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RESEARCH ARTICLE

Increased grazing intensity in pastures reduces the abundance and richness of ground spiders in an integrated crop-livestock system

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Abstract

Ground spiders can reflect the impacts of land-use intensification. In an integrated annual crop-livestock system, the grazing intensification can negatively influence the abundance and richness of ground spiders. We evaluated the difference in abundance, family and species richness, and species composition of ground spiders in the soybean and pasture environments, and the effect of grazing intensity on the spider community under a soybean-pasture rotation. We hypothesized that pastures would have higher spider species richness and a distinct species composition and that the increase in grazing intensity would reduce spider abundance and species richness. We conducted an experiment in an integrated annual crop-livestock system under a soybean-pasture rotation in southern Brazil that was managed for 14 years by alternating *Glycine max* for summer grain production and *Avena strigosa* + *Lolium multiflorum* for beef cattle grazing during the winter. We sampled four times over 2 years: twice after the grazing cycles and twice after the soybean harvests. Grazing intensification was measured as grazing heights of 10, 20, 30, and 40 cm. Pitfall traps were installed to capture ground spiders. A total of 2589 spiders were collected and classified into 23 families and 43 species. The abundance of spiders was seven times higher, and species richness was 35% higher in the postgrazing compared with the postsoybean environment. Linear mixed effects models showed that spider abundance and richness were strongly influenced by grazing height, particularly postgrazing, but the influence of grazing height on male spider abundance could still be detected in the postsoybean environment. We have shown for the first time that the management of grazing height affects the abundance and richness of spiders in an integrated annual crop-livestock system. To introduce a grazing cycle to a completely crop-centric production system and regulating grazing intensity can help maintain a more diverse spider community.

Keywords Araneae · Bioindicator · Soil fauna · Soybean · Pasture · Sustainable intensification

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Contents

1 Introduction

Land-use intensification is one option to meet the growing demand for food production without converting native ecosystems to agricultural areas, providing that the intensification avoids soil and environmental degradation through sustainability. Thus, it is necessary to combine agricultural practices with the conservation of biodiversity and ecological function in agricultural landscapes (Rockström et al. 2017). Integrated crop-livestock systems (ICLS) are one alternative for sustainable intensification as they synergistically exploit agricultural and livestock resources in combination with conservation-focused land use and management practices. Combining agricultural crops and pastures (Fig. 1) allows these components to be developed collaboratively and enables more efficient use of agricultural inputs, land and natural resources (Herrero et al. 2010; Kunrath et al. 2015).

In the Brazilian subtropics, the majority of agricultural areas are used for either soybean or corn production in the summer, and in the winter, they remain fallow or are planted with cover crops (i.e., black oats and ryegrass). These large areas could make the production system more economically stable by including pasture with the agricultural crops in an integrated crop-livestock system. With regard to the social and economic effects, including a pasture rotation in an integrated system allows greater efficiency in the operation of property machinery and human resources, a higher income per unit area through the diversification by livestock production and a reduction in agricultural risks and production costs (Moraes et al. 2014). However, the effects of the animal component on the environment are a substantial challenge in implementing this production model. Sustainable intensification, if not managed properly in an integrated crop-livestock system, can lead to decreased soil quality, which is important for grain productivity. Therefore, it is important to establish the animal density that can be used in these systems without compromising the soil and environmental quality.

Fig. 1 An overview of the integrated crop-livestock system conducted over 14 years with pasture-soybean succession. Livestock may represent a different income opportunity to farmers who use *Avena strigosa* and *Lolium multiflorum* as cover crops

In particular, intensive grazing harms soil invertebrates, which provide important ecosystem services such as regulation of nutrient availability, carbon sequestration (Bender et al. 2016), pest and disease control (Marín et al. 2016), and biopore formation. The loss of soil invertebrates occurs because overgrazing reduces soil cover, leads to soil compaction, changes soil temperature and humidity regimes, reduces water infiltration, and increases erosion (Eldridge et al. 2017). However, these effects may not be immediate, and the impacts of overgrazing are more easily detected in certain soil groups that respond rapidly to management practices and are highly sensitive to environmental disturbances. Ground spiders can reflect changes in land use and agricultural practices (Prieto-Benítez and Méndez 2011) as well as changes in the composition, abundance, and richness of other groups of soil organisms (Dennis et al. 2015). Spiders play an important role in natural biological control (Pekár et al. 2015), and they are sensitive to tillage (Haddad et al. 2011), seeding, harvesting, pesticide application (Rodrigues et al. 2013), grazing practices (Bucher et al. 2016), and plant cover removal (Bell et al. 2001) as well as to changes near the cropping areas.

Among other factors, vegetation has been reported to be a major influence on spider communities. The composition (plant species richness) and structure of vegetation (height of the plants) can reflect the diversity of potential invertebrate prey and habitat for spiders (Gallé et al. 2011). Therefore, low stocking densities of cattle in pasture environments offer more favorable conditions for the presence of spiders. Under low grazing intensity, the higher density, greater height and diversity, and more complicated architecture of plants provide a complex vegetation structure that benefits weaver spiders (Bell et al. 2001) by providing diverse materials and spaces in the litter for the construction of webs, and thus increases spider abundance and diversity (Dennis et al. 2015; Bucher et al. 2016). In an integrated crop-livestock system, the intensification of grazing can alter microhabitats and increase the fragmentation and dispersion of the litter, which reduces the diversity of araneofauna and selects for species associated with uncovered soil. In addition, agricultural regimes can alter spider populations through the availability of shelter and food.

We investigated how the difference between the soybean and pasture environments and variation in grazing intensity impacts the composition of spider communities in an integrated crop-livestock system. Specifically, the aims of the current study were to evaluate (1) the difference in abundance, family and species richness, and species composition of ground spiders in the soybean and pasture environments and (2) the effect of grazing intensity on the spider community under a soybean-pasture rotation. We hypothesized that pastures would have higher spider species richness and a distinct species composition and that the increase in grazing intensity would reduce spider abundance and species richness.

2 Materials and methods

2.1 Experimental site

This study was conducted in an integrated crop-livestock system located at Espinilho Farm in the São Miguel das Missões district, Rio Grande do Sul State (RS), Brazil (28°56′14.00″ S, 54°20′50.61″ W, 417 m) (Fig. 2a). This area is in the Cfa (humid subtropical) climatic zone according to the Koppen-Geiger classification system. The topography is slightly undulating, and the soil is classified as Rhodic Hapludox (Oxisol). The area consisted of natural pastures until 1993, when it was converted to a cultivated no-tillage soybean (*Glycine max* L.) cropping area for grain production alternating with black oat (*Avena strigosa* Schreb.) for seed production. In 2001, an ICLS was established under a soybean-pasture rotation. During the summer (November through April), soybean is cultivated for grain production; after the soybean harvest, the pasture is established by the sowing of black oat and the natural reseeding of Italian ryegrass (*Lolium multiflorum* Lam.) for continuous beef cattle grazing (May through October) (Kunrath et al. 2014).

2.2 Experimental design

To test whether the land use environment (soybean or pasture) and grazing intensity have an effect on ground spiders, we conducted a field experiment where we controlled grazing intensity by regulating the number of steers. The total experimental area comprised approximately 23 ha divided into 14 paddocks. Each paddock contained one of five treatments: four grazing heights (10, 20, 30, or 40 cm) distributed in randomized blocks with three replications (12 paddocks) and a no grazing control included among the treated blocks (2 paddocks). The size of the paddocks ranged from 0.8 (no grazing) to 3.6 ha (grazing) depending on the treatment applied, which is directly influenced by the stocking rate of the animals (Fig. 2b). During the stocking period, the pasture was exposed to continuous grazing with three tester steers per paddock. The grazing height was periodically monitored based on the measurement of 100 random points in each paddock using a graduated sward stick. Adjustments in the grazing heights were performed by adding animals as needed to maintain the pre-established grazing heights.

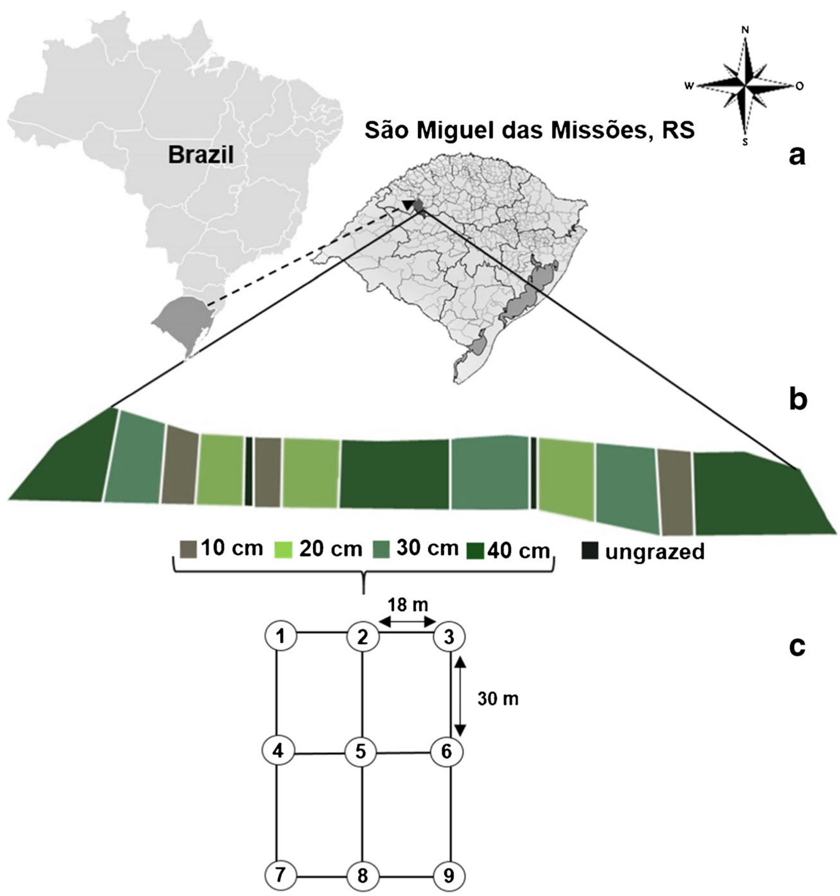


Fig. 2 **a** Geographic location of the integrated crop-livestock system in São Miguel das Missões, Rio Grande do Sul (RS), Brazil. **b** The experiment contained five treatments: four grazing heights (10, 20, 30, and 40 cm) distributed in randomized blocks with three replications (12 paddocks) with an ungrazed (control) included among the treated blocks (2 paddocks). Paddocks had different sizes, based on the grazing treatment applied as following (left to right): 2.19 ha, 1.60 ha, 0.90 ha, 1.32 ha, 0.10 ha, 0.86 ha, 1.31 ha, 2.87 ha, 2.10 ha, 0.10 ha, 1.49 ha, 1.89 ha, 1.07 ha, and 3.53 ha. **c** Sampling design and placement of traps in the center of the grazed paddocks

Sampling was conducted during four subsequent periods: two samplings during the "postgrazing" period at the end of the pasture cycle and immediately after the cattle were removed (from November 05–11, 2014 to November 1–7, 2015) and two samplings during the "postsoybean" period, immediately after the soybean harvest (from April 29–May 06, 2015 to May 06–13, 2016). In total, we collected spiders from 432 traps (4 grazing treatments × 3 blocks × 4 sampling periods × 9 traps). Data from the 9 traps were combined for the analyses (see below), representing 48 sampling units.

2.3 Ground spider sampling

A nine-point sampling design was established at the center of each grazing paddock during each sampling period. In each paddock, three 60 m transects spaced 18 m apart with three traps per transect were established (Fig. 2c). The spiders were sampled using pitfall traps, each of which consisted of a plastic container that was 10 cm in diameter and 20 cm deep and contained 500 mL of 80% ethanol. The traps were inserted into the ground so that the upper margin of the trap was aligned with the soil surface. In each collection event, the traps were placed in the same sampling locations according to geographic coordinates obtained with a real-time kinematic (RTK) GPS (1-cm accuracy) and remained in the field for 7 days. This study was conducted under the research permit number 4345–6 (SISBIO) issued by the Brazilian Ministry of the Environment.

In the laboratory, the collected spiders were preserved in an 80% ethanol solution, and all specimens were identified to the family level (adults were identified to the species level) using data from the literature. Species from the families Linyphiidae, Theridiidae, and Araneidae were identified at the Arachnida Diversity and Systematics Laboratory at Vale do Rio dos Sinos University (Universidade do Vale do Rio dos Sinos, UNISINOS), Brazil, and the other species were identified at the Arachnology Laboratory at Pontifical Catholic University of Rio Grande do Sul (Pontifícia Universidade Católica do Rio Grande do Sul, PUCRS). All specimens were deposited in the arachnology collection of the Natural Sciences Museum at PUCRS.

2.4 Data analysis

Because the environment and grazing height can affect reproduction (the number of juveniles produced) and survival (the number of juveniles that survive to become adults) of spiders (Mineo et al. 2010; Zmudzki and Laskowski 2012), we analyzed juvenile and adult (male and female) spiders separately.

The sampling sufficiency was assessed using a species accumulation curve based on the number of species found in each plot during the four collection events, totaling 48 sites. Species richness was estimated using the Chao 1 estimator, which is adequate for comparing samples with different sizes that may contain rare species.

For the statistical analyses, we quantified the average abundance of all pitfalls in a sampling unit by dividing the total number of individuals sampled in a paddock by the number of pitfalls used ($n = 9$). Both family and species richness increased nonlinearly with sampling effort. Therefore, we rarefied the community data to calculate the average family and species richness per pitfall in each sampling unit.

The composition of the ground spider community was evaluated by the turnover of species and families associated with differences in the environment and grazing height. We calculated the Bray-Curtis dissimilarity between all pairs of sampling units ($(48 \times 47)/2 = 1128$ unique pairs) separately for species and families. The association of the pairwise dissimilarities representing species and family composition for environment and grazing height was tested using a multivariate analysis of variance (adonis test). The composition analyses were conducted using the vegan R package (Oksanen et al. 2019).

The effects of environment (soybean vs. pasture) and grazing height on the abundance of juveniles, adult male and female spiders, total spider abundance, and on species and family richness were tested using linear mixed effects models (LMEs) fit by a maximum likelihood estimate. We used the lmerTest R package (Kuznetsova et al. 2017) for the model estimation, taking into account the sampling period (year) and block (spatial repetitions). The period and block were included as random effects on the intercept, and environment (postgrazing and postsoybean) and grazing height were included as fixed effects. The LME models were modeled with a Gaussian distribution because average abundance and rarefied richness are nonintegers. The coefficient of determination (R^2) was partitioned into the variance explained by the fixed factors (marginal R^2, R^2m) and the variance explained by the entire model, including both fixed and random effects (conditional R^2, R^2c). The coefficient of determination was calculated based on the likelihood-ratio test, using the r.squaredLR function of the MuMIn R package (Bartón 2019). All analyses were conducted using the R software version 3.6.0 (R Core Team 2018).

3 Results and discussion

3.1 Composition of the ground spider community associated with the integrated crop-livestock system

The results presented here consistently support the hypothesis that in the integrated crop-livestock system, the composition of the spider community in the pasture differs from the composition documented after the soybean harvest. There were significant changes in the composition of species and families colonizing the soils of the two cultivation areas. The abundance of individuals was seven times higher, and the species richness was 33% higher in pastures than in soybean.

Over the four samplings, a total of 2589 spiders were collected, of which, 1240 were juveniles and 1349 were adults (839 males and 510 females). The highest spider abundances were found in the postgrazing sampling events with 963 spiders in 2014 (51.8% juveniles, 31.4% adult males, and 16.8% adult females) and 1306 in 2015 (43.9% juveniles, 36.7% adult males, and 19.4% adult females). In the postsoybean harvest sampling events, only 133 spiders were collected in 2015 (46.6% juveniles, 23.3% adult males, and 30.1% adult females), and 187 spiders were collected in 2016 (56.7% juveniles, 14.4% adult males, and 28.9% adult females).

The spiders were classified into 23 families and 43 species (Fig. 3). The Linyphiidae were the predominant family, representing 63.5% of the total spider abundance in the integrated crop-livestock system followed by the Lycosidae (13.1%) and the Theridiidae (9.0%). The Linyphiidae were most abundant in the postgrazing samples (61.9% of the individuals in 2015 and 77.4% of the individuals in 2016) followed by the Lycosidae, Theridiidae, and Tetragnathidae. In the postsoybean harvest samples, the Theridiidae (34.6%) and Lycosidae (24.8%) predominated in 2015, and the Amphinectidae (34.7%) and Theridiidae (24.6%) predominated in 2016. The family composition differed between the postsoybean and postgrazing periods (adonis $p = 0.001$; $R^2 = 0.48$). Analysis of the distribution patterns showed a strong association of Tetragnathidae with pastures and Gnaphosidae with postsoybean fields. The Linyphiidae, Lycosidae, Theridiidae, and Amphinectidae were persistent in the soybean-pasture succession system, being collected in both environments (Fig. 3a). These results partly corroborate inventories of spiders in Brazilian pastures from the Pampas biome, in which Lycosidae, Hahniidae, Linyphiidae, and Theridiidae were the most abundant families found in grazed areas, whereas Tetragnathidae was exclusively found in ungrazed areas (Silva and Ott 2017).

A total of 33 species were found in the postgrazing samplings, whereas 22 spider species were collected in the postsoybean harvest samplings (Fig. 3b). The species

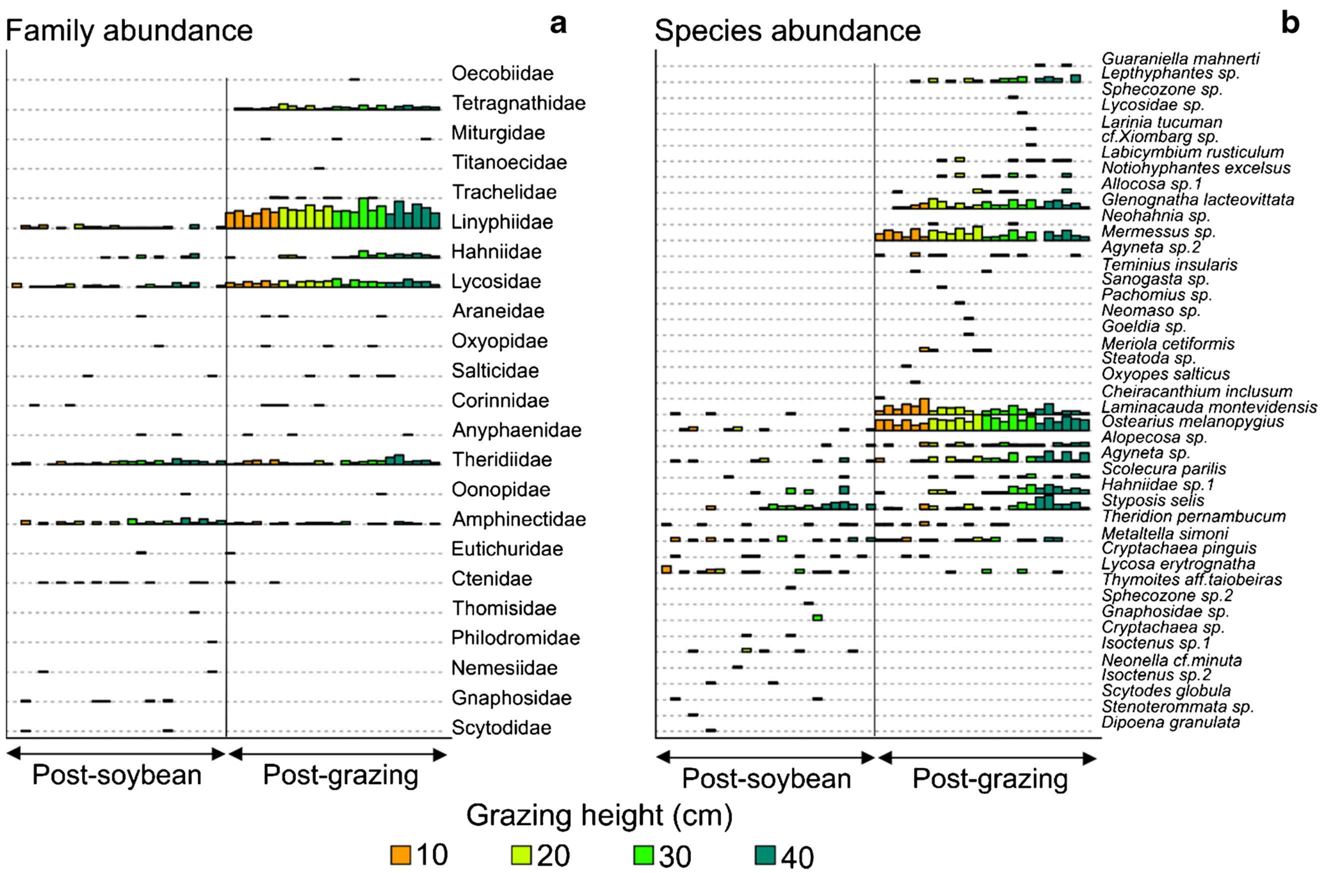


Fig. 3 Abundance of ground spider families (**a**) and species (**b**) collected in an integrated crop-livestock system after soybean harvest (postsoybean) and after cattle grazing (postgrazing) in paddocks with grazing heights of 10, 20, 30, and 40 cm. Each column in the graphs represents a sampling unit, and each row represents a family (**a**) or species (**b**). Although most spider families were observed in all treatments, some families (e.g., Linyphiidae) were much more abundant in the pasture (**a**). Several species were only observed in the pasture, and other species were exclusive to the soybean, (**b**) resulting in a strong change in species composition associated with the environment

accumulation curve did not reach an asymptote (data not shown), indicating that part of the diversity of the ground spider community was not inventoried. Based on the Chao 1 richness estimator, a total of 66 species were predicted, so 65.2% of the estimated total species were sampled. The low richness of spider species sampled may reflect the limitation of the method and traps used, which focus on soil-associated spiders and capture the most active spiders during the sampling period. Although we captured spiders with web behavior and used high intensity sampling, the low spider richness may also be related to the different vegetation strata and microhabitats in the pasture compared with the homogeneous environment in the postsoybean paddocks that may restrict the occurrence of many species (Höfer and Brescovit 2001). Species composition differed between the soybean and pasture environments (adonis $p = 0.001$; $R^2 = 0.31$). The species *Styposis selis*, *Lycosa erytrognatha*, *Metaltella simoni*, and *Hahniidae* sp.1 were most frequent in the postsoybean environment, and *Ostearius melanopygius*, *Mermessus* sp., *Laminacauda montevidensis*, and *Glenognatha lacteovittata* were associated with the postgrazing environment.

Changes in the composition of the spider community can be explained by the farming practices conducted in the integrated crop-livestock system. This agricultural system consists of a long and continuous soybean and pasture rotation (14 years) with environments of considerable homogeneity. In the postsoybean samplings, there were only crop residues and ryegrass seedlings in the initial stage of establishing, that may contributed to the low spider richness and abundance. Conversely, the postgrazing environment consisted of plants that ranged in biomass from 1.35 to 4.45 Mg ha^{-1} of shoot dry matter, with increasing biomass associated with the reduction in grazing intensity. Furthermore, during a soybean cycle, there are at least eight pesticide applications, which represent a considerable quantity of chemicals that are harmful to invertebrate fauna (Řezáč et al. 2010; Prieto-Benítez and Méndez 2011). Soybean harvesting also affects the spider community due to machinery traffic and particularly due to changes in vegetation structure (Kerzicnik et al. 2013). There is no pesticide application or machinery traffic during the grazing cycle, but intensified grazing can affect the arthropod communities through environmental disturbance, changes in plant diversity and vegetation structure, and a reduction in total resource abundance. However, the pasture environment in our study provided abundant plant resources when compared with the soybean environment. The density and height of the plants were higher and the continuous presence of cattle on the pasture contributed to the deposition of dung on the soil surface. Under such conditions, various soil meso- and macrofauna such as earthworms, beetles, diplopods, and mites are found and consequently attract predators such as spiders (personal observations made at the experimental site). It is possible that the presence of cattle dung led to an increase in the quantity and diversity of prey, which led to changes in the composition of the spider community.

In addition, the continuous trampling by the animals creates an uneven surface within the pasture, producing plant layers of varying heights that increase environmental complexity and favor the ground spider community (Schmidt et al. 2005; Dennis et al. 2015). Variation in vegetation architecture between the environments may explain differences in spider community composition (Gómez et al. 2016). In the pasture environment, the plant density was approximately 3,000,000 plants per ha (compared with ~ 300,000 in the soybean environment), and the linear leaves, the high number of tillers, and the architecture of the grasses may facilitate the construction of webs at the soil-plant interface and provide shelter to spiders (Podgaiski et al. 2013; Gómez et al. 2016). These environmental differences between the pasture and soybean environments caused certain species and families to occur in only one of the cropping areas or to show large population variation between the areas. Consequently, the strategies employed by the spiders to obtain resources also differed between the pasture and soybean environments. *Glenognatha lacteovitatta*, for example, occurred only within the pasture cycle at a grazing height above 20 cm. At these grazing intensities, this species found a more stable leaf arrangement to build its orb web (Podgaiski et al. 2013). After the soybean harvest, space web weavers predominated as indicated by the abundance of Theridiidae, as also reported by Liljesthröm et al. (2002). This family has a sedentary habit and can associate with lower vegetation strata by building their webs close to the ground in soybean crop litter. However, we found the theridid *Styposis selis* in both postsoybean and postgrazing environments, mainly associated with lower grazing intensity (40 cm).

Some species were recurrent throughout the soybean-pasture succession system (Fig. 3b), suggesting that these species can persist in environments with a high degree of human interference. The Linyphiidae spiders, particularly those in the subfamily Erigoninae, which exhibited higher abundance and species richness in the integrated crop-livestock system, are often associated with disturbed environments (Clark et al. 2004). This family is abundant in inventories associated with pasture (Clark et al. 2004), corn cropping areas (Royauté and Buddle 2012), coffee plantations (Marín et al. 2016), and *Pinus* plantations (Podgaiski and Rodrigues 2017). The most abundant species observed in this integrated crop-livestock system was *Ostearius melanopigius*, an agrobiont and cosmopolitan species typical of disturbed habitats (Szinetár and Samu 2012).

We documented a significant effect of environment on the composition of spiders in the integrated crop-livestock system; however, considerable variation remained unexplained both for family (52%) and species richness (69%). Seasonal variation in abiotic conditions (Aisen et al. 2017) and

Table 1 Summary of the generalized linear mixed effects models (LMEs) testing for the effect of grazing height and environment (pasture vs. soybean) on the abundance and species richness of ground spiders. R^2m: Variance of response variables explained by grazing and the environment (fixed effects; marginal). R^2c: Total variance of response variables explained by grazing and the environment (fixed effects) and by year and blocks (random effects). Model: y ~ grazing height + environment (postgrazing, postsoybean) + (1|sampling period (year) + (1|block)

Response variable	Fixed effects			Random effects		Df	R^2	
	Intercept	Grazing height	Environment	Year	Blocks		R^2m	R^2c
Abundance	8.335**	0.105***	−9.431*	1.691	0.402	48	0.76	0.86
Juvenile	3.993***	0.047**	−4.372*	0.336	0.247	48	0.78	0.81
Male	2.839*	0.037**	−3.494^{ns}	0.851	< 0.001	48	0.67	0.81
Female	1.502*	0.020**	−1.565^{ns}	0.457	0.0978	48	0.58	0.76
Family richness	1.040***	0.010***	−0.964**	0.005	< 0.001	48	0.85	0.86
Species richness	0.658***	0.006**	−0.652*	0.077	< 0.001	48	0.80	0.84

p value (* < 0.05, ** < 0.01, and *** < 0.001)

environmental characteristics such as vegetation structure and prey availability (Dennis et al. 2015; Michalko et al. 2019) may influence spider abundance and richness. During the sampling periods, we recorded an average of 24.9 °C, 14.8 °C, and 19.8 °C for maximum, minimum, and average temperature, respectively, and 15.6 mm average rainfall during the postgrazing periods; during the postsoybean periods, the averages for the weather variables from the two samplings were 20.0 °C, 11.3 °C, and 15.7 °C for maximum, minimum, and average temperature, respectively, and 7.2 mm average rainfall. These variables exhibited little variation due to the mild weather conditions during the samplings, which were performed in the spring (postgrazing) and autumn (postsoybean) seasons. Despite this lack of variation in temperature and rainfall, other random variables not measured may have affected the composition of the ground spider community.

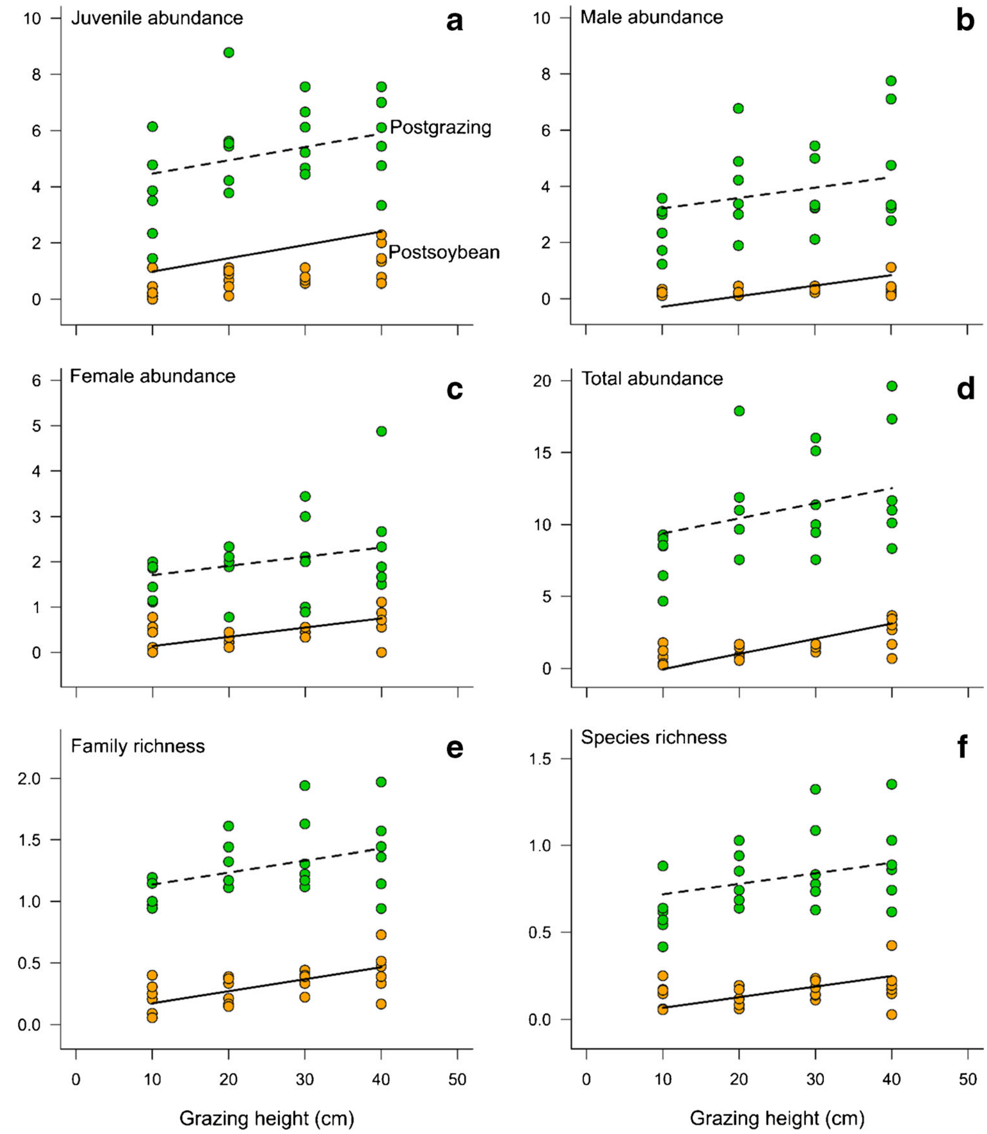
3.2 Effect of grazing height on the composition of the ground spider community

The results of the generalized linear mixed effects models supported our second hypothesis that the ground spider community is strongly influenced by grazing intensity (Table 1). There was a positive and significant relationship between ground spider abundance, species richness and family richness, and grazing height (reflecting decreasing grazing intensity). The models explained 86%, 81%, 81%, and 76% (R^2c) of the variation in the abundance of juveniles, males, females, and all individuals, respectively (Fig. 4a, b, c, and d). Environment did not have a significant effect on male and female spider abundance. Family (Fig. 4e) and species richness (Fig. 4f) showed a positive and highly significant relationship with grazing height, with 86% and 84% (R^2c) of the variation, respectively, explained by the model.

In the postgrazing sampling, grazing created a vegetation structure with an environmental gradient of well-defined variation in pasture height. After the soybean harvest, the environment was more homogeneous, but the plant residues added to the soil by the winter pasture also positively influenced the variation in spider abundance and richness as a function of pasture height. This pattern has also been observed in other studies, demonstrating that increased grazing intensity reduced spider abundance (Dennis et al. 2015) and species richness (Horváth et al. 2009). Higher grazing heights provide more complex vegetation structures, which foster greater abundance and species and family richness (Schmidt et al. 2005). This environmental complexity favors the presence of spiders that benefit from the formation of microhabitats (Bell et al. 2001) and from higher prey availability (Dennis et al. 2015), which create better conditions for habitat exploitation and an increased number of spiders (Marín et al. 2016). According to Bucher et al. (2016), cattle grazing at low stocking rates promotes spider diversity through vegetation heterogeneity, and this type of pasture management can contribute to biodiversity conservation and improve prey availability for other predators.

Our results showed that there was a greater abundance of males than females in both environments, indicating greater male activity. This activity may be related to the wandering behavior of males in search of more sessile female spiders, increasing the likelihood of males being caught in the interception traps (Mineo et al. 2010; Bizuet-Flores et al. 2015). The higher abundance of juveniles observed after both the grazing and soybean cycles suggests a constant recolonization of the environment. Spiders can colonize environments through active movement on the ground or long-distance migration through passive aerial dispersion (ballooning) (Bell et al. 2001). These means of dispersion can facilitate the rapid recovery of the spider community after a major disturbance

Fig. 4 Effect of grazing height (10, 20, 30, and 40 cm) on the abundance (number) of juveniles (**a**), males (**b**), females (**c**), total ground spiders (**d**), and family richness (**e**) and species richness (**f**). Each point corresponds to a sample unit (paddock) management targets for continuously stocked mixed oat × annual ryegrass pasture in a no-till integrated crop-livestock system and represents the average abundance (male, female, juvenile, or total abundance) or the rarefied richness (family or species). Different colors indicate the postgrazing environment (green) and the postsoybean environment (orange). Predictions were based on linear mixed effects models (LMEs) that include random effects (sampling period, 2 years postsoybean and 2 years in postgrazing) and blocks (spatial replications). Abundance and richness were higher in postgrazing (pasture) compared with postsoybean environments, and grazing intensity (lower pasture height) negatively affected the abundance and richness of ground spiders, mainly in the postgrazing environment



(Szinetár and Samu 2012). The process of colonization can be constant and mediated by dispersers that remain at the site due to food availability. One strategy to enhance spider recolonization is to maintain the landscape surrounding agricultural areas as a refuge. At the experimental site where the samplings were conducted, there is an area of natural vegetation adjacent to all the paddocks, which the spiders may have used as a refuge, thus playing an important role in agroecosystem services.

4 Conclusions

This study contributes information supporting a more comprehensive use of the agroecosystem with the aim of reconciling agricultural production and sustainability. The significant reduction in the abundance and richness of spiders in collections following the soybean cycles compared with those following the pasture cycles suggests that the spider fauna is impacted by soybean cultivation. The introduction of a pasture cycle into a purely agricultural production system leads to several modifications that are beneficial to the fauna such as the increased input of plant and animal residues into the soil and reduced pesticide application and machinery traffic, that allow the spider community to be more abundant and more diverse. Increasing the abundance and diversity of ground spiders results in greater environmental balance, the promotion of ecosystem services (pest population control), and a reduced need to use pesticides, which contribute to increased agricultural sustainability. However, pasture management should prioritize reducing the stocking density to maintain a more diverse soil fauna community because grazing intensification is associated with a reduction in the abundance and richness of spider families and species.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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