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SPIDER DIVERSITY IN COFFEE PLANTATIONS WITH DIFFERENT MANAGEMENT IN SOUTHEAST MEXICO

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ABSTRACT. We tested the hypothesis that coffee systems with organic management have higher spider diversity by comparing a control (rainforest area) and two coffee systems, one with organic and the other with conventional management. Spiders were sampled every two weeks over three months during the dry season and three months during the rainy season in 2000. Spider alpha diversity was analyzed using Shannon and Simpson indices. We also used the Cody index for beta diversity and cluster analysis for analyzing changes in species abundance hierarchies. 2261 individuals were collected (including juveniles and adults) representing 20 families, 56 genera and 97 species. In most cases the alpha diversity indices showed no relation between management gradient and spider diversity. When compared across seasons, spider diversity differed significantly only in organic management. Species turnover among the three sites (Cody index) was highest between the two coffee farms but not so clearly in the dry vs. rainy season; the conventional management shared the fewest species with the forest. Cluster analysis showed changes in abundance hierarchy related to management type. Our results did not support the proposed hypothesis of a direct positive correlation between management gradient and alpha spider diversity. In contrast, beta diversity showed that management and seasons influenced species composition.

Keywords: Araneae, agroecosystems, management gradient, species composition

Spiders are ubiquitous predators that are abundant and diverse in agricultural ecosystems. Spider assemblages have the ability to limit population growth of arthropod pests alone or in combination with other natural enemies (Mansour et al. 1980; Oraze & Grigarick 1989; Riechert & Bishop 1990; Carter & Rypstra 1995).

Different studies have shown that spiders' influence on prey populations depends on spider density or biomass. Therefore, relatively high spider abundance has been considered a requirement for pest control in agricultural systems (Greenstone 1999; Riechert 1999; Sunderland & Samu 2000), but the role of spider diversity in prey regulation is less understood.

A diverse assemblage of spiders may occupy a variety of biotopes in agroecosystems and, as a whole, are likely to be active throughout the day. Therefore, a diverse spider assemblage will leave fewer refuges for potential prey in time and space. Due to variation in spider size and/or prey capture strategies, spiders should be able to capture prey that vary in size and/or developmental stages (Sunderland 1999; Henaut et al. 2001). For example, Riechert et al. (1999) found that there seemed to be no single spider species that regulates pests or maintains temporal consistency, as well as a diverse assemblage of spider species.

The complexity of vegetation structure has been suggested to be an important habitat component that affects spider density and diversity in both natural ecosystems (Lowrie 1948; Barnes 1953; Barnes & Barnes 1955; Greenstone 1984) and agroecosystems (Hatley & MacMahon 1980; Alderweireldt 1994;

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Rypstra & Carter 1995; Downie et al. 1999). Vegetation structure could influence spiders through a variety of biotic and abiotic factors, namely structures for webs, temperature, humidity, level of shade cover, abundance and type of prey, refuges from natural enemies and intraguild predation (Wise 1993; Samu et al. 1999; Rypstra et al. 1999).

Coffee agroecosystems are particularly useful systems for exploring how vegetation structures affect spiders diversity and density. It has a diversified arthropod fauna (Ibarra 1990; Ibarra & García 1998) and a range of different management systems (Perfecto et al. 1996; Moguel & Toledo 1999). Coffee plantations commonly include shade trees normally used to regulate sun intensity on coffee shrubs, but the level of shade used is variable according to land management practices. Land management also affects arthropod density, since density and cover of shade trees, and agronomic inputs are important regulators of correlated microclimatic and structural variables, that in turn affect other biological factors (Perfecto et al. 1996). Shade tree density, height, and diversity vary along a management gradient from ‘‘rustic’’ (introduction of coffee shrubs in the undisturbed forest) to ‘‘unshaded monocultural’’ systems. Reduction or elimination of tree shade cover and/or introduction of agrochemicals could cause a variety of changes, e. g., increased soil and air temperatures, a lower soil water content, a decreasing abundance and diversity of soil microorganisms, and a decrease of soil fertility (Moguel & Toledo 1999). Furthermore, a greater diversity and abundance of shade trees and the lack of agrochemical inputs in coffee farms promotes the presence and preservation of a higher associated biodiversity than in conventional coffee systems (Perfecto & Snelling 1995; Perfecto et al. 1996; Greenberg et al. 1997).

On a conventional coffee farm in Mexico, Ibarra (1990) found that natural enemies (predators and parasites) accounted for 25% of total arthropod abundance and 41% of total arthropod species richness. This suggests that the abundance and diversity of natural enemy assemblages could make a significant contribution in regulating insect herbivores (spiders were found to be an important component of the natural enemy guild, comprising 25% of species richness and 56% of abundance for this guild excluding ants).

The aim of this study was to quantify the effects of coffee management upon spider diversity. We tested the hypothesis that coffee systems with organic management have higher spider diversity than coffee systems with conventional management by comparing systems along a management gradient from an uncultivated area (rainforest) to two coffee systems differing in management practices.

METHODS

Study areas.—We established three study sites as a shade gradient, from a small rainforest area to two coffee plantations with different types of vegetative structure and management. The two plantations, Irlanda (15° 10′ N, 92° 20′ W, elevation 830–900 m) and Hamburgo (15° 10′ N, 92° 19′ W, elevation 900–990 m) are located 65 km and 60 km, respectively, to the NNW of Tapachula, Chiapas, Mexico. The two coffee farms are contiguous and differ markedly in vegetative arrangement, shade intensity (diversity, height and density of shade trees) and agrochemical inputs. Hamburgo follows a modern conventional coffee system, with low shade tree density (15 shade trees per ha, interspersed with coffee shrubs) and a low diversity of shade trees (two *Inga* species and one *Miconia* species, with regulated height of 5–7 m). Coffee shrubs (about 3330 coffee shrubs per ha) are planted in straight lines (regardless of slope variations) and agrochemical inputs (synthetic insecticides, herbicides and fertilizers) are used twice at year (September and May). In contrast, Irlanda uses an organic technology with higher shade tree density (50 trees per ha, interspersed with coffee shrubs) and higher diversity of shade trees (four *Inga* species and several native trees, with height varying between 5 to 25 m), coffee shrubs (about 3060 coffee shrubs by ha) are planted along contours, and without use of agrochemical inputs (Ibarra et al. 1995). Several areas inside Irlanda have never been cultivated; one of these, ‘‘Reserva la Montañita,’’ has rainforest vegetation and high tree density (about 55 trees per ha) and was used as control site.

Spider sampling.—We sampled every two weeks for three months in the dry season (February–April 2000) and again for three months in the rainy season (June–August

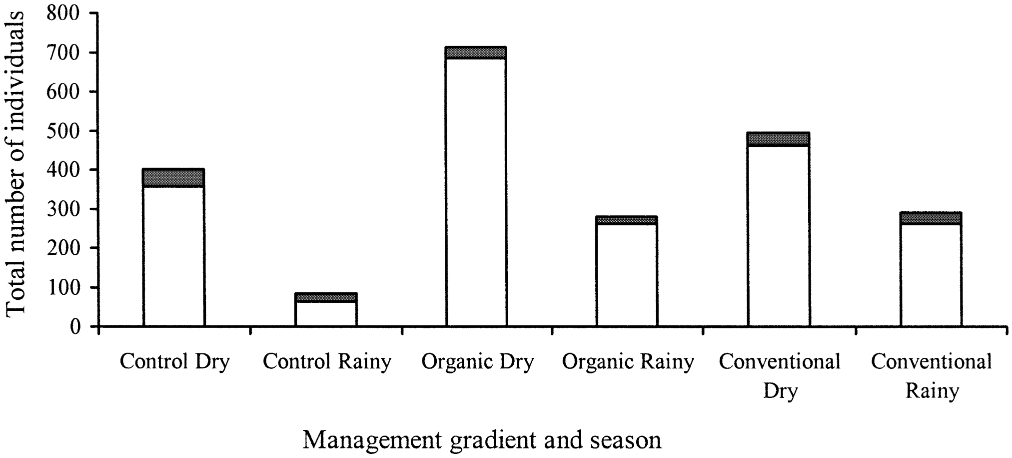

Figure 1.—Number of spider specimens collected from different management sites and seasons. White bars represent web-builder spider guild. Diagonal bars represent hunter spider guild.

2000) for a total of six samples in each site during each season. At each site, two collectors (MAPR and JAGB) searched for spiders visually through the entire shrub (leaves, branches and trunks) and removed them by hand (Churchill & Arthur 1999). During sampling, eight coffee plants were chosen at random on each study site, (each collector sampling four plants). The plants were not contiguous shrubs and were separated from each other by a minimum of two coffee plants, and were sampled only once throughout the study to avoid negative sampling effects. Due to periodical pruning practices, the coffee shrubs are all about the same height and volume in each site. As the control site lacked coffee bushes, spiders were sampled from one species of native bush (a woody species of the genus *Piper*) similar to the coffee plants with respect to height, architecture and foliage structure. Care was made to use always the same type and size of *Piper* plants. The specimens were preserved in 80% ethanol and determined to the taxonomic level of species or undetermined species (when a species level determination was not possible). The specimens were deposited in the Arachnological Collection of El Colegio de la Frontera Sur located in Tapachula, Chiapas, Mexico. Undetermined species were compared with similar determined species located in the Arachnological Collection to reduce determination fails.

Analyses.—We analyzed species' alpha diversity using Shannon (H′) and Simpson (D) indices. These two indices were chosen because they reflect two different aspects of diversity: Shannon's index is more sensitive to rare species, and Simpson's index is sensitive to changes in the abundance the most common species (Magurran 1988). Calculations of these indices were made with totals of species and undetermined species, and functional groups (web builders and cursorial hunters) for each site and season. We used the Hutchinson t tests to detect significant differences in H′ values between sites and seasons. The Cody index was used to evaluate beta diversity (rate of species change) between sites (Magurran 1988). Cluster analyses were used to detect differences according to their relative abundance in the species composition for sites and seasons (McCune & Mefford 1997).

RESULTS

We collected 2261 individuals, including juveniles and adults: 992 from the organic management site, 485 from the control site and 784 from the conventional management site. The collected specimens represented 20 families, 56 genera and 98 species, including 54 species determined only to genus and 14 species determined only to family, because they were juveniles and consequently could not be determined to genus or species level. Nevertheless, they were carefully compared with the determined species in the ECOSUR collection, and with the other collected species

Table 1.—Spider species diversity indices by management site and spider grouping. Values are noted for dry season and rainy season.

	Species richness		Shannon index		Simpson index	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
Control all spiders	47	30	2.77	2.94	0.111	0.084
Organic all spiders	32	36	1.54	2.59	0.346	0.126
Conventional all spiders	51	45	2.87	2.75	0.103	0.152
Control web builders	37	24	2.54	2.78	0.134	0.101
Organic web builders	24	27	1.36	2.37	0.375	0.143
Conventional web builders	38	33	2.67	2.45	0.117	0.185
Control hunters	10	6	1.51	1.16	0.367	0.455
Organic hunters	8	9	1.75	2.04	0.208	0.149
Conventional hunters	13	12	2.19	2.18	0.153	0.156

in the corresponding family or genus, and could be recognized as distinct morphospecies. Abundance decreased in all sites from dry (1608) to rainy season (653) (Fig. 1)

Alpha diversity.—The conventional management site had the highest species richness in both seasons, for both web-building and hunting spider guilds. The sites with the lowest species richness (for all spiders and functional groups) were the organic management in the dry season and the control site for the rainy season (Table 1).

Dry season: Shannon Index: Overall, spider diversity was significantly higher in conventional management than in organic management (t = 16.3, df = 920, $P < 0.005$) and in the control (t = 14, df = 551, $P < 0.05$) (Table 1). For the functional groups, the web builders showed the same trend as the overall spider analysis, with significantly higher diversity in conventional management than in organic management (Table 1) (t = 17, df = 724, $P < 0.001$) and in the control (t = 13.8, df = 325 $P < 0.001$). For the hunting spiders, the highest diversity was recorded in conventional management and lowest in control, showing significant differences only between these two sites (t = 2.63, df = 103, $P < 0.025$). Simpson index: Total and web building spider dominance was highest in organic management and lowest in conventional management (Table 1). However, for hunting spiders, the control showed the highest dominance and conventional management the lowest.

Rainy season: Shannon Index: Spider diversity was significantly higher in control than in organic management for all spiders (t = 2.38 df = 53, $P < 0.05$) and web builders (t = 2.62, df = 20 $P < 0.01$) (Table 1). For the hunting spiders, diversity was higher in conventional management than in the control site (t = 3.21, df = 67.3 $P < 0.005$), and in the control site was lower than in the organic management site (t = 2.71, df = 18.5, $P < 0.025$). Simpson index: Total and web building spiders' dominance was highest in conventional management and lowest in control (Table 1), whereas the hunters showed the opposite trend, with control having the highest dominance and organic management the lowest.

Seasons contrast: Shannon Index: In comparing overall spider diversity for each site, only organic management differed significantly by season (t = 10.9, df = 1020, $P < 0.005$). Furthermore, only web building spiders in organic management differed significantly between seasons (t = 11.3, df = 967, $P < 0.005$).

Beta diversity.—Highest values for all spiders using the Cody diversity index were recorded in both seasons among conventional management and control. On the other hand, the lowest exchange of species was found in both seasons between organic management and conventional management, being the most similar in species composition (Table 2). Web builders shared the same pattern as all spiders in both seasons. In the dry season, hunting spiders were most similar between the control and organic management but in the rainy season were most similar between conventional management and organic management.

During the dry season, some species were found at only one site. *Spintharus flavidus*

Table 2.—Cody diversity indices for spider collected by management sites and spider grouping. Values are noted for dry season/rainy season.

	Total spiders	Web builders	Hunters
Control vs Organic	19.5/17.5	14.5/12.5	5/4.5
Control vs Conventional	22.5/19	15.5/13.5	7.5/5
Organic vs Conventional	18/12.5	11/9	7.5/3.5

Hentz 1850 (Theridiidae), *Exalbidion sexmaculatum* (Keyserling 1884) (Theridiidae) were exclusive to control plots; *Verrucosa arenata* (Walckener 1833) (Araneidae) and *Tama* sp. (Hersilidae) were found only in organic management; *Cheiracanthium* sp. (Miturgidae), *Dictyna* sp. (Dyctinidae) and *Verrucosa* sp. (Araneidae) were present only in conventional management during both seasons.

Cluster analysis.—Cluster analysis showed that during both seasons spiders four species group form: dominants, subdominants, commons and rare (less than two individuals). In the dry season *Leucauge* sp. was dominant in all sites, *L. argyra* (Walckenaer 1842) (Tetragnathidae) was subdominant in the control and dominant in the coffee plantations, and *Jalapyphantes* sp. (Linyphiidae) was dominant in the control, subdominant in organic management and common in conventional management (Fig. 2). In the rainy season, *Leucauge* sp. was common in the control site and dominant in the coffee plantations. *Leucage argyra* was dominant in the control site, subdominant in organic management and common in conventional management. *Wulfila* sp. (Anyphaenidae) was particularly dominant in the control site; *Jalapyphantes* sp. was common in the control plot, dominant in organic management and subdominant in conventional management. *Spermophora* sp. (Pholcidae) was subdominant in the control, dominant in organic management and rare in conventional management. *Theridion omiltemi* Levi 1959 (Theridiidae) was rare in the control site, dominant in organic management and subdominant in conventional management (Fig. 2).

DISCUSSION

Most studies regarding the role of shade tree density and diversity in coffee plantations have found a higher species diversity in more diverse coffee agroecosystems (Perfecto et al. 1996; Greenberg et al. 1997). Perfecto & Snelling (1995) found that species diversity of ground-foraging ants decreased with shade reduction whereas coffee-foliage-foraging ant diversity did not change along the same shade gradient.

In our study, there was no apparent trend between management and spider diversity. Most cases (11 out of 18), according to species richness, Shannon and Simpson indices, showed no relation between management and spider diversity. In only two cases did we find that spider diversity decreased with management intensification. Surprisingly, in five cases, we found an increase in spider diversity as land management increased. These results are contrary to what has previously been reported (Perfecto et al. 1996; Greenberg et al. 1997), and there are several possible explanations. An uncontrolled factor that could affect spider diversity was the presence and density of insectivorous birds, which are known to predate spiders intensely (Gunnarsson 1998). Some studies have found that shaded coffee plantations have higher bird species richness and abundance than poor shaded plantations (Perfecto et al. 1996; Moguel & Toledo 1999), this different predation level could affect spiders' abundance and composition, by selectively reducing numbers of those spiders species more exposed to bird predation. Another explanation is the possibility that relative diversity levels change between years, as we only made a one-year study, and therefore results should be interpreted with caution.

The organic management site had the lowest spider species richness and diversity, and the highest dominance in the dry season (according to all alpha indices used) with the exception of hunting spiders. In both seasons, web-building spiders were more abundant and had higher species richness than hunting spiders. Among the web-building spiders, *Leucauge argyra* and *Leucauge* sp. were found disproportionately abundant in all sites, but

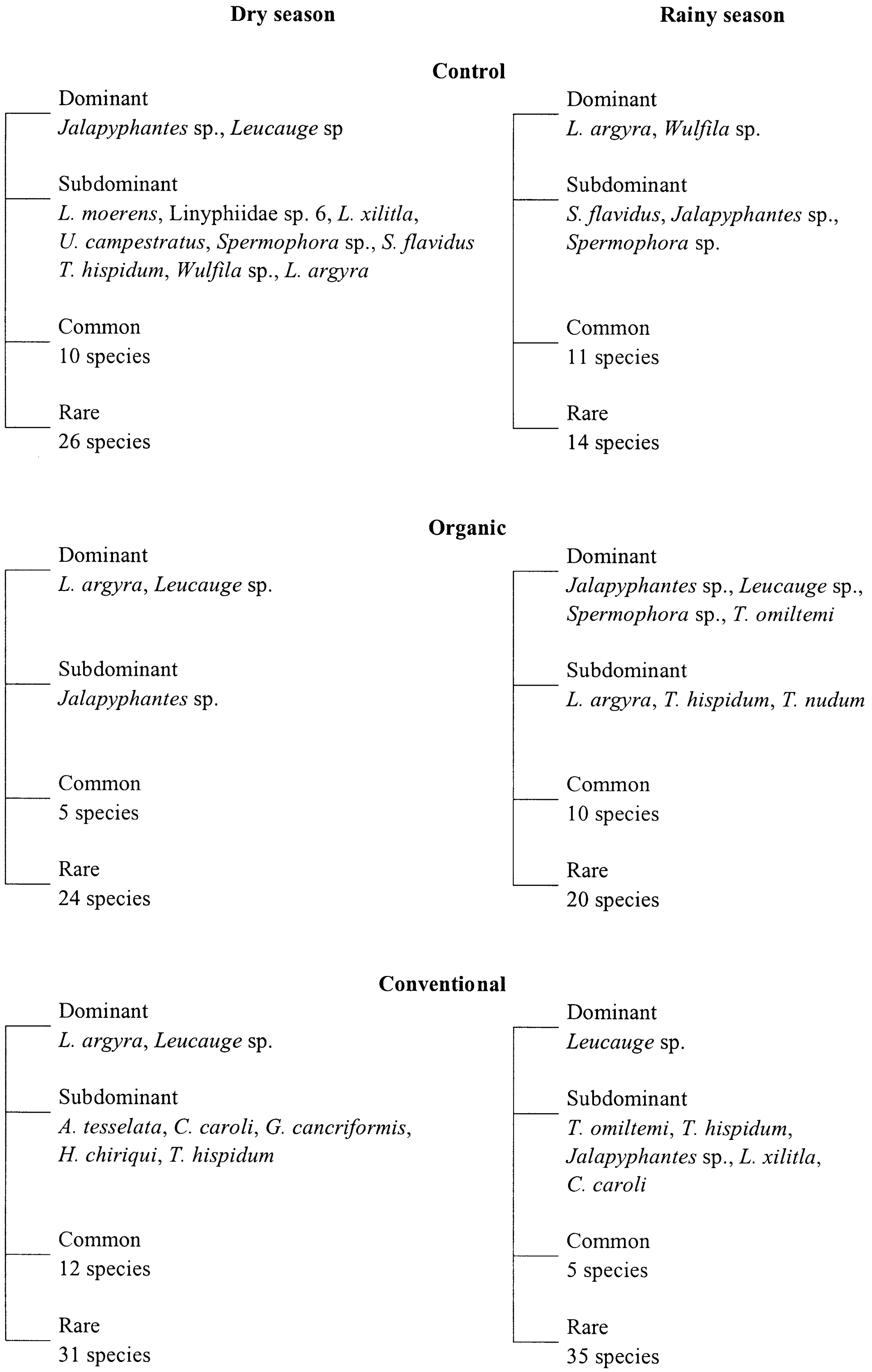

Figure 2.—Cluster analyses showing abundance species hierarchies for different management sites and seasons.

most notably in organic management. The extreme dominance of the *Leucauge* spp. in organic management was the cause for the high values estimated by Simpson index (which is more sensitive to dominant species). The Shannon index values are most affected by species richness and secondarily by evenness. The organic management with low species richness and extreme dominance (reduced evenness) therefore had low Shannon index values.

Several authors consider that dominant species tend to exploit resources more efficiently than non-dominant species (Agnew & Smith 1989; Mason et al. 1997). Extreme dominance of *Leucauge* spp. in organic management compared to control and conventional management in the dry season may be because the optimum, in shade and humidity conditions, for these species are those of the organic management (intermediate between the control and the conventional sites). *Leucauge mariana* has been reported as a very abundant species in disturbed habitats in Central America (Eberhard 1988; Eberhard & Huber 1998). For these reasons, these species could be more abundant in the coffee systems than in the control site, but the dominance of this species should be subject of a particular study.

Spider diversity under the organic management significantly increased in the rainy season due to an increase in species richness and a decrease in the dominant species abundance. In contrast, in conventional management and control, there were no significant differences between the seasons. Theoretically, when populations of competitive dominant species decrease or disappear, species diversity might increase (Putman 1994). In organic management, in the rainy season, *Leucauge* spp. were less common. This could explain why *Spermophora* sp. and *Theridion omiltemi* were more frequently encountered in the rainy season, and became dominant species.

As indicated by the beta diversity index, turnover of species between organic and conventional management in the dry season was similar to the corresponding value between organic and control site. However, in the rainy season, organic and conventional management shared more species than did organic management and control site. These results support the existence of a gradient in species composition, from control site to conventional management, with organic as intermediate, although in the rainy season the difference between organic and conventional management was reduced. This might be explained because in the rainy season the interference of clouds and rain with solar irradiation reduces the differences in temperature and humidity, making the coffee farms more similar in these variables.

Additionally, the exclusive presence of a spider species at one site may be related to the existence of a favorable microclimate and/or an adequate web support for these species. For example, *Spintharus flavidus* and *Epeirotypus brevipes* O. P.-Cambridge 1894 were found only in the control siteand not at other the sites. *Spintharus flavidus*, had been poorly studied taxonomically and is common under the leaves of bushes (Levi 1954), so it is possible that it could prefer the non disturbed control site, in opposition to the periodically perturbed coffee plantations. On the other hand, *E. brevipes* was found only on control habitat, and is known that the spiders of this family live almost exclusively in wet or humid, shaded forest habitats (Coddington 1986). Some species collected were singletons, as in the case of *Dolichognatha* sp. and *Tetragnatha* sp., and could reflect a demographic rarity (Halfter & Ezcurra 1992).

In the dry season, *Leucauge* sp. and *L. argyra* were among the dominant and subdominant species at all sites, showing that they were not affected by the management gradient. However, with a seasonal change from dry to rainy season, *L. argyra* became considerably less abundant in all sites and was dominant in control (17 individuals), subdominant in organic management (15) and common in conventional management (7).

Alpha diversity comparisons did not support our hypothesis that spider diversity decreases with decreasing shade. The extreme dominance of the *Leucauge* spp., and possibly the higher density of predatory birds, affected the results at this level. In contrast beta diversity results (analyzed by Cody index) and the cluster analyses, supported the existence of a gradient of species composition from control to conventional management, showing effects at structural community level, with changes of species hierarchy due to coffee management.

With the use of a *Piper* plant species as control, which probably has chemical components distinct to those of the coffee plant, arises the possibility of having different effects on the insect fauna associated with this plant, and hence indirectly on the spider fauna. Some species in the *Piper* genus have been reported to have compounds with deterrent or insecticide properties (e.g. Dyer et al. 2003; Siddiqui et al. 2003; Lale & Alaga 2001). But Marquis (1991) found that the number of insect herbivore species on the *Piper* plants found in La Selva, Costa Rica, varied greatly with plant species, some species can support a high diversity of insects (e. g. *P. arieianum* with 95 herbivore species). As we could not determine the species of the control plant, the differences in diversity between the control and the two coffee systems found in this work should be taken with caution.

These results reflect only the differences in spider community at the understory level (coffee bushes) for the year of study; but it will be interesting to analyze the whole agroecosystem, including arboreal, herbaceous and soil strata.

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