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Does the Silvopastoral System Alter Hymenopteran Fauna (Insecta: Hymenoptera) in *Brachiaria decumbens* Monocultures?

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ABSTRACT The aim of this study was to evaluate whether environmental changes promoted by the conversion from a *Brachiaria decumbens* monoculture to a silvopastoral system can be measured by the diversity, richness, abundance, and constancy of insects of the order Hymenoptera. A Malaise trap for collecting insects was installed in a *B. decumbens* area managed as a silvopastoral system, and another was installed in a monoculture system. Hymenoptera richness and abundance were determined based on the number of morphospecies and specimens, respectively. The diversity and constancy indices were calculated using the Shannon–Wiener and Bodenheimer methodologies. Fifteen families of Hymenoptera were collected, seven of which were unique to the monoculture system. The samples from the silvopastoral system were significantly more abundant (3,889) and rich (305) compared with those from the monoculture system, which were much less abundant (1,473) and rich (173). Similar trends were noted for the families Formicidae, Ichneumonidae, and Braconidae. Additionally, these families and Sphecidae showed significantly greater diversity in the silvopastoral system. Formicidae and Braconidae were constant in both systems, while Ichneumonidae was constant only in the silvopastoral system. The families Vespidae, Pompilidae, and Apidae were more diverse; Chalcididae, Pompilidae, Sphecidae, Halictidae, Evaniidae, and Gasteruptiidae were more abundant; and Vespidae had more richness in the monoculture system. The conversion from the monoculture system to the silvopastoral system can be measured by the occurrence of Hymenoptera, especially the families Formicidae, Ichneumonidae, and Braconidae, which can be used as potential bioindicators.

KEY WORDS Insecta, biological indicator, signal grass, diversity, Brazil

The pasture system in Brazil is mostly composed of *Brachiaria* spp. (Zimmer et al. 1994, Macedo 1995). The pastures formed with this forage remain productive for 2–3 yr and thereafter begin to show signs of degradation (Rodrigues and Rodrigues 1996). In order to gain increased efficiency of forage use, research is needed for the establishment of production systems. Accordingly, in the 1990s, the silvopastoral system was introduced in southern Brazil (Lustosa 2008).

The silvopastoral system consists of a combination of trees, pasture, and cattle in the same area. The conversion from the monoculture to silvopastoral system aims at the recovery of biological diversity and the maintenance of the integrity of various ecological processes that are vital in the areas used for livestock, resulting in environmental benefits, increased productivity, and financial returns for the farmers (Murgueitio et al. 2008). Moreover, these combinations of pastures and trees cause microclimatic changes that alter insect diversity due to the creation of various niches (Stern et al. 1976).

A better understanding of the process of change from a monoculture to a silvopastoral system is possible based on population surveys of insects. Insects are considered good indicators of the levels of environmental impact, due to their great diversity of species and habitats, and their importance in biological processes of natural ecosystems. They are also excellent organisms for evaluating the impact of formation of forest fragments, as these insects are highly influenced by habitat heterogeneity (Thomanzini and Thomanzini 2000).

Studies on the silvopastoral environment have been reported by Sofia and Suzuki (2004), Souza et al. (2005), Auad et al. (2010, 2011, 2012), Giraldo et al. (2011), and García-Tejero et al. (2013). However, a comparison of the entomofauna in silvopastoral and monoculture systems of *Brachiaria decumbens* in Brazil has not yet been reported. These studies are important in measuring the modifications promoted by the silvopastoral system through changes in diversity, abundance, and constancy of insects.

The order Hymenoptera comprises one of the most diverse groups of arthropods, and insects of this order are known to be sensitive to habitat fragmentation and environmental changes (Fraser et al 2008, Maeto et al 2009). In general, changing the abundance, diversity, and composition of a group of biological indicators can

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be used to measure changes in the environment (Brown 1997).

The objective of this study was to assess whether the environmental changes brought about by the conversion from a monoculture system of *B. decumbens* to a silvopastoral system can be measured by diversity, abundance, richness, and constancy of Hymenoptera.

Materials and Methods

The study was conducted at the Embrapa Dairy Cattle Research Center, Brazil (with geographical coordinates of 21° 33′22″ south latitude, 43° 06′15″ west longitude and 410 m altitude).

The experiment was conducted in pastures of *B. decumbens* established in November 1997, comprising areas of 8 ha in the silvopastoral system and 8 ha in the monoculture system, which were under rotational grazing. The distance between the two systems was of 1,000 m. In the silvopastoral system, the pasture was divided into a 30-m wide area with alternating bands of 10 m of *Eucalyptus grandis*, *Acacia mangium*, *Acacia angustissima*, and *Mimosa artemisiana*. The monoculture system contained only *B. decumbens*.

A Townes-type Malaise trap was used for insect capture in each production system form January 2008 to June 2009. This trap was used because it has been successfully used in many other studies of local entomofauna (Matthews and Matthews 1970, Darling and Packer 1988, Noyes 1989, Campbell and Hanula 2007, Inclan and Stireman 2011, Auad et al. 2011). Furthermore, the Malaise traps outperform other arthropod-collecting techniques (in terms of number of species and individuals collected, as well as operating efforts) in open and semiopen habitats. We used only one Malaise type trap per site because the large numbers of insects captured was sufficient to characterize the population dynamics of Hymenoptera present at each site.

The traps were inspected every 15 d, and the captured insects were preserved in 70% alcohol and transported to the Laboratory of Entomology at the Embrapa Dairy Cattle Research Center, Brazil. The collected material was categorized into orders and families, fixed with entomological pin, and maintained in entomological boxes. After the collected insects were sorted, specimens corresponding to the order Hymenoptera were classified into their respective families and quantified.

The richness and abundance were determined based on the number of morphospecies and specimens sampled, respectively. The constancy rate was obtained using the Bodenheimer method (Silveira Neto et al. 1976), $C = P \times 100/N$, where P represents the number of collections containing the morphospecies studied and N represents the total number of collections. Based on the results obtained, the families were classified as constant (present in >50% of samples), accessory (present in 25–50% of samples), or accidental (present in <25% of samples). The Shannon–Wiener (H') index was used to analyze the diversity and was calculated in the Past program version 2.17 (Hammer et al. 2001).

To compare the diversity of Hymenopteran families in the silvopastoral and monoculture systems, the Mann–Whitney U test in the Past program version 2.17 (Hammer et al. 2001) was used. To check for significant difference in abundance and richness of specimens and morphospecies, we used the chi-square (χ^2) test in the Bioestat program version 3.0 (Ayres et al. 2003). Rarefaction curves to richness were generated with EstimateS 8.2.0 software. The estimator (S) was used for the calculation of the expected species richness values.

The climate data were recorded daily from meteorological station located in the experimental field of Embrapa. The climatic data for the study period were recorded between times of changing the collection receptacles. The Spearman test was applied to analyze the correlations between temperature, relative humidity, and precipitation and the population density of the Hymenoptera, using the Bioestat program version 3.0 (Ayres et al. 2003)

Results and Discussion

B. decumbens pastures managed in a silvopastoral system changed the fauna of Hymenoptera. At the end of 18 mo of collection, abundance (3,889) and richness (305) in the silvopastoral system were significantly enhanced compared with the abundance (1,473) and richness (173) in the monoculture system (Table 1). The major species richness in the silvopastoral system was also evidenced by the rarefaction curve. The number of morphospecies estimated was 305 and 173 in the silvopastoral and monoculture systems, respectively, considering the total number of sampled specimens. In both systems, the species richness continued to increase until the end of the rarefaction curve (Fig. 1). This suggests that the environmental changes resulting from the conversion from a monoculture to a silvopastoral system can be measured by the abundance and richness of Hymenoptera. The number of individuals is the result of a balance between physical, chemical, or biological factors, and vegetation is a key factor in determining biodiversity (Ricklefs 2001). The availability of plant resources and climate stability in more diverse environments supplement the dietary needs of insects, favoring their greater abundance. According to Jose (2012), the role of agroforestry systems in enhancing biodiversity is much more important on degraded lands or in landscapes dominated by monoculture.

We verified the occurrence of 15 families, eight of which occurred in both systems, and seven (Halictidae, Anthophoridae, Evaniidae, Gasteruptiidae, Eurytomidae, Cimbicidae, and Cephidae) were unique to monoculture (Table 1). The Formicidae, Ichneumonidae, and Braconidae families had a significantly higher richness and abundance in the silvopastoral system compared with the monoculture system, while Chalcididae, Pompilidae, Sphecidae, Halictidae, Evaniidae, and Gasteruptiidae families showed a significantly higher abundance, and Vespidae had more richness in the monoculture system. For Apidae, there was no

Table 1. Comparison of the indices of richness and abundance of the families of the order Hymenoptera in silvopastoral and monoculture systems, sampled from January 2008 to June 2009 in the city of Coronel Pacheco, Brazil

Families	Richness				Abundance			
	Silvopastoral	Monoculture	X^2	*P*	Silvopastoral	Monoculture	X^2	*P*
Formicidae	129	36	52.418	<0.0001	3,288	707	1,667.48	<0.0001
Ichneumonidae	70	26	20.167	<0.0001	224	92	55.139	<0.0001
Braconidae	31	7	15.158	<0.0002	117	67	13.587	0.0003
Vespidae	27	48	5.88	0.0209	181	196	0.597	0.4709
Chalcididae	18	9	3.000	0.1237	23	93	42.241	<0.0001
Pompilidae	15	18	0.273	0.7277	28	59	11.046	0.0013
Sphecidae	9	8	1.000	1.0000	22	177	120.729	<0.0001
Apidae	6	9	0.600	0.6056	6	16	4.545	0.055
Halictidae	0	5	—	—	0	33	33.000	<0.0001
Anthophoridae	0	2	—	—	0	3	—	—
Evaniidae	0	1	—	—	0	13	13.000	0.0009
Gasteruptiidae	0	1	—	—	0	11	11.000	0.0026
Eurytomidae	0	1	—	—	0	4	—	—
Cimbicidae	0	1	—	—	0	1	—	—
Cephidae	0	1	—	—	0	1	—	—
Total	305	173	36.452	<0.0001	3,889	1,473	1088.597	<0.0001

P, level of significance; X^2, Chi-square test.

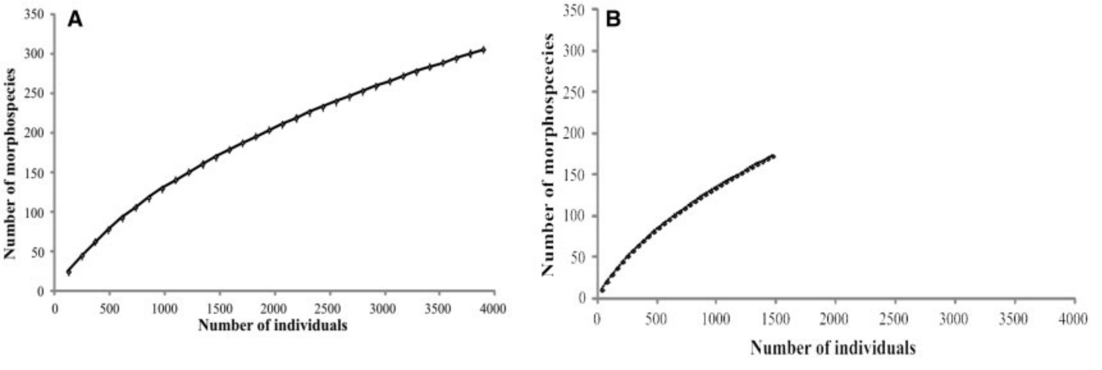

Fig. 1. Morphospecies rarefaction curves (scaled by indivduals) for silvopastoral (A) and monoculture (B) systems. Solid lines: expected morphospecies richness.

significant difference in species richness or abundance between the systems (Table 1). According to Giraldo et al. (2011), tropical regions that use fodder trees and shrubs along with grasses offer a useful landscape management tool that may contribute to the conservation of biodiversity and stability of ecological processes.

The unique families of the monoculture system were accidental, except for Halictidae, which was accessory (Table 2); however, all of them were low in abundance (Table 1) throughout the study period. The Formicidae, Vespidae, and Braconidae families were constant in both systems, while Ichneumonidae was only constant in the silvopastoral system. Pompilidae, Sphecidae, and Chalcididae were only constant in the monoculture system (Table 2). The constancy index estimates the degree of adaptation of these families, indicating that the habitat features biotic and abiotic factors conducive to their success and development. Only Pompilidae and Sphecidae families in the silvopastoral system and Halictidae in the monoculture system were classified as accessory, indicating that these families remained at an intermediate stage of adaptation (present in 25–50% of samples; Table 2). Because it is a production system with ~11 yr from deployment until insect collection, it is believed that the constancy index may already be stabilized.

The diversity of families in the monoculture system (H' = 2.05) was not significantly different compared with silvopastoral system (H' = 1.24; Table 2). When this parameter is evaluated within each family, the diversity was significantly higher in the silvopastoral system for Ichneumonidae, Formicidae, Sphecidae, and Braconidae compared with the monoculture system (Table 2). This result indicates that the vegetation associated with *B. decumbens* in a silvopastoral system is effective for the maintenance and biological conservation of these families.

With the modification of a natural habitat, many species leave the fragment, and numerous individuals or species are killed or even cease to exist until a new equilibrium is established (Thomanzini and Thomanzini 2000). This is illustrated by a significantly lower number of morphospecies observed, showing the reduction of the diversity within the Formicidae, Ichneumonidae, and Braconidae families in the monoculture system.

The diversity of Pompilidae, Vespidae, and Apidae were significantly higher in the monoculture system compared with the silvopastoral system. It is suggested that the monoculture of *B. decumbens* had a greater number of specific prey compared with the silvopastoral system and this may have contributed to a greater diversity of Pompilidae and Vespidae families in the monoculture system. The diversity index of the family Vespidae in the monoculture system of this study was also higher than that obtained by Auad et al. (2010) in *B. decumbens* pastures in a silvopastoral system (H' = 1.64). In contrast, no significant differences were found between the diversity (H') of the two systems for Chalcididae (Table 2).

Table 2. Comparison of the indices of constancy and diversity of the families of the order Hymenoptera in silvopastoral and monoculture systems, sampled from January 2008 to June 2009 in the city of Coronel Pacheco, Brazil

Families	Silvipastoral		Monoculture		U	*P*
	C	H'	C	H'		
Ichneumonidae	X	3.76	Z	2.92	1036.0	<0.001
Formicidae	X	3.46	X	2.12	2240.0	<0.001
Chalcididae	Z	2.72	X	1.42	138.0	0.423
Pompilidae	Y	2.48	X	2.63	85.0	0.012
Vespidae	X	2.32	X	3.14	645.0	<0.001
Apidae	Z	1.79	Z	1.92	18.0	0.020
Sphecidae	Y	1.67	X	0.91	16.5	0.034
Braconidae	X	1.66	X	1.39	171.0	<0.001
Halictidae			Y	0.85		
Anthophoridae			Z	0.63		
Eurytomidae			Z	0		
Gasteruptiidae			Z	0		
Evaniidae			Z	0		
Cimbicidae			Z	0		
Cephidae			Z	0		
Total		1.244		2.05	79.00	0.168

C—X, constant; Y, accessory; Z, accidental.
H'—diversity.
P, level of significance; U, Mann–Whitney test.

The families Ichneumonidae, Formicidae, and Braconidae had higher richness, abundance, and diversity in silvopastoral system. Moreover, these families were constant in both environments (Formicidae and Braconidae) or only in the silvopastoral system (Ichneumonidae) (Tables 1 and 2). Thus, these three families may be useful as potential bioindicators for assessing the environmental changes brought about by the conversion from a monoculture of *B. decumbens* to a silvopastoral system. These results corroborate those of Wink et al. (2005) who reported that many insects are bioindicators of environmental quality and degradation due to the various roles they play in nature, their close relationship to the heterogeneity of ecosystems and ecological processes, and their high degree of sensitivity to climate change.

The sampled specimens within the families selected as bioindicators are ecologically important because they interact with other organisms at all trophic levels (Formicidae) or act as natural enemies (Ichneumonidae and Braconidae). The predominance of these families was previously observed by Auad et al. (2012) in *Brachiaria* pasture maintained in a silvopastoral system.

We noted a large disparity in the number of Hymenoptera specimens collected, with records of 4 specimens in December 2008 and 517 specimens in April 2008 in the silvopastoral system. Similarly, 0 and 344 specimens were collected in the monoculture system in June 2008 and May 2009, respectively (Fig. 2).

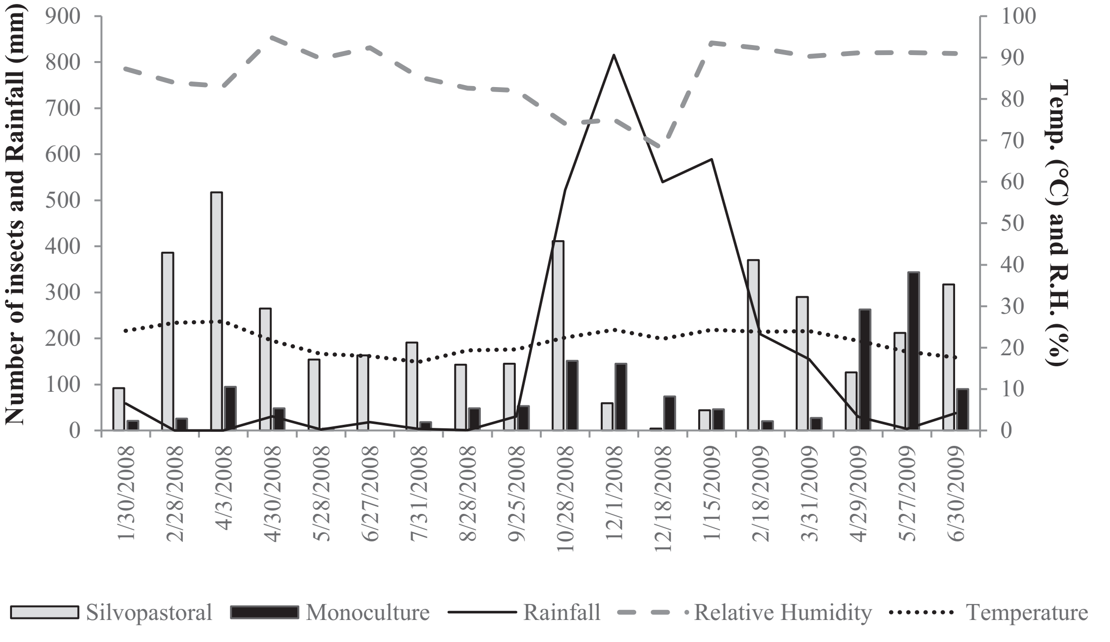

Fig. 2. Population survey of Hymenoptera from silvopastoral and monoculture systems and its correlation with temperature, relative humidity, and rainfall, sampled from January 2008 to June 2009 in the city of Coronel Pacheco, Brazil.

No significant correlation was observed between the number of individuals sampled and climatic factors such as temperature ($r = 0.14$; $t = 0.565$; $P = 0.580$), relative humidity ($r = 0.09$; $t = 0.333$; $P = 0.744$), or rainfall ($r = -0.38$; $t = -1.644$; $P = 0.120$) during the sampled period in the silvopastoral system. Likewise, no significant correlation was observed between temperature ($r = -0.02$; $t = -0.092$; $P = 0.928$), relative humidity ($r = -0.07$; $t = -0.279$; $P = 0.784$), or rainfall ($r = -0.10$; $t = 0.3994$; $P = 0.695$) with the number of individuals collected in the monoculture system. However, there was a concentration of the number of sampled individuals in some months of the year, with 50% of specimens collected in the months of February, March, and April 2008 in the silvopastoral system and 61% of the specimens sampled in October 2008, November 2008, April 2009, and May 2009 in the monoculture system (Fig. 2). Auad et al. (2012) also found no significant differences in the correlation between temperature, relative humidity, and rainfall and the number of Hymenoptera collected in previous years, using the same silvopastoral area of this study.

It is worth noting that, from the total number of individuals, Formicidae was the most abundant family, representing 85 and 48% of the total specimens sampled in the silvopastoral and monoculture systems, respectively. These results corroborate those of Auad et al. (2012) who reported that 80% of Hymenoptera collected in the *Brachiaria* pasture in the silvopastoral system were from the Formicidae family. Many of these belong to the beneficial insects and, according to Queiroz et al. (2006), are important for the conservation of biodiversity and are useful as biological indicators. Importantly, the presence of trees in the environment generated a large volume of leaf litter and according to Delabie and Fowler (1995) and Wall and Moore (1999), 50 and 62% of the ant fauna in tropical forests, respectively, may be associated with the decomposition process of plant debris. Ant population surveys in subsequent years may help to assess the changes in the flora–fauna interaction induced by the silvopastoral system. According to Niemi and McDonald (2004), these bioindicators contribute to the diagnosis of possible causes of environmental change.

Thus, we conclude that changes resulting from the conversion from a monoculture to a silvopastoral system can be measured by the occurrence of insects of the order Hymenoptera, especially the families Formicidae, Ichneumonidae, and Braconidae.

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