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Soil and litter fauna of cacao agroforestry systems in Bahia, Brazil

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Abstract Agroforestry systems deposit great amounts of plant residues on soil and this leads to high levels of soil organic matter content and has increased soil biodiversity and improved its conservation. This study compares the distribution of meso and macrofaunal communities in soil and litter under cacao agroforestry systems and in a natural forest in the southern Bahia state of Brazil. Soil and litter samples were obtained in September 2003, February 2004, and August 2004 in five cacao agroforestry systems. The systems evaluated included: cacao renewed under *Erythrina* sp. (*Erythrina poeppigiana*) (CRE); cacao renewed under natural forest (Cabruca, CRF); an old cacao system under *Erythrina* sp. (OCE); an old cacao system under a natural forest system (Cabruca, OCF) and a cacao germplasm collection area (CGC). As a reference soil and litter under a natural forest (NF) was included. Organisms were collected over a 15-day period with a Berlese–Tullgren apparatus. The density and richness of total fauna varied distinctly according to sites, sampling time and material sampled (soil and litter). 16,409 of fauna were recovered from soil and litter samples and the density of total fauna was 2,094 individuals m^{-2} in the litter and 641 individuals m^{-2} in the soil. The richness was 11.8 in the litter and 7.5 in the soil. The cacao agroforestry systems adopted for growing cacao in the southern Bahia region of Brazil have beneficial effects on the soil and litter faunal communities, and such systems of cacao cultivation could be considered as a conservation system for soil fauna. The development of a litter layer resulted in higher abundance and diversity of soil fauna.

Keywords Rain forest · Biodiversity · Soil invertebrates · Biological indicators

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Introduction

The Brazilian Atlantic rain forest is threatened by large-scale clearings and also by the traditional slash and burn practice of farmers. Consequently the original forested area was reduced to about 95%. Most of this area is degraded land with severe depletion of their biodiversity, poor management of the vegetative cover and low soil fertility. However, the Brazilian Atlantic rain forest is the largest cocoa-growing area on the eastern coast of Brazil with around 400,000 hectares of cacao plantation (*Theobroma cacao* L., Malvaceae) (Delabie et al. 2007; Gama-Rodrigues et al. 1999).

Cacao SAF's consists of a combination of cacao trees, non-woody (banana, cassava, etc.) and woody species (erythrina, gliricidia, etc.) under natural forest (NF) or under homogeneous forest. The traditional cacao SAF of southern Bahia, Brazil is a cacao plantation (cabruca) under a thinned NF and is shaded by forest trees. The vegetation structure and stratification of cabruca plantations are considered to be similar to that of natural forests. The cabruca has received much attention recently because of its economic importance for the region and also because cacao cultivation in traditional, shaded systems favors the conservation of a high proportion of species of the Atlantic Forest landscape (Delabie et al. 2007). In the past 50 years, a new system has been developed where the original forest trees are completely eliminated before planting. The cacao plants are generally shaded with introduced leguminous *Erythrina* trees and cacao trees are planted in twice the density of cabruca systems (Delabie et al. 2007; Müller and Gama-Rodrigues 2007; Schroth et al. 2006).

Agroforestry systems are generally considered to have a positive effect on the conservation of biodiversity by minimum tillage, quantity, and quality of litter, diversification, and especially incorporation of trees (of several species), shade, deep and perennial root systems that create a more suitable environment for soil faunal communities (Brown et al. 2006; López-Hernández et al. 2004; Barros et al. 2003; Vohland and Schroth 1999).

Soil organisms comprise a huge number of species that play a central role in various ecosystem functions that provide valuable ecosystem services that sustain soil quality and plant growth, as a driving force in nutrient cycling by fragmenting and ingesting litter material and interacting with the microorganisms that decompose and mineralize the vegetable residue (Yang et al. 2007; Höffer et al. 2001; Huhta 2007; Barros et al. 2004; Lavelle et al. 2001; Wardle et al. 1998). Soil management practice can have dramatic effects upon soil invertebrate communities (Cassagne et al. 2006; Rossi and Blanchart 2005; Barros et al. 2002, 2003; Decaëns et al. 2004) and may therefore lead to important changes in soil functioning. Fauna community also varies with nature of vegetative cover, quality of plant litter and seasonal variations (Sileshi and Mafongoya 2006; Wardle et al. 2006; Moço et al. 2005; Rossi and Blanchart 2005).

The objective of our study was to determine the distribution of meso and macrofauna in soil and litter with sampling time in five different cacao agroforestry systems and in a NF in the southern region of Bahia state of Brazil.

Materials and methods

The study was conducted on the Research Station of MARS Center of Cocoa Science, Itajuípe located in the southern region of Bahia, Brazil. The research farm is situated in a humid, tropical climate with an annual mean rainfall of 1500 mm which is well distributed throughout the year. Soil and litter samples were taken from five cacao agroforestry systems: renewed cacao (25-years-old) under *Erythrina* system (CRE), renewed cacao (25-years-old) under NF (cabruca system, CRF), an old cacao (25-years-old) under *Erythrina* system (OCE), an old cacao (70-years-old) under NF system (Cabruca, OCF) and from cacao germplasm (15 years old) collection area (CGC) where plantations of cacao clones resistant to witch's broom (*Crinipellis pernicious*) have been planted. Soil samples were also collected from NF next to the agroforestry systems to serve as reference of faunal activites.

Cacao with Erythrina spp. represents a cacao plantation under Erythrina shade trees (*Erythrina* spp.) and "cabruca" represents a cacao plantation under NF. Renewed cacao systems represent grafting (5 years old) of old trees with witches' broom (*C. pernicious*) resistant genetic material originated from the cacao germplasm collection of MARS Center of Cocoa Science. The areas used for NF, CRE, CRF, and OCF were on Oxisols whereas OCE and CGC were established on Inceptsols.

The soils were collected during September 2003, February 2004, and August 2004. In each site, four litter (all plants residue on soil surface) and soil (0–5 cm) samples were collected from a plot area of 0.25 × 0.25 m (Moço et al. 2005).

Organisms were extracted over a 15-day period with a Berlese–Tullgren apparatus using 25 W bulbs suspended 10 cm above the top of the samples

(Palacios-Vargas et al. 2007; Cassagne et al. 2003, 2006; Chagon et al. 2001). Fauna was collected in 2% acetylsalicylic acid and counted under a binocular microscope (Moço et al. 2005). The invertebrates were then classified into higher taxonomic levels and counted for their density and richness. Fauna was divided into different functional groups: herbivores, microbial grazers, predators, saprophagous, social, and other insects (that represent more than one feeding habit). Three indices were adopted: 1) diversity was measured with the Shannon index ($H(s) = \Sigma\ ni.\ \ln ni$, where $H(s)$ is species diversity and ni is the percentage contribution of species i to the total abundance), 2) Pielou evenness index ($e = H/\log S$, where H = Shannon index; S = Number of groups) and 3) influence of plant coverings on soil fauna communities with V index.

The data was checked for normality of distribution by Lilliefors test and the homogeneity of variances by Bartlett test. The total fauna density was log-transformed, the richness data were square root-transformed and the density of soil faunal groups was log $(x + 1)$-transformed. The data was analyzed with three-way ANOVA: sites (6 levels), material sampled (soil and litter—2 levels), seasons (3 levels) and interactions. Duncan's honestly significant difference was calculated for comparison of means.

To evaluate the degree of soil fauna responses to agroforestry systems (tillage), the index V (indices of change) was used (Wardle 1995), i.e., $V = (2\ \mathrm{DAFS}/\mathrm{DAFS} + \mathrm{DNF}) - 1$, where DSAF is the density of soil or litter fauna in cacao agroforestry systems and DNF is the density of soil or litter fauna in NF. The index V ranges from -1 (organisms occurring only under NF) to $+1$, (organisms occurring only under SAF) and with 0 indicating equal density under both SAF and NF systems. Categories were defined to express the degree of response to tillage (Table 1).

Table 1 Categories of inhibition or stimulation of soil fauna to express the degree of response to tillage (Agroforestry system) using V index (Adapted from Wardle 1995)

Categories	V index
Extreme inhibition by tillage	$V < -0.67$
Moderate inhibition by tillage	$-0.33 > V > -0.67$
Mild inhibition by tillage	$0 > V > -0.33$
No change	0
Mild stimulation by tillage	$0 < V < 0.33$
Moderate stimulation by tillage	$0.33 < V < 0.67$
Extreme stimulation by tillage	$V > 0.67$

Results

The density and richness of total fauna and the density of microbial grazers and saprophagous varied distinctly depending on the sites, sampling time, and material sampled (soil and litter) (Table 2). The maximum density and richness of total fauna were found in CRF. The mean density of microbial grazers (soil and litter) was minimum in NF. The saprophagous density (soil) was maximum on renewed cacao (CRF and CRE) and the highest density of other group (soil) was in CRF and NF. The density of herbivores was low in all sites (soil and litter). The litter of CRF also hosted the highest density of predators and other group (Tables 3–6).

The mean density and richness of total fauna (soil and litter) and the density of microbial grazers, social insects, saprophagous, and herbivores were higher in February and August 2004 compared with September 2003. The mean density of total fauna were 1,711 (February 2004), 1,420 (August 2004) and 970 (September 2003) individuals m^{-2}, and the mean richness of total fauna were 10.7 (February 2004), 10.4 (August 2004) and 7.9 (September 2003) (Table 2).

16,409 of fauna were recovered from soil and litter samples, and more fauna community was found in the litter (12,561 individuals) than in soil and consequently the mean density and richness of total fauna and the density of microbial grazers, saprophagous, and herbivores were maximum in the litter. The density of total fauna was 2,094 individuals m^{-2} in the litter and 641 individuals m^{-2} in the soil. The richness was 11.8 in the litter and 7.5 in the soil (Tables 3–6).

The fauna collected (soil and litter) belongs to 26 taxas and these taxas were allocated to six functional groups. Collembola was the only taxa which occurred as microbial grazers and represented 41% of total faunal group (soil and litter). Formicidae dominated the social insects group (98%) in the soil and litter and represented 32% of all animals recovered in this survey. Oligochaeta and Symphyla dominated the

Table 2 ANOVA table of F-value on the effect of sites, sampling time, material sampled and their interactions on density and richness, density of faunal groups and Shannon and Pielou index of soil and litter fauna

	d.f.	Density	Richness	Microbial grazers	Social Insects	Saprophagous	Predators	Other	Herbivores	Shannon index	Pielou index
Sites	5	3.19**	6.14***	6.94***	0.68 NS	4.74*	6.46***	3.64**	0.69 NS	2.91*	0.55 NS
Sampling time	2	13.50***	13.89***	11.10***	4.78*	16.06**	1.07 NS	1.59 NS	7.16**	0.84 NS	1.86 NS
Material sampled	1	84.40***	82.27***	78.26***	2.14 NS	74.72***	3.54 NS	24.25***	56.17***	0.46 NS	14.20**
Sampling time × sites	10	1.18 NS	1.66 NS	1.68 NS	1.26 NS	4.17**	1.40 NS	1.09 NS	1.68 NS	1.12 NS	0.99 NS
Material sampled × sites	5	1.13 NS	1.89 NS	0.37 NS	0.78 NS	1.80 NS	2.11 NS	0.93 NS	0.48 NS	3.27 NS	1.68 NS
Sampling time × Local sampling	2	4.50*	4.10*	2.62 NS	0.23 NS	1.21 NS	2.81 NS	2.70 NS	0.99 NS	0.64 NS	0.65 NS
Sampling time × Material sampled × sites	10	2.32*	1.11 NS	1.08 NS	0.82 NS	2.48*	1.23 NS	0.60 NS	0.85 NS	0.85 NS	1.16 NS

NS not significant

*, **, *** significant at 5%, 1% and 1‰, respectively. Total d.f. = 108

saprophagous soil fauna (38%) and Diptera (lv.) the saprophagous litter fauna (24%). Saprophagous was the functional group with a greater number of individual taxa: 12 taxas in the litter and 10 taxas in the soil. The most abundant taxa in the soil and litter as predator was Pseudoscorpionida (42%) and Coleoptera was the most abundant as the other group (66%) and Hemiptera as herbivores (39%) (Tables 5, 6).

The Social insect (Formicidae—43%) was the dominant functional group in the soil. The rest were listed as fallows in the order of abundance: microbial grazers (25%) > saprophagous (14%) > predators and other (8%) > herbivores (3%). However, the dominant functional group in the litter was microbial grazers (46%) followed in the order: social insects (29%) > saprophagous (13%) > other (6%) > predators and herbivores (3%) (Tables 5, 6).

The Shannon index varied depending on the sites only in the soil and Pielou index varied in the sites in the soil in September 2003 and February 2004, and Pielou index also varied among material sampled only in September 2003. The Shannon index in the soil ranged from 1.12 (CGC) to 2.75 (CRE) and in the litter from 1.55 (CRE) to 2.48 (OCF), and Pielou index in the soil ranged from 0.52 (NF) to 0.92 (OCF) and in the litter from 0.46 (CRE) to 0.74 (OCF). In general, soil CGC (soil) showed the lowest average of Shannon index, and NF (soil), the lowest Pielou index in the first two sampling time (Tables 2, 7).

All categories of inhibition or stimulation of soil faunal growth were found in all sites. Inhibition or stimulation of organisms was influenced by sampling time and local sampling (soil and litter). In general, cacao agroforestry systems contain approximately more than 50% of stimulated organisms. In September (2003) and August (2004), inhibit organisms were more abundant than stimulate organisms. In February (2004), about 50% of organisms mainly in litter were extremely stimulated. A few organism populations were not changed by nature of cacao agroforestry systems (Fig. 1).

Discussion

Sites, sampling time, and material sampled can significantly affect density and richness of total fauna, microbial grazers and saprophagous. This

Table 3 Density of faunal groups in soil and litter of different cacao agroforestry systems and natural forest during sampling time

Density (individual m^{-2})

	Sep./03				Feb./04				Aug./04				Mean
	Soil		Litter		Soil		Litter		Soil		Litter		
NF	776 ± 472	AB a	1088 ± 395	AB a	892 ± 257	A a	304 ± 39	B a	472 ± 84	A b	2772 ± 863	AB a	1050 B
CRE	280 ± 122	AB b	2692 ± 753	A a	728 ± 182	A b	3192 ± 745	A a	768 ± 155	A a	1468 ± 238	AB a	1521 AB
CRF	524 ± 188	A b	1864 ± 400	AB a	1508 ± 329	A a	2768 ± 714	A a	752 ± 236	A b	3556 ± 885	A a	1829 A
OCF	216 ± 31	AB a	568 ± 69	B a	660 ± 120	A b	3536 ± 1578	A a	724 ± 263	A b	2452 ± 901	AB a	1359 B
OCE	224 ± 67	AB b	1468 ± 597	AB a	1196 ± 461	A a	2184 ± 329	A a	336 ± 51	A b	1924 ± 541	AB a	1222 B
CGC	120 ± 33	B b	1824 ± 605	AB a	580 ± 168	A b	2984 ± 1723	A a	776 ± 185	A a	1044 ± 374	B a	1221 B
Mean	357 ± 217	b *B*	1584 ± 550	a *A*	927 ± 288	b *A*	2495 ± 1049	a *A*	638 ± 177	b *A*	2203 ± 717	a *A*	

NF natural forest; *CRE* renewed cacao under Erythrina system; *CRF* renewed cacao under forest system; *OCF* old cacao under forest system; *OCE* old cacao under Erythrina system and *CGC* cacao germplasm collection

Values followed by the same capital letter(s) within each column are not significantly different according to the Duncan test ($P = 0.05$)

Values followed by the same letter (s) within each row and within each date of sampling are not significantly different at Duncan test $P = 0.05$

Mean values for all sites combined by sampled material (soil or litter) and date of sampling, followed by the same italicized letter(s), are not significantly different according to Duncan test ($P = 0.05$)

Table 4 Richness of faunal groups in soil and litter of different cacao agroforestry systems and NF during sampling time

Richness													
Groups of fauna													
	Sep./03				Feb./04				Aug./04				Mean
	Soil		Litter		Soil		Litter		Soil		Litter		
NF	5.3 ± 1	A b	10.8 ± 1	A a	9.0 ± 1	A a	8.8 ± 1	B a	8.8 ± 1	A b	15.0 ± 1	AB a	9.6 B
CRE	5.0 ± 1	A b	11.3 ± 1	A a	11.0 ± 1	A a	14.3 ± 3	A a	9.3 ± 1	A a	12.5 ± 2	BC a	10.6 AB
CRF	7.0 ± 1	A a	10.5 ± 2	A a	11.5 ± 0	A a	14.3 ± 1	A a	8.8 ± 2	A b	18.3 ± 2	A a	11.7 A
OCF	6.8 ± 1	A a	10.5 ± 1	A a	8.5 ± 1	A a	8.8 ± 1	B a	7.3 ± 1	AB b	11.8 ± 2	BC a	8.9 B
OCE	5.0 ± 1	A b	8.8 ± 1	A a	11.5 ± 2	A a	12.5 ± 1	AB a	7.5 ± 1	AB b	11.8 ± 2	BC a	9.5 B
CGC	3.5 ± 1	A b	10.5 ± 1	A a	4.8 ± 1	B b	12.8 ± 1	AB a	4.8 ± 1	B b	8.8 ± 0	C a	7.5 C
Mean	5.4 ± 1	b *C*	10.4 ± 1	a *B*	9.4 ± 2	b *A*	11.9 ± 2	a *AB*	7.7 ± 1	b *B*	13.0 ± 2	a *A*	

NF natural forest; *CRE* renewed cacao under Erythrina system; *CRF* renewed cacao under forest system; *OCF* old cacao under forest system; *OCE* old cacao under Erythrina system and *CGC* cacao germplasm collection

Values followed by the same capital letter(s) within each column are not significantly different according to the Duncan test ($P = 0.05$)

Values followed by the same letter (s) within each row and within each date of sampling are not significantly different at Duncan test ($P = 0.05$)

Mean values for all sites combined by sampled material (soil or litter) and date of sampling, followed by the same italicized letter(s), are not significantly different according to Duncan test ($P = 0.05$)

suggests that fauna attributes were more sensitive than Shannon and Pielou indices and the other groups recovered in this study.

There is not an apparent tendency between the differences for density and richness of total fauna and the density of the functional group and Shannon and Pielou indices between NF and cacao agroforestry systems. This is probably because these sites have similar structures and maintain steady conditions, reflecting a homogeneous distribution of fauna communities. In general, invertebrate communities seem to be best conserved when the derived system has a structure similar to that of its original system, such as pastures planted in savanna areas and tree-based systems (SAF's) of forest areas (Brown et al. 2004; Barros et al. 2003; Fragoso et al. 1997; Decaëns et al. 1994). Furthermore, plant diversification in agroforestry and forest systems provide a diversity of microhabitats, contribute to a larger density and soil biological diversity (Laossi et al. 2008; Richter et al. 2007; Brown et al. 2006; Wardle et al. 2006; Tapia-Coral et al. 1999), and the spatial heterogeneity of the litter layer in mixed tree plantations should lead to small scale differences in the composition of faunal communities (Lavelle et al. 2003; Vohland and Schroth 1999).

There is no evidence rainfall distribution could explain the higher density and richness of total fauna (soil and litter) and the density of microbial grazers, social insects, saprophagous, and herbivores in February and August 2004 because the rainfall was well distributed during September 2003–August 2004 period.

The greatest density of microbial grazers, saprophagous and herbivores, and density and richness of total fauna on litter, showed the importance of this layer to maintain a favorable microclimate condition to faunal communities. Furthermore, litter buildup from cacao tree associated with shade trees has been reported at approximately 9,924 kg/ha (Fontes 2006). This litter on the soil surface serves as a source of energy and nutrients (large amount of labile C and N) that improves faunal habitat and protects them from predators. Litter removal usually leads a decline in micro and macroarthropods populations in soil (Sayer 2005; Barros et al. 2003).

Cacao agroforestry systems and NF provided a useful refuge for microbial grazers (Collembola) and

Table 5 Density of soil faunal groups in different cacao agroforestry systems and NF

	NF		CRE		CRF		OCF		OCE		CGC	
	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%
Microbial grazers	31 b	4.3	139 a	23.5	264 a	28.4	180 a	33.8	96 a	17.4	243 a	46.2
Collembola	31 ± 17	4.3	139 ± 50	23.5	264 ± 112	28.4	180 ± 95	33.8	96 ± 59	17.4	243 ± 119	46.2
Social insects	476 a	66.5	193 a	32.6	338 a	36.3	177 a	33.2	281 a	51.1	209 a	39.7
Formicidae	473 ± 317	66.4	193 ± 120	32.6	335 ± 250	36.1	176 ± 108	33.0	273 ± 215	49.6	189 ± 95	35.9
L. Formicidae	0	0.0	0	0.0	0	0.0	0	0.0	8 ± 12	1.5	20 ± 29	3.8
Isoptera	3 ± 3	0.4	0	0.0	3 ± 4	0.3	1 ± 2	0.2	0	0.0	0	0.0
Saprophagous	76 ab	10.6	138 a	23.5	124 a	13.5	84 ab	16	68 bc	12.3	35 c	6.7
Blattodea	0	0.0	7 ± 10	1.1	0	0.0	1 ± 2	0.2	0	0.0	0	0.0
Diplopoda	11 ± 6	1.5	16 ± 11	2.7	19 ± 9	2.0	11 ± 8	2.1	5 ± 5	1.0	4 ± 4	0.8
Gastropoda	0	0.0	1 ± 2	0.2	5 ± 8	0.6	0	0.0	0	0.0	0	0.0
Isopoda	3 ± 3	0.4	4 ± 6	0.7	3 ± 3	0.3	3 ± 3	0.6	0	0.0	0	0.0
Diptera (lv.)	8 ± 5	1.1	8 ± 4	1.4	7 ± 6	0.7	4 ± 3	0.8	23 ± 9	4.1	7 ± 5	1.3
Oligochaeta	11 ± 6	1.5	21 ± 12	3.6	20 ± 8	2.2	17 ± 11	3.3	20 ± 11	3.6	12 ± 10	2.3
Pauropoda	1 ± 2	0.2	5 ± 4	0.9	9 ± 8	1.0	21 ± 27	3.9	0	0.0	0	0.0
Protura	8 ± 9	1.1	57 ± 53	9.7	8 ± 8	0.9	0	0.0	4 ± 4	0.7	0	0.0
Psocoptera	31 ± 24	4.3	4 ± 4	0.7	8 ± 9	0.9	4 ± 4	0.8	11 ± 7	1.9	3 ± 3	0.5
Symphyla	3 ± 4	0.4	15 ± 11	2.5	45 ± 27	4.9	23 ± 12	4.3	5 ± 5	1.0	9 ± 6	1.8
Predators	51 a	7.1	56 a	9.5	82 a	8.7	69 a	12.9	27 a	4.9	5 b	1.1
Araneae	7 ± 6	0.9	8 ± 6	1.4	12 ± 6	1.3	20 ± 7	3.8	8 ± 5	1.5	1 ± 2	0.3
Chilopoda	11 ± 8	1.5	23 ± 16	3.8	31 ± 17	3.3	12 ± 5	2.2	11 ± 6	1.9	3 ± 3	0.5
Diplura	9 ± 6	1.3	0	0.0	4 ± 4	0.4	0	0.0	5 ± 5	1.0	1 ± 2	0.3
Pseudoscorpionida	24 ± 12	3.4	25 ± 14	4.3	35 ± 17	3.7	37 ± 25	6.9	3 ± 3	0.5	0	0.0
Other	67 a	9.4	54 ab	9.0	75 a	8.0	19 b	3.6	56 ab	10.2	25 b	4.8
Coleoptera (ad.)	52 ± 23	7.3	43 ± 12	7.2	39 ± 25	4.2	15 ± 6	2.8	27 ± 15	4.8	13 ± 8	2.5
Coleoptera (lv.)	15 ± 7	2.1	11 ± 6	1.8	35 ± 20	3.7	4 ± 3	0.8	21 ± 14	3.9	12 ± 12	2.3
Hymenoptera	0	0.0	0	0.0	1 ± 2	0.1	0	0.0	8 ± 7	1.5	0	0.0
Herbivores	15 a	2.1	12 a	2.1	47 a	5.0	4 a	0.8	23 a	4.1	9 a	1.8
Diptera (ad.)	3 ± 3	0.4	4 ± 4	0.7	4 ± 3	0.4	1 ± 2	0.3	4 ± 3	0.7	5 ± 8	1.0
Hemiptera	9 ± 9	1.3	8 ± 7	1.4	40 ± 49	4.3	3 ± 3	0.5	19 ± 15	3.4	4 ± 3	0.8
Lepidoptera (lv.)	3 ± 3	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Thysanoptera	0	0.0	0	0.0	3 ± 4	0.3	0	0.0	0	0.0	0	0.0
Total	716 ± 296	100.0	592 ± 174	100	930 ± 305	100	533 ± 185	100	551 ± 326	100	526 ± 172	100

NF natural forest; *CRE* renewed cacao under Erythrina system; *CRF* renewed cacao under forest system; *OCF* old cacao under forest system; *OCE* old cacao under Erythrina system and *CGC* cacao germplasm collection

Table 6 Density of litter faunal groups in different cacao agroforestry systems and NF

	NF		CRE		CRF		OCF		OCE		CGC	
	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%
Microbial grazers	367 b		1239 a		1393 a		552 a		880 a		1307 a	
Collembola	367 ± 284	26.4	1239 ± 429	50.6	1393 ± 526	51.1	552 ± 311	25.3	880 ± 277	47.3	1307 ± 950	67.0
Social insects	559 a	40.3	674 a	27.5	557 a	20.4	1218 a	55.7	450 a	24.2	198 a	10.2
Formicidae	535 ± 320	38.5	671 ± 316	27.4	543 ± 317	19.9	1203 ± 878	55.0	443 ± 225	23.8	193 ± 127	9.9
L. Formicidae	23 ± 35	1.7	3 ± 3	0.1	13 ± 15	0.5	15 ± 21	0.7	7 ± 6	0.4	5 ± 6	0.3
Isoptera	1 ± 2	0.1	0	0.0	1 ± 2	0.0	0	0.0	0	0.0	0	0.0
Saprophagous	176 a	12.8	338 a	13.8	413 a	15.1	242 a	11.1	205 a	11.0	232 a	11.9
Blattodea	9 ± 14	0.6	0	0.0	3 ± 3	0.1	0	0.0	0	0.0	0	0.0
Diplopoda	51 ± 30	3.7	28 ± 10	1.1	24 ± 16	0.9	17 ± 11	0.8	16 ± 10	0.9	29 ± 15	1.5
Embioptera	1 ± 2	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Gastropoda	1 ± 2	0.1	8 ± 7	0.3	9 ± 6	0.3	3 ± 4	0.1	3 ± 3	0.1	21 ± 9	1.1
Isopoda	32 ± 27	2.3	65 ± 30	2.7	112 ± 96	4.1	41 ± 35	1.9	8 ± 6	0.4	1 ± 2	0.1
Diptera (lv.)	25 ± 13	1.8	61 ± 20	2.5	33 ± 12	1.2	21 ± 12	1.0	116 ± 33	6.2	123 ± 126	6.3
Oligochaeta	15 ± 8	1.1	9 ± 5	0.4	12 ± 8	0.4	19 ± 10	0.9	7 ± 4	0.4	4 ± 3	0.2
Pauropoda	1 ± 2	0.1	95 ± 90	3.9	79 ± 65	2.9	111 ± 53	5.1	17 ± 23	0.9	11 ± 9	0.5
Protura	3 ± 3	0.2	23 ± 15	0.9	28 ± 15	1.0	3 ± 3	0.1	11 ± 7	0.6	4 ± 4	0.2
Psocoptera	15 ± 9	1.1	21 ± 14	0.9	17 ± 7	0.6	16 ± 11	0.7	23 ± 16	1.2	36 ± 17	1.8
Symphyla	23 ± 11	1.7	28 ± 27	1.1	93 ± 46	3.4	11 ± 7	0.5	4 ± 4	0.2	3 ± 3	0.1
Thysanura	0	0.0	0	0.0	3 ± 4	0.1	0	0.0	0	0.0	0	0.0
Predators	91 ab	6.6	70 bc	2.9	141 a	5.2	31 c	1.4	69 bc	3.7	32 c	1.6
Araneae	27 ± 10	1.9	17 ± 10	0.7	28 ± 13	1.0	9 ± 6	0.4	45 ± 42	2.4	19 ± 10	1.0
Chilopoda	11 ± 6	0.8	9 ± 8	0.4	35 ± 12	1.3	5 ± 5	0.2	19 ± 8	1.0	9 ± 6	0.5
Diplura	5 ± 5	0.4	0	0.0	4 ± 6	0.1	5 ± 8	0.2	0	0.0	0	0.0
Pseudoscorpionida	48 ± 22	3.5	44 ± 33	1.8	69 ± 26	2.5	9 ± 6	0.4	5 ± 5	0.3	4 ± 4	0.2
Dermaptera	0	0.0	0	0.0	5 ± 8	0.2	3 ± 3	0.1	0	0.0	0	0.0
Other	153 ab	11.1	88 ab	3.5	160 a	5.9	72 b	3.3	168 a	9.1	76 ab	4.0
Coleoptera (ad.)	113 ± 40	8.2	55 ± 33	2.2	108 ± 43	4.0	41 ± 22	1.9	124 ± 73	6.7	40 ± 14	2.1
Coleoptera (lv.)	37 ± 14	2.7	28 ± 13	1.1	51 ± 21	1.9	24 ± 16	1.1	33 ± 14	1.8	27 ± 18	1.4
Hymenoptera	3 ± 3	0.2	5 ± 5	0.2	1 ± 2	0.0	7 ± 6	0.3	11 ± 7	0.6	9 ± 5	0.5
Herbivores	42 a	3.1	41 a	1.8	64 a	2.3	70 a	3.2	88 a	4.8	105 a	5.4
Diptera (ad.)	9 ± 7	0.7	12 ± 6	0.5	4 ± 3	0.1	5 ± 5	0.2	16 ± 9	0.9	36 ± 18	1.8

Table 6 continued

	NF		CRE		CRF		OCF		OCE		CGC	
	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%	Ind. m^{-2}	%
Hemiptera	17 ± 8	1.2	9 ± 5	0.4	24 ± 11	0.9	17 ± 12	0.8	12 ± 7	0.6	41 ± 19	2.1
Lepidoptera (lv.)	0	0.0	4 ± 3	0.2	3 ± 3	0.1	4 ± 6	0.2	1 ± 2	0.1	0	0.0
Orthoptera	3 ± 3	0.2	1 ± 2	0.1	4 ± 4	0.1	3 ± 4	0.1	0	0.0	07	0.0
Thysanoptera	13 ± 13	1.0	15 ± 8	0.6	29 ± 16	1.1	41 ± 41	1.9	59 ± 41	3.2	28 ± 22	1.4
Total	1388 ± 691	100	2450 ± 660	100	2728 ± 707	100	2185 ± 1109	100	1860 ± 75	100	1950 ± 1042	100

NF natural forest; *CRE* renewed cacao under Erythrina system; *CRF* renewed cacao under forest system; *OCF* old cacao under forest system; *OCE* old cacao under Erythrina system and *CGC* cacao germplasm collection

Table 7 Shannon and Pielou index of faunal groups in soil and litter of different cacao agroforestry systems and natural forest

	Shannon index						Pielou index					
	September/03		February/04		August/04		September/03		February/04		August/04	
	Soil	Litter	Soil	Litter	Soil	Litter	Soil	Litter	Soil	Litter	Soil	Litter
NF	1.32 BCb	2.34 A a	1.70 BCab	2.26 A a	2.31 A a	2.06 Aa	0.63 B a	0.70 A a	0.52 B a	0.73 A a	0.74 A a	0.53 A a
CRE	2.19 ABa	1.55 A a	2.75 A a	1.94 A a	2.29 A a	2.36 A a	0.82 ABa	0.46 A a	0.80 A a	0.51 A a	0.71 A a	0.66 A a
CRF	2.12 ABa	1.78 A a	2.30 ABa	2.32 A a	2.07 ABa	2.35 A a	0.74 ABa	0.52 A a	0.65 ABa	0.65 A a	0.68 A a	0.57 A a
OCF	2.48 A a	2.48 A a	2.05 ABCa	1.59 A a	1.81 AB a	1.91 A a	0.92 A a	0.74 A a	0.66 ABb	0.52 A a	0.64 A b	0.55 A a
OCE	1.94 ABCa	1.97 A a	2.36 AB a	1.75 A a	2.31 A a	2.26 A a	0.80 AB a	0.67 A a	0.71 AB a	0.49 A a	0.81 A a	0.64 A a
CGC	1.12 C a	1.84 A a	1.22 C a	1.95 A a	1.24 B a	2.16 A a	0.69 ABa	0.55 A a	0.60 ABa	0.54 A a	0.60 A a	0.69 A a
Mean	1.86 a *A*	1..99 a *A*	2.06 a *A*	1.97 a *A*	2.00 a *A*	2.18 a *A*	0.76 a *A*	0.60 a *B*	0.66 b *A*	0.57 a *A*	0.70 ab *A*	0.61 a *A*

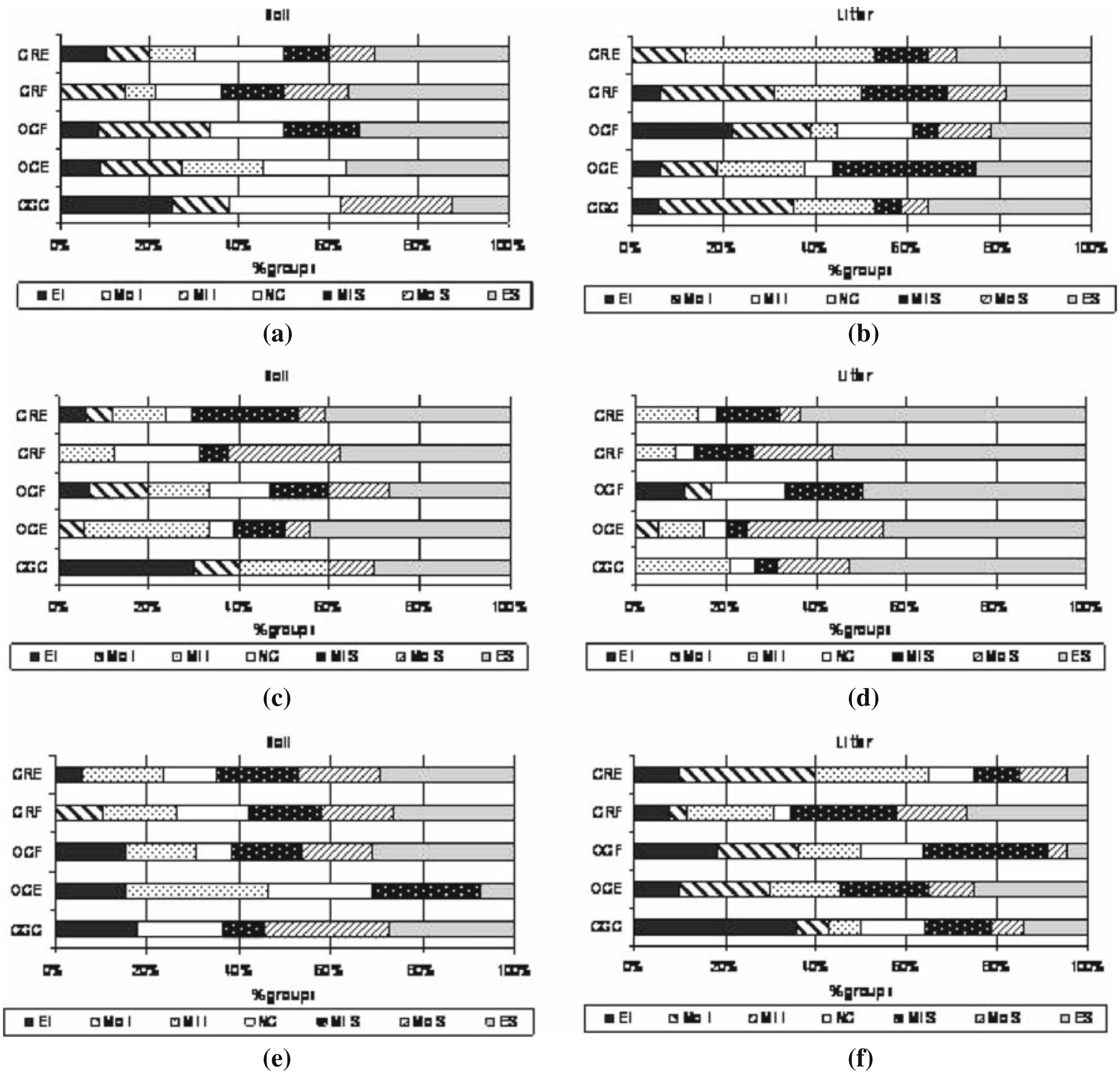
NF natural forest; *CRE* renewed cacao under Erythrina system; *CRF* renewed cacao under forest system; *OCF* old cacao under forest system; *OCE* old cacao under Erythrina system

and *CGC* cacao germplasm collection

Dates followed by the same capital letter(s) in each column are not significantly different at Duncan test ($P = 0.05$)

Dates followed by the same letter(s) in each row and in each sampling date are not significantly different at Duncan test ($P = 0.05$)

Dates followed by the same italicized letter(s) in mean's row and in each local sampling are not significantly different at Duncan test ($P = 0.05$)



CRE - renewed cacao under Erythrina system; CRF - renewed cacao under forest system; OCF - old cacao under forest system; OCE - old cacao under Erythrina system and CGC - cacao germplasm collection

EI - Extreme inhibition, Mo I - Moderate inhibition, Mi I - Mild inhibition, NC - No change, Mi S - Mild stimulation, Mo S - Moderate stimulation, ES - Extreme stimulation.

a, b – September 2003; c, d – February 2004; e, f – August 2004

Fig. 1 *V* index from groups of soil and litter fauna in different cacao agroforestry systems. CRE—renewed cacao under Erythrina system; CRF—renewed cacao under forest system; OCF—old cacao under forest system; OCE—old cacao under Erythrina system; CGC—cacao germplasm collection; EI—Extreme inhibition; Mo I—Moderate inhibition; Mi I—Mild inhibition; NC—No change; Mi S—Mild stimulation; Mo S—Moderate stimulation and ES—Extreme stimulation. **a**, **b**—September 2003; **c**, **d**—February 2004; **e**, **f**—August 2004

social insects (majority Formicidae). Collembola are among the most abundant arthropod groups in the organic layers of forest soils, playing an important role in microfragmentation of litter and stimulating nutrient cycling and the activity of bacteria and fungi colonies (Salamon et al. 2008; Cassagne et al. 2006).

Therefore, cacao agroforestry systems should be considered a landscape management for conservation of soil and litter fauna. Shaded cacao systems protect a large number of ant species from several different components of the ant community by forest-like structure of this agroecosystems (Delabie et al. 2007).

Formicidae is the most important faunal group observed in the tropical region by their diversity and abundance (Moço et al. 2005; Silva and Silvestre 2004; Pellens and Garay 2000). The ants accomplish important functions, such as biological control of pests, improvement of soil aeration, soil water infiltration and soil organic matter incorporation. In infertile soils, the soil improvement by activity of ants is a key factor for growth of vegetation (Folgarait 1998).

The *V* index showed the cacao agroforestry systems as land use which stimulates fauna communities mainly in the February 2003 in both soil and litter. These results confirm earlier findings that the agroforestry systems have a positive effect on the conservation of biodiversity (Mcadam et al. 2007; Sileshi and Mafongoya 2006). Further research is needed as ways of generating information about the factors that enhances the multiplicity of organisms under ground which are able to carry out essential functions that lead to a sustainable cacao agroforestry management.

Conclusion

The cacao agroforestry systems adopted for growing cacao in the southern region of Bahia, Brazil have beneficial effects on the soil and litter faunal communities, and such systems of cacao cultivation could be considered as a conservation system for soil fauna. The development of a litter layer resulted in higher abundance and diversity of soil fauna.

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References

Barros E, Pashanasi B, Constantino R, Lavelle P (2002) Effects of land-use system on the soil macrofauna in western Brazilian Amazonia. Biol Fertil Soils 35:338–347

Barros E, Neves A, Blanchart E, Fernandes ECM, Wandelli E, Lavelle P (2003) Development of the soil macrofauna community under silvopastoral and agrisilvicultural systems in Amazonia. Pedobiologia (Jena) 47:273–280. doi:10.1078/0031-4056-00190

Barros E, Grimaldi M, Sarrazin M, Chauvel A, Mitja D, Desjardins T, Lavelle P (2004) Soil physical degradation and changes in macrofaunal communities in Central Amazon. Appl Soil Ecol 26:157–168

Brown GG, Moreno AG, Barois I, Fragoso C, Rojas P, Hernández B et al (2004) Soil macrofauna in SE Mexican pastures and the effect of conversion from native to introduced pastures. Agric Ecosyst Environ 103:313–327. doi:10.1016/j.agee.2003.12.006

Brown GG, Römbke J, Höfer H, Verhaagh M, Sautter KD, Santana DLQ (2006) Biodiversity and function of soil animals in Brazilian agroforestry systems. In: Gama-Rodrigues AC, Barros NF, Gama-Rodrigues EF, Freitas MSM, Viana AP, Jasmin JM, Marciano CR, Carneiro JGA (eds) Sistemas Agroflorestais: Bases Científicas para o desenvolvimento sustentável. UENF, Campos dos Goytacazes, pp 217–242

Cassagne N, Gers C, Gauquelin T (2003) Relationships between Collembola, soil chemistry and humus types in forest stands (France). Biol Fertil Soils 37:355–361

Cassagne N, Gauquelin T, Bal-Serin MC, Gers C (2006) Endemic Collembola, privileged bioindicators of forest management. Pedobiologia (Jena) 50:127–134. doi:10.1016/j.pedobi.2005.10.002

Chagon M, Paré D, Hébert C, Camié C (2001) Effects of experimental liming on collembolan communities and soil microbial biomass in a southern Quebec sugar maple (Acer saccharum Marsh.) stand. Appl Soil Ecol 17:81–90. doi:10.1016/S0929-1393(00)00134-7

Decaëns T, Lavelle P, Jimenez JJJ, Escobar G, Rippstein G (1994) Impact of land management on soil macrofauna in the oriental llanos of Colombia. Eur J Soil Biol 30:157–168

Decaëns T, Jimenez JJ, Barros E, Chauvel A, Blanchart E, Fragoso C, Lavelle P (2004) Soil macrofaunal communities in permanent pastures derived from tropical forest or savanna. Agric Ecosyst Environ 103:301–312

Delabie JHC, Jahyny B, Nascimento IC, Mariano SF, Lacau S, Campiolo S et al (2007) Contribution of cocoa plantations to the conservation of native ants (Insecta: Hymenoptera: Formicidae) with a special emphasis on the Atlantic forest fauna of southern Bahia, Brazil. Biodivers Conserv 16:2359–2384. doi:10.1007/s10531-007-9190-6

Folgarait PJ (1998) Ant biodiversity and its relationship to ecosystem functioning: the review. Biodivers Conserv 7:1221–1244. doi:10.1023/A:1008891901953

Fontes AG (2006) Ciclagem de nutrientes em sistemas agroflorestais de cacau no sul da Bahia. Campos dos Goytacazes, RJ: Universidade Estadual do Norte Fluminense, 2006. (Tese de Doutorado)–Universidade Estadual do Norte Fluminense, 71p

Fragoso C, Brown GG, Patrón JC, Blanchart E, Lavelle P, Pashanasi B et al (1997) Agricultural intensification, soil biodiversity and agrecosystem function in the tropics: the role of earthworms. Appl Soil Ecol 6:17–35. doi:10.1016/S0929-1393(96)00154-0

Gama-Rodrigues AC, de Barros NF, Mendonça ES (1999) Alterações edáficas sob plantios puros e mistos de espécies florestais nativas do sudeste da Bahia, Brasil. Rev Bras Cienc Solo 23:581–592

Höffer H, Hanagarth W, Garcia M, Martius C, Franklin E, Römbke J et al (2001) Structure and function of soil fauna communities in Amazonian anthropogenic and natural ecosystems. Eur J Soil Biol 37:229–235. doi:10.1016/S1164-5563(01)01089-5

Huhta V (2007) The role of soil fauna in ecosystems: a historical review. Pedobiologia (Jena) 50:489–495

Laossi KR, Barot S, Carvalho D, Desjardins T, Lavelle P, Martins M et al (2008) Effects of plant diversity on plant biomass production and soil macrofauna in Amazonian pastures. Pedobiologia (Jena) 51:397–407

Lavelle P, Barros E, Blanchart E, Brown G, Desjardins T, Mariani L, Rossi J-P (2001) SOM management in the tropics: why feeding the soil macrofauna? Nutr Cycl Agroecosyst 61:53–61

Lavelle P, Senapati B, Barros E (2003) Soil Macrofauna. In: Schroth G, Sinclair FL (eds) Trees, crops and soil fertility. CABI Publishing, Wallingford, pp 303–324

López-Hernández D, Araújo Y, López A, Hernández-Valencial I, Hernández C (2004) Changes in soil properties and earthworm populations induced by long-term organic fertilization of the sandy soil in the Venezuelan Amazonian. Soil Sci 169:188–194. doi:10.1097/01.ss.0000122524.03492.b7

Mcadam JH, Sibbald AR, Teklehaimanot Z, Eason WR (2007) Developing silvopastoral systems and their effects on diversity of fauna. Agrofor Syst 70:81–89. doi:10.1007/s10457-007-9047-8

Moço MKS, Gama-Rodrigues EF, Gama-Rodrigues AC, Correia MEF (2005) Caracterização da fauna edáfica em diferentes coberturas vegetais na região norte fluminense. Rev Bras Cienc Solo 29:555–564. doi:10.1590/S0100-06832005000400008

Müller MW, Gama-Rodrigues AC (2007) Sistemas Agroflorestais com cacaueiro. In: Valle RR (ed) Ciência, Tecnologia e Manejo do Cacaueiro. CEPLAC/CEPEC, Ilhéus, pp 246–271

Palacios-Vargas JG, Castanõ-Meneses G, Gómez-Anaya JA, Martínez-Yrizar A, Mejía-Recamier BE, Martínez-Sánchez J (2007) Litter and soil arthropods diversity and density in a tropical dry forest ecosystem in Western Mexico. Biodivers Conserv 16:3703–3717. doi:10.1007/s10531-006-9109-7

Pellens R, Garay I (2000) Edaphic macroarthopod communities in fast-growing plantations of Eucalyptus grandis former hill maid (Myrtaceae) and AOCFia mangium wild (Leguminosae) in Brazil. Eur J Soil Biol 35:77–89. doi:10.1016/S1164-5563(99)00209-5

Richter A, Maria Klein A, Tscharntke T, Tylianakis JM (2007) Abandonement of coffee agroforests increases insect abundance and diversity. Agrofor Syst 69:175–182. doi:10.1007/s10457-006-9020-y

Rossi J-P, Blanchart E (2005) Seasonal and land-use induced variations of soil macrofauna composition in the Western Ghats, southern India. Soil Biol Biochem 37:1093–1104

Salamon JA, Scheu S, Schaefer M (2008) The Collembola community of pure and mixed stands of beech (*Fagus sylvatica*) and spruce (*Picea abies*) of different age. Pedobiologia (Jena) 51:385–396

Sayer EJ (2005) Using experimental manipulation to assess the roll of leaf litter in the functioning of forest ecosystems. Biol Rev Camb Philos Soc 80:1–31. doi:10.1017/S1464793105006846

Schroth G, Mota MSS, Jerozolimski A (2006) Agroforestry and the conservation of forest cover and biodiversity in tropical landscapes – on – site and off – site effects and synergies with environmental legislation. In: Gama-Rodrigues AC, Barros NF, Gama-Rodrigues EF, Freitas MSM, Viana AP, Jasmin JM, Marciano CR, Carneiro JGA (eds) Sistemas Agroflorestais: Bases Científicas para o desenvolvimento sustentável. UENF, Campos dos Goytacazes, pp 67–86

Sileshi G, Mafongoya PL (2006) Variation in macrofaunal communities under contrasting land use systems in eastern Zambia. Appl Soil Ecol 33:49–60. doi:10.1016/j.apsoil.2005.09.003

Silva RR, Silvestre R (2004) Riqueza da fauna de formigas (Hymenoptera: Formicidae) que habita as camadas superficiais do solo em Seara, Santa Catarina. Papeis Avulsos Zoologia 44:1–11

Tapia-Coral SC, Luizão FJ, Wandelli EV (1999) Macrofauna of the sedan chair in systems cocoa agroforestry on abandoned pastures in the Amaonian Central. Acta Amazonica 29:477–495

Vohland K, Schroth G (1999) Distribution patterns of the litter macrofauna in agroforestry and monoculture plantations Amazonian central in the affected by plant species and management. Appl Soil Ecol 13:57–68. doi:10.1016/S0929-1393(99)00021-9

Wardle DA (1995) Impacts of disturbance on detritus food webs in agriculture-ecosystems of contrasting tillage and weed management practices. Adv Ecol Res 26:105–182. doi:10.1016/S0065-2504(08)60065-3

Wardle DA, Verhoef HA, Clarholm M (1998) Trophic relationships in the soil microfood-web: predicting the responses to a changing global environmental. Glob Chang Biol 4:713–727. doi:10.1046/j.1365-2486.1998.00206.x

Wardle DA, Yeates GW, Barker GM, Karen IB (2006) The influence of plant litter diversity on decomposer abundance and diversity. Soil Biol Biochem 38:1052–1062. doi:10.1016/j.soilbio.2005.09.003

Yang X, Warren M, Zou X (2007) Fertilization responses of soil litter fauna and litter quantity, quality and turnover in low and high elevation forests if Puerto Rico. Appl Soil Ecol 37:63–71. doi:10.1016/j.apsoil.2007.03.012