2	14.0	15.4	30.0	14.6	12.8	13.3	13.4
V (%)	21.0	36.1	25.5	55.5	67.7	16.7	23.9	57.3	69.1	82.1	6.3	32.4	53.9	49.6	63.8
Bd (Mg m^{-3})	0.9	1.1	1.0	1.1	1.1	0.9	0.9	1.1	1.2	1.2	1.0	1.1	1.2	1.2	1.2
TP (m^3 m^{-3})	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Micro (m^3 m^{-3})	0.4	0.4	0.5	0.3	0.5	0.5	0.4	0.6	0.5	0.5	0.3	0.4	0.5	0.5	0.5
Macro (m^3 m^{-3})	0.2	0.2	0.1	0.2	0.1	0.2	0.3	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1
Bio (m^3 m^{-3})	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.2	0.1	0.0	0.1	0.1
RP (Mpa)	0.5	1.3	1.9	1.4	1.7	0.6	0.8	1.9	1.6	1.3	0.8	2.6	2.3	1.4	1.2
Sand (g kg^{-1})	231	233	197	247	364	300	340	299	251	298	362	313	318	320	315
Clay (g kg^{-1})	373	347	406	427	434	448	352	386	398	394	445	404	358	393	421
Silt (g kg^{-1})	224	209	284	297	202	252	307	315	351	308	193	284	324	287	264
WMD (mm)	5.4	4.7	5.7	5.5	4.9	5.5	4.9	5.8	5.4	5.4	4.8	5.6	5.6	5.9	5.9

Total organic carbon (TOC); total nitrogen (N); pH in SMP solution (SMP); phosphorus (P); potassium (K) organic matter (OM); aluminum (Al); saturation by aluminum (m); calcium (Ca); magnesium (Mg); potential acidity (H+Al); cation exchange capacity at pH 7.0 (CEC pH 7.0); base saturation (V); soil density (Ds); total porosity (TP); microporosity (Micro); macroporosity (Macro); resistance to penetration (RP); sand content (Sand); silt content (Silt); clay content (Clay); and weighted mean diameter (WMD). Carbon and nitrogen determined by dry combustion; pH(H_2O) at a ratio of 1:1 v/v; SMP, P, K, OM, Al^{3+}, m%, Ca^{2+}, Mg^{2+}, H+Al, CEC pH 7.0, and V (%) were determined according Tedesco et al. (1995); Bd, TP, Micro, Macro, and Bio were determined as described in Claessen (1997); resistance to penetration (RP) was measured with a Marconi® bench penetrometer in the central portion of the soil samples contained in the volumetric rings, with a stable moisture content of 6 kPa. Sand, silt, and clay fractions determined by the pipette method.

The physical and chemical properties were considered as explanatory environmental variables, where the collinear soil variables were removed from the statistical model and later used to establish the correlation between them and the families of spiders in redundancy analysis (RDA) using the Canoco 4.5 program (ter Braak and Smilauer, 1998).

RESULTS

In all, 479 individuals were captured, distributed among 20 families, 40 genera, and eight named species (Table 3). The soil traps (Table 4) captured 37 morphospecies distributed among 19 families. The manual collection method yielded 28 morphospecies distributed among 13 families (Table 5). The two methods combined yielded 54 morphospecies among 20 families (Table 3). Of the 20 families, six occurred exclusively in the traps, and three in the manual collection group. Taken together, according to the abundance data of individuals captured by the manual collection methods and by the traps, the most frequent families in relation to the total number of captured individuals (479 individuals) were as follows: *Linyphiidae* (172 individuals or 35.9 %), *Lycosidae* (106 individuals or 22.1 %), *Theridiidae* (84 individuals or 17.5 %), *Hahniidae* (31 individuals or 6.5 %), *Salticidae* (16 individuals or 3.3 %), and *Oonopidae* (15 individuals or 3.1 %), representing 88.51 % of individuals captured (Table 3).

Although there were no significant differences in the Shannon-Wiener (H') diversity values by the Tukey test at 5 %, there was a slight increase in H' in NF between sampling times (0.48 in winter and 0.41 in summer, table 3). The same behavior was observed for the trap method, in which NF exhibited H' values of 0.30 in winter and 0.36 in summer (Table 4). For manual collection, the values of H' in NF were 0.03 during the winter and 0.06 during the summer (Table 5). The same trend occurred for families richness, where areas with lower levels of anthropogenic intervention such as NF and ER had the highest richness, and those with some level of management, such as PA, CLI, and NT had lower values of richness.

Principal component analysis separated soil use systems and spider families by the soil traps method (Figures 2a and 2b). Principal component 1 (PC1) accounted for 40.7 % and principal component 2 (PC2) accounted for 24.7 %, a total of 65.4 % of the total variation. There was high abundance of spider families in native forest (NF) and eucalyptus reforestation (ER) areas, whereas in systems with greater pasture management (PA), no-tillage annual crops (NT), and crop-livestock integration (CLI), there was a slight decrease in abundance (Figure 2a). The families *Pholcidae*, *Oonopidae*, *Amaurobiidae*, *Salticidae*, *Linyphiidae*, *Scytodidae*, *Corinnidae*, *Gnaphosidae*, and *Hahniidae* were more related to systems with lower levels of anthropogenic intervention, whereas *Theridiidae*, *Oxyopidae*, *Araneidae*, *Lycosidae*, *Tetragnathidae*, and *Amphinectidae* were more related to land use systems with some type of anthropic intervention (PA, CLI, and NT).

During the summer, the families of spiders collected in soil traps had a different composition (Figure 2b). *Caponiidae*, *Amaurobiidae*, *Zodariidae*, *Oonopidae*, *Ctenidae*, and *Miturgidae* were present only in NF (Table 4) and the families *Corinnidae*, *Linyphiidae*, *Scytodidae*, and *Gnaphosidae* were more strongly related with CLI, since a smaller proportion of families, such as *Lycosidae*, *Hahniidae*, *Tetragnathidae*, *Salticidae*, and *Filistatidae* were present only in ER, PA, and NT; PCA explained 56.9 % of this variation - 37.0 % for PC1 and 19.9 % for PC2.

For the manual collection method (Figures 2c and 2d), a reduced number of individuals was collected, especially because this method is commonly used for organisms solely in the soil. Native forest concentrated the highest abundance of individuals in winter (Figure 2c) and had a higher relation with *Prodidomidae*, *Palpimanidae*, *Linyphiidae*, *Amaurobiidae*, *Corinnidae*, while the systems with some level of anthropic intervention had greater relation only with *Lycosidae*.

Table 3. The total number of individuals (spider families) caught in western Santa Catarina by the combination of two sampling methods (manual collection and soil traps) in two contrasting seasons (winter and summer) in native forest (NF), eucalyptus reforestation (ER), pasture (PA), crop-livestock integration (CLI), and no-tillage annual crop (NT)

Manual collection and traps	Winter					Summer				
Family/genus/species	NF	ER	PA	CLI	NT	NF	ER	PA	CLI	NT
Amaurobiidae	1	0	0	0	0	0	0	0	0	0
gen.? sp.1*	1	0	0	0	0	3	0	0	0	0
N.I. sp.1*	0	0	0	0	0	1	0	0	0	0
Amphinectidae	0	0	0	1	0	0	0	0	0	0
Araneidae	0	0	1	0	0	1	0	1	0	0
Caponiidae	0	0	0	0	0	2	0	0	0	0
Corinnidae	0	0	0	0	0	3	1	0	0	0
Corinna sp.1	2	2	0	0	0	0	1	0	0	0
Falconina sp.1	0	0	0	0	0	1	1	0	0	0
Ctenidae	0	0	0	0	0	0	0	0	0	0
Isoctenus sp.1	0	0	0	0	0	1	0	0	0	0
Gnaphosidae	0	2	0	0	1	0	1	0	0	1
Zimiromus sp.1	0	0	0	0	0	0	0	0	0	3
Hahniidae	1	11	0	1	0	0	0	0	0	0
Neohahnia sp.1	1	0	0	0	0	0	9	0	0	5
gen.? sp.1*	1	0	0	0	0	2	0	0	0	0
Linyphiidae	14	4	8	5	4	8	8	3	4	6
Agyneta sp.1	5	12	1	0	0	2	5	2	0	0
Agyneta sp.2	0	0	0	0	0	2	0	0	0	0
Erigone sp.1	0	1	1	2	0	0	1	2	0	1
Erigone sp.2	1	2	8	15	5	0	1	0	1	0
Linyphiidae sp.1	0	0	0	0	0	1	0	0	0	0
Mermessus sp.1	1	8	0	1	1	0	0	0	0	0
Moyosi sp.1	1	0	0	0	0	1	0	0	0	0
Neomaso sp.1	4	0	0	0	0	1	0	0	0	0
Neomaso sp.2	0	0	0	0	0	1	0	0	0	0
Laminacauda sp.1	0	0	0	0	0	0	1	0	0	3
Ostearius sp.1	0	0	0	0	1	3	0	2	0	0
Scolecura sp.1	0	3	1	0	0	1	0	0	0	0
Sphecozone novaeteutoniae	2	0	0	0	0	0	0	0	0	0
Vesicapalpus sp.1	0	0	1	0	0	0	0	0	0	0
Lycosidae	4	0	3	6	2	4	6	18	19	14
Allocosa sp.1	0	0	1	3	3	2	0	1	4	0
Allocosinae sp.1	0	0	0	1	0	0	0	0	0	0
Trochosa sp.1	0	0	1	2	1	0	0	0	1	0
Trochosa sp.2	0	0	3	0	2	0	0	0	0	3
Lobizon humilis	0	0	0	0	0	1	0	0	1	0
Miturgidae	0	0	0	0	0	0	0	0	0	0
Odo sp.1	0	0	0	0	0	1	0	0	0	0
Oonopidae	0	1	0	0	0	1	0	0	0	0
Gen.1 sp.1*	0	0	0	0	0	3	0	0	0	0
Neoxyphinus sp.1	3	0	0	0	0	0	0	0	0	0
Hexapopha sp.1	1	0	0	0	0	0	0	0	0	0
Neotrops sp.1	0	0	0	0	0	3	0	0	0	0
Neoxyphinus termitophilus	1	0	0	0	0	2	0	0	0	0
Oxyopidae	0	0	1	0	0	0	0	0	0	0
Palpimanidae	0	0	0	0	0	0	0	0	0	0
Otiothops sp.	0	0	1	0	0	0	0	0	1	0
Pholcidae	0	0	0	0	0	0	0	0	0	0
Mesabolivar aff. difficilis	1	0	0	0	0	0	2	0	0	0
Salticidae	1	2	0	0	0	0	1	1	0	1
Cotinusa sp.1	0	0	0	1	0	0	0	0	0	0
Corythalia sp.1	2	2	0	0	0	0	0	0	0	0
Corythalia sp.2	0	0	0	0	0	0	0	4	0	0
Euophryinae sp.1	0	0	0	1	0	0	0	0	0	0
Scytodidae	0	1	0	0	0	0	1	0	0	0
Tetragnathidae	0	0	0	0	0	0	0	0	1	0
Azilia histrio	1	0	0	0	0	0	0	0	0	0
Glenognatha australis	0	0	4	3	3	0	0	1	0	0
Theridiidae	1	0	5	0	0	7	4	15	8	5
Cryptachaea sp.1	0	0	0	0	0	0	0	0	1	9
Dipoena pumicata	1	0	0	1	0	0	0	0	0	0
Dipoena sp.1	1	0	0	0	0	0	0	1	1	0
Euryopis sp.1	1	0	0	0	0	1	0	1	0	0
Euryopis sp.2	0	0	0	0	0	0	3	0	0	0
Exalbidion sp.1	0	0	0	0	0	1	0	0	0	0
Guaraniella sp.1	1	0	1	0	1	1	0	0	0	0
Steatoda sp.1	0	0	0	0	0	0	0	0	8	1
Steatoda sp.2	0	0	0	0	0	0	0	0	1	0
Styposis sellis	1	0	0	0	0	0	0	0	0	0
Styposis sp.1	1	0	0	0	0	0	1	0	0	0
Zodariidae	0	0	0	0	0	0	0	0	0	0
Tenedos sp.1	0	0	0	0	0	1	0	0	0	0
Average diversity (H')	0.48 a[(1)]	0.39 a	0.33 a	0.25 a	0.23 a	0.41 a	0.42 a	0.27 a	0.17 a	0.11 a
Average richness	1.78 a	1.41 a	1.22 a	1.26 a	1.19 a	1.70 a	1.52 a	1.11 ab	1.04 ab	0.70 b
Total richness	28	14	16	14	11	31	17	13	13	12
Total individuals	56	51	41	43	24	62	47	52	51	52

[(1)] Means followed by the same letters do not differ from each other by the Tukey test at 5 %. Taxa followed by * indicates the impossibility of morphological identification.

In the summer, by the manual collection method (Figure 2d), *Theridiidae*, *Oonopidae*, *Amaurobiidae*, *Tetragnathidae*, *Hahniidae*, and *Corinnidae* were more abundant in NF. In the land use systems where the level of anthropic intervention was greater, the frequency of spiders was low. The *Salticidae* family had a greater relationship with CLI, whereas the families *Linyphiidae* and *Palpimanidae* with ER; the clear distinction between the occurrence of determined families in the land use systems is explained by PC1 at 55.7 % and by PC2 at 15.1 %, for a total of 70.8 % of the total variation.

When abundance values were added for the two methods (soil traps and manual collection) (Figures 2e and 2f) and analyzed by PCA, some families maintained associations with the land use systems, regardless of the sampling method. For example, *Oonopidae* and *Amaurobiidae* were captured only in areas of NF (Table 3). In addition, there was a considerable increase in the number of families between sampling times, with 17 families in the summer and 19 in the winter, compared to 15 families in the winter and 16 families in the summer captured using soil traps (Figures 2a and 2b) and 8 and 9 using the manual method (Figures 2c and 2d).

Redundancy analysis (RDA) showed that of all the physical and chemical properties, only a few were strongly associated with some spider families. For soil traps (Figures 3a and 3b), organic matter content (OM) was correlated with *Amaurobiidae*, *Theridiidae*, *Oonopidae*, *Pholcidae*, *Linyphiidae*, and *Corinnidae*. Magnesium contents correlated mainly with *Tetragnathidae* and *Lycosidae*. During summer, resistance to penetration (RP) showed high correlation with the families *Gnaphosiidae*, *Salticidae*, *Theridiidae*, and *Tetragnathidae*, whereas OM showed a strong relation to *Ctenidae*, *Miturgidae*, *Oonopidae*, *Araneidae* and *Filistatidae*.

For the manual collection method, the geometric mean diameter (GMD) of the aggregates showed correlation with *Theridiidae* and *Prodidomidae*, and OM contents correlated with *Palpimanidae* and *Prodidomidae*. During the summer, OM was the property most correlated with the majority spider families (Figures 3a, 3b, 3c, and 3d). Redundancy analysis performed on the two sampling methods showed an increase in the number of physical and chemical variables selected by the statistical model, thus allowing greater reliability in the results. Among the 24 physical and chemical variables analyzed (Table 2), only 13 were among those that most correlated with the spider families: resistance to penetration (RP), bulk density (Bd), macroporosity (Macro), biopores (Bio), mean weight-diameter (MWD), water content (moisture), Ca, Mg, and K, which had high values in the agricultural production sites (CLI and NT); total organic carbon (TOC), soil organic matter (OM), aluminum (Al) and nitrogen (N) contents, in NF.

DISCUSSION

The diversity of spider families was inversely proportional to the intensity of land use. This result is related to the biological regulator role of spiders, which are conditioned to the biological complexity in various ecological niches, whether soil or surface litter, and in the interaction between these two (Liu et al., 2015a,b). In this respect, native forest (NF) had the highest spider diversity, regardless of the sampling period, possibly due to the vegetation, which maintains the microclimate and moisture/humidity, as well as the diversity of microhabitats at this site (Malumbres-Olarte et al., 2013). The ecological stability in natural vegetation favors accumulation of surface litter in quantity and quality. In addition, various soil organisms that are attracted by the diversity of plant residues, become potential prey for spiders. Thus, the OM contents (Figures 3a, 3b, 3c, and 3d) become an indirect conditioner for greater abundance of spider families.

The population fluctuations observed in agroecosystems are due to seasonality in soil conditions, as well as modification in plant structure, which may be designated as environmental stressors, especially in agricultural areas (CLI and NT), whose management, despite being conservationist, nevertheless involves the use of agrochemicals for pest control. In this respect, the interaction among management practices is noteworthy,

Table 4. Total number of individuals (spider families) caught in western Santa Catarina in soil traps in two contrasting seasons (winter and summer) in native forest (NF), eucalyptus reforestation (ER), pasture (PA), crop-livestock integration (CLI), and no-tillage annual crops (NT)

Traps	Winter					Summer				
Family/genus/species	**NF**	**ER**	**PA**	**CLI**	**NT**	**NF**	**ER**	**PA**	**CLI**	**NT**
Amaurobiidae	1	0	0	0	0	0	0	0	0	0
N.I. sp.1*	0	0	0	0	0	1	0	0	0	0
Amphinectidae	0	0	0	1	0	0	0	0	0	0
Metaltella sp.1	0	0	0	0	0	0	0	0	0	0
Araneidae	0	0	1	0	0	1	0	1	0	0
Caponiidae	0	0	0	0	0	2	0	0	0	0
Corinnidae	0	0	0	0	0	3	1	0	0	0
Corinna sp.1	1	1	0	0	0	0	1	0	0	0
Falconina sp.1	0	0	0	0	0	1	1	0	0	0
Ctenidae	0	0	0	0	0	0	0	0	0	0
Isoctenus sp.1	0	0	0	0	0	1	0	0	0	0
Gnaphosidae	0	2	0	0	1	0	1	0	0	1
Hahniidae	1	11	0	1	0	0	0	0	0	0
Neohahnia sp.1	1	0	0	0	0	0	9	0	0	5
Linyphidae	14	4	8	5	4	8	8	3	4	6
Agyneta sp.1	5	12	1	0	0	1	5	2	0	0
Agyneta sp.2	0	0	0	0	0	2	0	0	0	0
Erigone sp.1	0	1	0	0	0	0	1	1	0	1
Erigone sp.2	1	2	8	15	5	0	1	0	1	0
Mermessus sp.1	1	4	0	1	1	0	0	0	0	0
Neomaso sp.1	4	0	0	0	0	1	0	0	0	0
Ostearius sp.1	0	0	0	0	1	3	0	2	0	0
Sphecozone novaeteutoniae	2	0	0	0	0	0	0	0	0	0
Vesicapalpus sp.1	0	0	1	0	0	0	0	0	0	0
Scolecura sp.1	0	3	1	0	0	0	0	0	0	0
Lycosidae	4	0	3	6	2	4	6	18	19	14
Allocosa sp.1	0	0	1	3	3	2	0	0	4	0
Allocosinae	0	0	0	1	0	0	0	0	0	0
Trochosa sp.1	0	0	1	2	1	0	0	0	1	0
Trochosa sp.2	0	0	3	0	2	0	0	0	0	3
Miturgidae	0	0	0	0	0	0	0	0	0	0
Odo sp.1	0	0	0	0	0	1	0	0	0	0
Oonopidae	0	1	0	0	0	1	0	0	0	0
Hexapopha sp.1	1	0	0	0	0	0	0	0	0	0
Neotrops sp.1	0	0	0	0	0	3	0	0	0	0
Neoxyphinus termitophilus	1	0	0	0	0	2	0	0	0	0
Oxyopidae	0	0	1	0	0	0	0	0	0	0
Pholcidae	0	0	0	0	0	0	0	0	0	0
Mesobolivar sp.1	1	0	0	0	0	0	0	0	0	0
Salticidae	1	2	0	0	0	0	1	1	0	1
Corythalia sp.1	1	0	0	0	0	0	0	0	0	0
Cotinusa sp.1	0	0	0	1	0	0	0	0	0	0
Scytodidae	0	1	0	0	0	0	1	0	0	0
Tetragnathidae	0	0	0	0	0	0	0	0	1	0
Glenognatha australis	0	0	4	3	3	0	0	1	0	0
Theridiidae	1	0	5	0	0	7	4	15	8	5
Cryptachaea sp.1	0	0	0	0	0	0	0	0	1	9
Exalbidion sp.1	0	0	0	0	0	1	0	0	0	0
Guaraniella sp.1	0	0	0	0	0	1	0	0	0	0
Steatoda sp.1	0	0	0	0	0	0	0	0	8	1
Steatoda sp.2	0	0	0	0	0	0	0	0	1	0
Styposis sp.1	0	0	0	0	0	0	1	0	0	0
Dipoena sp.1	1	0	0	0	0	0	0	0	0	0
Guaraniella sp.1	1	0	1	0	1	0	0	0	0	0
Styposis sp.1	1	0	0	0	0	0	0	0	0	0
Zodariidae	0	0	0	0	0	0	0	0	0	0
Tenedos sp.1	0	0	0	0	0	1	0	0	0	0
Average diversity (H')	0.30 a[(1)]	0.32 a	0.24 a	0.09 a	0.11 a	0.36 a	0.29 a	0.23 a	0.18 a	0.19 a
Average richness[1]	1.26 a	1.33 a	1.04 a	0.93 a	0.70 a	1.41 a	1.19 a	1.00 a	1.11 a	1.11 a
Total richness	21	14	9	10	10	20	13	14	11	11
Total individuals	47	41	44	48	46	44	48	39	39	24

[(1)] Means followed by the same letters do not differ from each other by the Tukey test at 5 %. Taxa followed by * indicates the impossibility of morphological identification.

Table 5. The total number of individuals (spider families) captured in western Santa Catarina by manual capture in soil monoliths in two contrasting seasons (winter and summer) in native forest (NF), eucalyptus reforestation (ER), pasture (PA), crop-livestock integration (CLI), and no-tillage annual crops (NT)

Manual collection from soil monoliths	Winter					Summer				
Family/genus/species	NF	ER	PA	CLI	NT	NF	ER	PA	CLI	NT
Amaurobiidae	0	0	0	0	0	0	0	0	0	0
gen.? sp.1*	1	0	0	0	0	3	0	0	0	0
Corinnidae	0	0	0	0	0	0	0	0	0	0
Corinna sp.1	1	1	0	0	0	0	0	0	0	0
Gnaphosidae	0	0	0	0	0	0	0	0	0	0
Zimiromus sp.1	0	0	0	0	0	0	0	0	0	3
Hahniidae	0	0	0	0	0	0	0	0	0	0
gen.? sp.1*	1	0	0	0	0	2	0	0	0	0
Linyphiidae	0	0	0	0	0	0	0	0	0	0
Agyneta sp.1	0	0	0	0	0	1	0	0	0	0
Erigone sp.1	0	0	1	2	0	0	0	1	0	0
Linyphiidae sp.1	0	0	0	0	0	1	0	0	0	0
Mermessus sp.1	0	4	0	0	0	0	0	0	0	0
Moyosi sp.1	1	0	0	0	0	1	0	0	0	0
Neomaso sp.2	0	0	0	0	0	1	0	0	0	0
Laminacauda sp.1	0	0	0	0	0	0	1	0	0	3
Scolecura sp.1	0	0	0	0	0	1	0	0	0	0
Lycosidae	0	0	0	0	0	0	0	0	0	0
Allocosa sp.1	0	0	0	0	0	0	0	1	0	0
Lobizon humilis	0	0	0	0	0	1	0	0	1	0
Oonopidae	0	0	0	0	0	0	0	0	0	0
Gen.1 sp.1*	0	0	0	0	0	3	0	0	0	0
Neoxyphinus sp.1	3	0	0	0	0	0	0	0	0	0
Palpimanidae	0	0	0	0	0	0	0	0	0	0
Otiothops sp.	0	0	1	0	0	0	0	0	1	0
Pholcidae	0	0	0	0	0	0	0	0	0	0
Mesabolivar aff. difficilis	0	0	0	0	0	0	2	0	0	0
Prodidomidae	0	0	0	0	0	0	0	0	0	0
*Gen.*1 sp.1*	0	0	0	0	0	0	0	0	1	0
Salticidae	0	0	0	0	0	0	0	0	0	0
Corythalia sp.1	1	2	0	0	0	0	0	0	0	0
Corythalia sp.2	0	0	0	0	0	0	0	4	0	0
Euophryinae sp.1	0	0	0	1	0	0	0	0	0	0
Tetragnathidae	0	0	0	0	0	0	0	0	0	0
Azilia histrio	1	0	0	0	0	0	0	0	0	0
Theridiidae	0	0	0	0	0	0	0	0	0	0
Dipoena pumicata	1	0	0	1	0	0	0	0	0	0
Dipoena sp.1	0	0	0	0	0	0	0	1	1	0
Euryopis sp.1	1	0	0	0	0	1	0	1	0	0
Euryopis sp.2	0	0	0	0	0	0	3	0	0	0
Styposis sellis	1	0	0	0	0	0	0	0	0	0
Average diversity (H')	0.03 a[(1)]	0.03 a	0.00 a	0.00 a	0.00 a	0.06 a	0.00 a	0.02 a	0.00 a	0.00 a
Average richness	0.19 a	0.07 a	0.04 a	0.11 a	0.00 a	0.41 a	0.22 a	0.22 a	0.15 a	0.07 a
Total richness	10	3	2	3	0	10	3	5	4	2
Total individuals	12	7	2	4	0	15	6	8	4	6

[(1)] Means followed by the same letters do not differ from each other by the Tukey test at 5 %. Taxa followed by * indicates the impossibility of morphological identification.

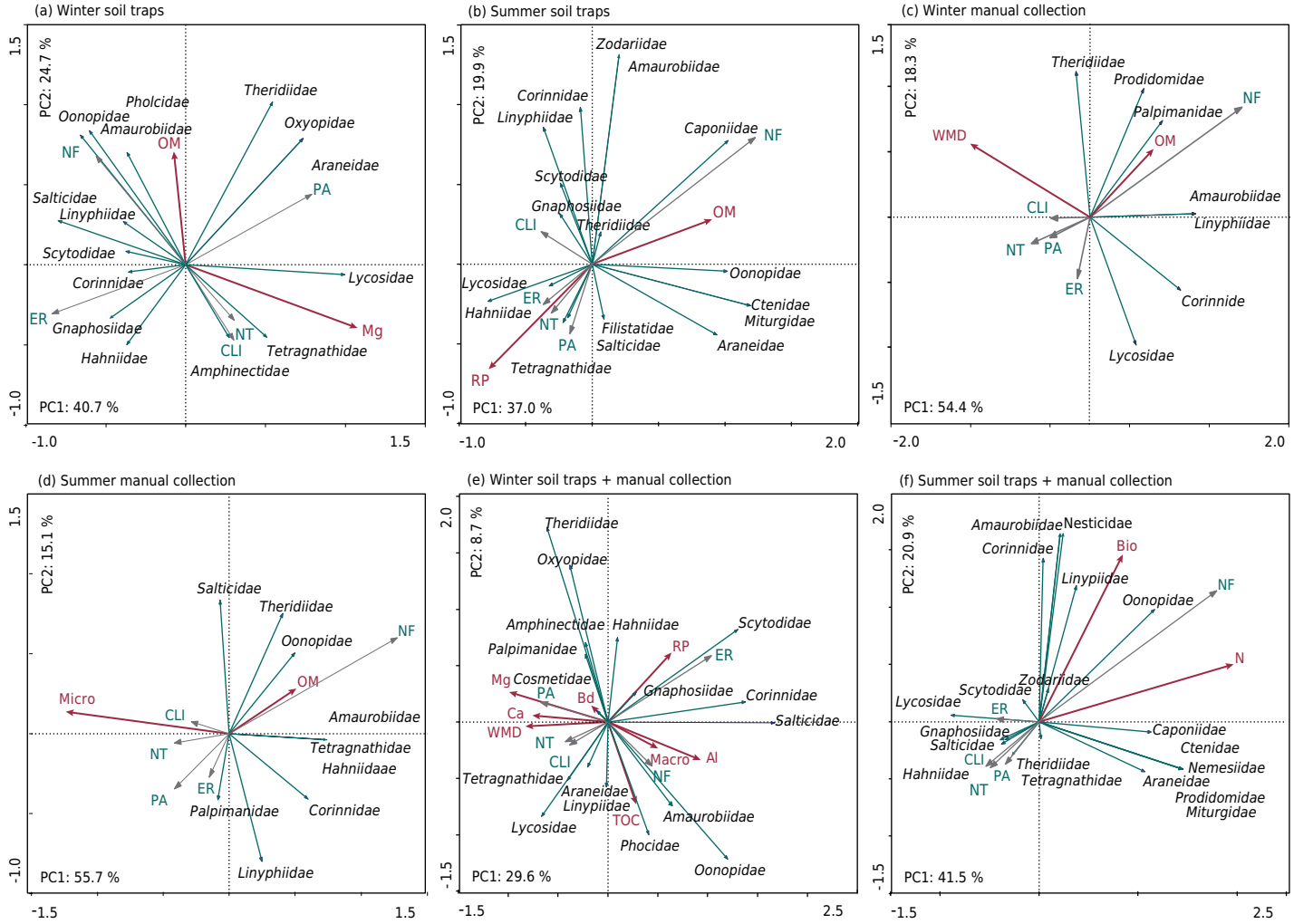


Figure 2. Principal component analysis (PCA) for spider families (in italics) and environmental variables (in red) in native forest systems (NF), eucalyptus reforestation (ER), pasture (PA), crop-livestock integration (CLI), and no-tillage annual crops (NT) in western Santa Catarina in two seasons: winter and summer. Two methods of collection (traps and manual collection). OM = organic matter; Mg = magnesium; RP = resistance to root penetration; WMD = weighted mean diameter; Micro = microporosity; Macro = macroporosity; COT = total organic carbon; Al = aluminum; Bd = soil bulk density; Ca = calcium; Bio = biopores; N = nitrogen; PC1 = main component 1; PC2 = main component 2.

such as input application, machine traffic, and alteration of vegetation, which may be critical stress factors for the spider communities established there.

These practices alter the structure of the prey community; species more sensitive to such changes are forced to migrate to other sites and species less-dependent on environmental resources remain. Stenroth et al. (2015) found strong association of the *Linyphiidae* family with agricultural areas when evaluating the relationships between riparian predators and aquatic insect distribution patterns. This partially corroborates our results, since this family was more associated with CLI areas (Figure 2b) and ER (Figure 2d) during the summer. It is noteworthy that there was no distribution pattern of this family among the land use systems, suggesting that these individuals migrate according to the availability of resources in the sampling time, since during the winter *Linyphiidae* was more associated with NF.

Association of *Lycosidae* with agricultural areas was reported by Stenroth et al. (2015), corroborating our results. Individuals of this family were mostly collected in areas of NT (Figure 2a), CLI (Figures 2b and 2e), and ER (Figure 2d). Environmental stress factors, together with global climate change, can be a critical factor in loss of biodiversity (Mantyka-Pringle et al., 2015). The relationship between spider diversity and vegetation type has already been reported by Baldissera et al. (2008), especially in araucaria and eucalyptus areas.

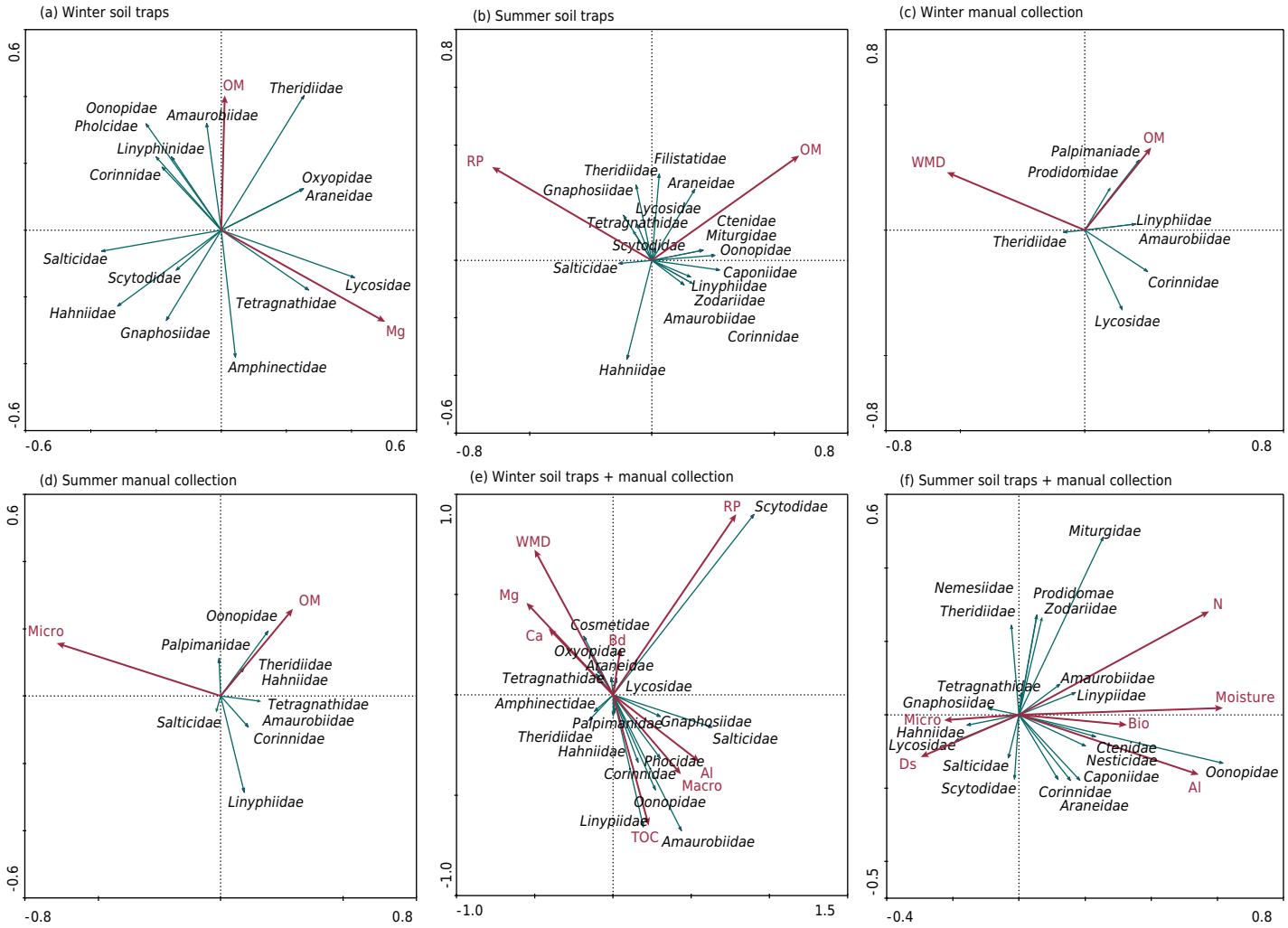


Figure 3. Redundancy analysis (RDA) for spider families (in italics) and environmental variables (in red) in western Santa Catarina in two seasons: winter and summer. Two methods of collection (traps and manual collection); OM = organic matter; Mg = magnesium; RP = resistance to root penetration; WMD = weighted mean diameter; Micro = microporosity; Macro = macroporosity; TOC = total organic carbon; Al = aluminum; Bd = soil bulk density; Ca = calcium; Bio = biopores; N = nitrogen; Moisture = soil moisture.

The low spider diversity (H') found in CLI (Tables 2, 3, and 4) may be related to the low floristic diversity (Malumbres-Olarte et al., 2013), as well to the introduction of cattle, which, in addition to changing the soil physical properties, such as soil bulk density (Bd) and resistance to penetration (RP), may also indirectly collaborate as a limiting factor in the establishment of spiders, especially due to the fact that animal trampling in PA and CLI increase RP by compaction, which possibly hinders the establishment of other soil organisms (potential prey) and reduces the supply of food to spiders. In this sense, Kajak et al. (1999) demonstrated that Bd was one of the factors responsible for reduction in spiders in pasture areas, and that soil moisture also affected the diversity of these organisms.

It should be noted that the areas with lower plant diversity (ER and PA), regardless of sampling method and time, had low spider diversity (<0.5). This animal prefers areas with greater diversity of plant residues (Baretta et al., 2007). In an ecological study, it was demonstrated that successional stage of the plant community delimited microhabitats favorable to spiders, explaining the preference of these organisms for areas with a lower degree of human intervention (Hemm and Höfer, 2012).

The sensitivity of spiders to soil management responses was studied by Lafage and Pétillon (2014), who found a high short-term response in the management of pasture areas in the west of France, with *Lycosidae* as the most prevalent family in all locations sampled. This partially corroborates our results, in which this family represented 22.1 %

of the total individuals collected. Management conditions were the main causes of the reduction in spider diversity in another study conducted by Alcayaga et al. (2013), especially through disorganization of vegetation and soil moisture. In Brazil, Baretta et al. (2007) showed that drastic events, such as accidental burning in araucaria and pasture areas in the State of São Paulo, affected the diversity of spider families.

Considering the scale of human intervention that was established, NF is considered the most conserved environment, and NT the condition with the highest interference of use. Thus, some families were more associated with environments with a lower level of intervention, such as *Oonopidae*, which was more associated with NF areas, as reported by Lo-Man-Hung et al. (2011).

One of the major limitations in assessing spider biodiversity is related to the metrics used (Aubin et al., 2013). Most studies have used a small number of samples and only a single method for capturing the biodiversity of a given group, not taking environmental variables into account. The considerable number of spider families captured in soil traps would be a good point of departure for understanding the structure of the spider community. However, this method is more associated with families that are less demanding in terms of environmental variables and that inhabit several niches of the environments, whether soil or surface litter.

Some authors indicate that the plant composition of the site evaluated creates a favorable habitat structure for spider development (D'Alberto et al., 2012; Rodriguez-Artigas et al., 2016). Spiders are dependent on a well-established trophic chain, and therefore need to actively forage, regardless of their feeding strategy. Thus, it is understood that an environment with diversified plant structure attracts other organisms that will serve as prey for spiders. This confirms the great diversity of spiders in the scale of intensity of human interference between native forest (NF), as the most stable and biodiverse environment, and no-tillage annual crops (NT), as the least stable and with the lowest diversity of spiders.

The low richness and abundance of spiders captured by the manual collection method, especially in NT, reflects the main limitation of the method: capture of spiders that are strictly in the soil, that is, that only forage the soil and surface litter, such as *Palpimanidae*. They were found only in the collections that used the manual collection method. Moreover, the soil traps were not effective for this family, since, in general, this family does not travel long distances in search of food. This behavior has already been reported by Cerveira and Jackson (2005) when evaluating the predatory behavior of *Palpimanus* spp. when disturbed. These spiders tend to move little and remain inactive. In this sense, low mobility facilitated capture through manual collection.

Although the manual collection method is internationally recognized, and its effectiveness has been tested for soil organisms, sampling amplitude for spiders is greater when combined with soil traps, mainly because they increase the number and diversity of individuals captured, providing greater information for interpretation of the ecological niches in which they are found. The ecological role of spiders stands out as determinants in control of the food chain and, therefore, for overall assessment of species, it is necessary that all niches of the ecosystem, whether terrestrial or arboreal, be sampled using both sampling methods (manual capture and soil traps) (Figures 2e and 2f).

This combined sampling condition may not address the basic assumptions of quantitative or qualitative methods, such as the impossibility of extrapolating the number of individuals per square meter collected by the soil trap method, as results coming from the manual collection method are usually expressed. When uniting the two sampling methods, such extrapolation is not possible. A new conception of sampling directed toward the biodiversity of soil organisms is needed so as to increase the number of spider families collected, and thus increase knowledge about this taxon in the areas sampled, in such a way that the sampling methods complement each other.

It is necessary to reiterate that greater refinement in taxonomic information (greater number of species), correlated with soil physical and chemical properties, can improve the use of spider populations as sensible indicators to guide management practices. According to this, higher spider biodiversity can be related with land uses that increase some soil properties, such as organic matter, biopores, macroporosity, Ca^{2+}, and Mg^{2+}.

CONCLUSIONS

The native forest has greater diversity of spiders. In the areas of no-tillage annual crops, there is a drastic reduction of individuals in the sample, which indicates a negative effect of the intensity of land use on spider biodiversity.

Use and management of the soil condition specific families of spiders, revealing *Lycosidae* as more resistant to environmental impacts and others, such as *Oonopidae* and *Amaurobiidae*, as more sensitive.

Soil traps are more sensitive to spider families that inhabit the soil surface, whereas the manual collection method is more sensitive to soil-dwelling organisms (*edaphic sensu stricto*).

The eucalyptus reforestation, pasture, and no-tillage annual crop areas showed low abundance of spider families, selecting only families less demanding in terms of environmental resources, such as *Salticidade* and *Lycosidae*.

It is recommended that both sampling methods be used to capture the greatest diversity of spider families, making inventory and monitoring work more effective and comprehensive.

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