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Plant community influences on earthworms in Lamto savannahs (Côte d'Ivoire)

Ehouman N'guetta Moïse*[12], Tiho Seydou[12], Yéo Kolo[12], Dagnogo Mamadou[2]

[1,2] Université Abobo Adjamé & station d'écologie de Lamto.
[2] UFR des sciences de la nature, Université d'Abobo – Adjamé, 02 BP 801 Abidjan 02, Côte d'Ivoire.
*[12] corresponding author e-mail: ehmoise@yahoo.fr
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ABSTRACT

Objectives: To determine the variation of plant communities (above ground biodiversity) and earthworm community structure (below ground biodiversity) in three vegetations types (grassy savannah, woody savannah and forest).

Methodology and results: The experiment waswas conducted in Lamto savannahs (Côte d'Ivoire) in both the rainy and dry season. This experiment consisted of sampling earthworms and plants and measuring environmental parameters in a regular grid (50 m x 50 m) in three vegetation types (forest, woody savannah and grassy savannah). In each vegetation type 100 monoliths of soil were dug out (50 cm x 50 cm x 30 cm). The species of the plants harvested in each unit of 5 m x 5 m were counted and identified. Ordination method such as correspondence analysis CA and canonical correspondence analysis (CCA) were used to establish relation between earthworms and plants families. CCA showed that, the variance accounted for plants families was nearly half of total variance extracted by CA in forest and woody savannah data. The remaining variance was due to environmental parameters and the undetermined parameters.

Conclusions and application of findings: Earthworms species were highly correlated to plants in the different environment types. However in grassy savannah, the variance accounted for plants families was a weak portion. Moreover the multiple correlations between the axes and plants were fairly weak. This interaction between earthworm species and plants can be applied in the agro-ecosystem to improve soil fertility. Because the decomposition of plants litters by earthworms is involved in the mineralization of soil organic matter.

Keywords: canonical correspondence analysis, correspondence analysis, earthworms, Lamto, plants, savannahs

INTRODUCTION

Terrestrial ecosystem functioning consists of linkage between the diversity of organisms above- and below-ground (Hooper et *al*., 2000; Putten et *al*., 2009). The studies on above-and below-ground interactions are focused on two approaches (Putten et *al.,* 2009): The first is the primary producer approach, which considers how roots and leaves, above-and below-ground herbivores, pathogens and symbionts and their predators interact. The interaction can be direct, or indirect, via modifications in plant compounds (Eisenhauer & Scheu, 2008). The second is the detritus approach which considers how dead organic material (detritus), microbial decomposers, detritivores, microbivorous organisms and predators interact (Wardle, 2002). In recent years, a growing body of empirical studies have shown that aboveground-belowground interactions have important consequences for community organisation and ecosystem processes (Wardle, 1997). These studies deal with the link between litter transformers (macrofauna and mesofauna) such as annelids (earthworms), ants, termites, isopods, diplopods and plants community via litter decomposition. In these processes earthworms are known to be one of the main groups (Lavelle, 1997). Their activities (soil aeration, porosity and litter decomposition) are important in the vegetation pattern (Jouquet et *al*., 2006; Brown et *al*., 2000). Several reviews have already analyzed specific types of above- and belowground interactions. These include interactions between below ground decomposers and above ground invertebrates (Scheu, 2001). However these researchers did not point out the linkage between soil fauna (earthworms) as below-ground biodiversity and plants community that constitute above-ground biodiversity. Earthworm activities are important in vegetation variation and succession. But the correlation between earthworms and vegetation pattern in a given ecosystem is not well documented. This study hypothesizes that vegetation type influences earthworm distribution according to seasonal variation. The aim of this study was to determine the variance accounted for plants communities (aboveground biodiversity) in earthworm community structure (belowground biodiversity) in three vegetations types (grassy savannah, woody savannah and forest).

MATERIAL AND METHODS

Site description: The study site was located in the natural Reserve of Lamto (6°N, 5°2W) in Central Côte d'Ivoire. The reserve is a transition zone composed of semi – deciduous humid forest in the South and Soudanian savannahs in the North. The 2700 ha of the reserve are covered by a mosaic of forest and savannah vegetation which is referred to as Guinean savannah. The study plots were located in a grassy savannah, woody savannah and forest. The savannahs are maintained by annual burning. Lamto is characterized by a bimodal rainfall indicating two wet seasons from April to July and from September to October. Mean annual temperature over 10 years (2000 – 2010) was 28.4°C while rainfall is in the range of 8.4 mm in January to 189.7 mm in June. Most soils lie on granitic bedrock and are classified as ferralsols (F.A.O. classification).

Earthworms sampling: Earthworms sampling was carried out from July to September in the rainy season and from December to January 2009 in dry season, on a 50 x 50 m size-plot (fig. 1) obtained from three types of vegetation (grassy savannah, woody savannah and forest). Each plot was gridded at 5 m intervals to yield a block system of 10 "columns" and 10 "lines"; giving a total of 100 subplots of 25 m^2 each. A total of 100 monoliths of 50 cm sides and 30 cm depth were systematically taken from the grid. Earthworms were extracted by direct hand sorting from the three successive strata of 10 cm depth (Lavelle, 1978). All earthworms were preserved in 4 % formaldehyde. Individuals were then separated in the laboratory into species, counted and weighed. Species were determined using the taxonomic guide developed by Omodeo & Vaillaud (1967) and Cszudi & Tondoh (2007).

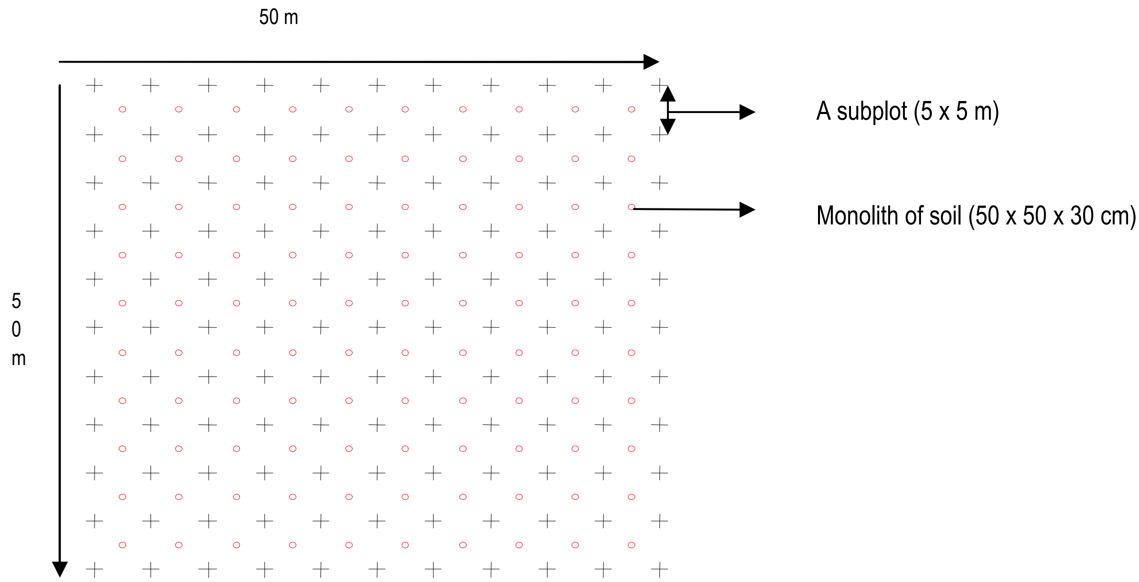

Figure.1: Regular grid (50 x 50 m)

Vegetation sampling: In the different sites (Grassy savannah, Woody savannah and forest), plants were collected in the both rainy and dry season in the same regular grid (50 m x 50 m) used for earthworms sampling. Each subplot (5 m x 5 m) was divided in 4 subplots (2.5 m x 2.5 m). These subunits were marked out with ribbons. Then the plants of each subplot were counted individually in order to determine the density of all plants within each subplot. Thus the total density of plants on the regular grid was determined by adding the plants of each subplot. Plants were identified to species before grouping them into family for statistical analysis.

Environmental parameters: Total carbon (total C) was measured by dry combustion using a LECO CNS 2000 analyzer (LECO corporation, St Joseph, MI).The pH was determined using a Mettler-Toledo-GmBH MP Ph meter. To determine soil moisture, soil cores were placed in a steam room at 105°C for 48 hours. These soil parameters (total C, pH, Soil moisture) were determined to assess the proportion of variance they do explain in the distribution of earthworms on each vegetation type.

Statistical analysis: To study the relation between aboveground (vegetation) and belowground (earthworms) biodiversity, an ordination method (gradient method analysis) developed by Ter Braak (1986, 1987) and (Lebreton et *al*., 1988) was used in order to summarize all the information in the community. Thus correspondence analysis (CA) and canonical correspondence analysis (CCA) were used. CA was at the first time used to summarize the dispersion of species in order to know the main variation account for earthworms' species data. Canonical ordination is used to detect the pattern of variation in species data that can be explained better by the plants families. CCA was particularly adapted to analyze relation between species and habitat (Palmer, 1983; Ter Braak, 1986, 1987, 1988). The aim of canonical ordination is to detect the main pattern in the relation between the species and the observed environment (Jongman et *al*., 1995). This technique was used to interpret our data because those collected in community ecology and landscape ecology are mostly multivariate i.e. each statistical sampling unit is characterized by many attributes. These data are complex, showing sampling error, redundancy and bulky (Gauch, 1982). All ordinations were performed using CANOCO software for windows (V.4.51). The Monte Carlo permutation test was applied to investigate the statistical significance of CCA axis. Moreover canonical coefficients were used to determine which plants contributed to linear relation with canonical axes.

Variance partitioning: For each CCA, a variance partitioning procedure focused on two sets of predictor matrices was used to determine the likelihood of success of the environmental parameters (pH, organic carbon, and soil moisture) and plant family variables for explaining patterns in earthworm community structure.

The procedure consists to partition the total variation of earthworm assemblage into the following sources of variation: (i) plants families, (ii) environmental parameters, and (iii) unexplained variation. To calculate the individual part of the variability, earthworm species data matrix, the environmental parameters and plants family data matrices were subjected to a series of partially constrained ordinations.

RESULTS

Density of earthworm species and plants families: A total of 19 species of earthworms were recorded within the three sites during the dry and rainy season surveys. *Millsonia omodeoi*, *Chuniodrilus zielae, Chuniodrilus palustris* and *Sthulmania porifera* were the most abundant in grassy savannah during the wet season. *Millsonia omodeoi* had the highest density in woody savannah, followed by *Chuniodrilus zielae* and *Dichogaster agilis. D. agilis* was the most abundant species in forest in rainy season followed by *Chuniodrilus zielae* and *Chuniodrilus palutris*. In dry season, *Millsonia omodeoi* was the single species which dominated in density. Table 1 summarizes the seasonal average density of earthworms. The different sites such as grassy savannah, forest and woody savannah were ordered successively in the decreasing of density in both rainy season and dry season. The student test indicated that in rainy season, grassy savannah embodied more worms than woody savannah ($p<0.01$) whereas the woody savannah embodied more worms than forest ($p<0.05$). There was no significant difference between grassy savannah and forest ($p>0.05$). However in dry season there was significant difference between this pairs of habitats ($p<0.01$) excepting woody savannah and forest ($p>0.05$). A total of 41 families of plants were recorded in the three stands of vegetation (forest, woody savannah, grassy savannah) in both rainy and dry season (Table 2).

Table1: Density of earthworms (ind/m^2) in the three stands of vegetation across seasons (mean ±SE, n=100)

Earthworm species	Rainy season			Dry season		
	Grassy savannah	**Woody savannah**	**Forest**	**Grassy savannah**	**Woody savannah**	**Forest**
Dichogaster saliens	0.24±0.16	1.6±0.59	0.24±0.16	0	0	0
Millsonia omodeoi	21.68±1.4	24.4±1.6	7.72±0.94	30.68±1.82	14.6±0.83	11.6±0.12
Sthulmania porifera	23.84±2.47	7.08±1.2	1.08±0.65	0.52±0.21	0.28±0.15	0
Chuniodrilus zielae	21.96±2.74	15.04±2.07	13.36±1.57	6.8±0.84	2.2±0.36	2.96±0.53
Chuniodrilus palustris	11.68±1.79	1.44±0.42	12.68±1.95	0.48±0.26	0.16±0.12	0.08±0.05
Agastrodrilus multivesiculatus	1.64±0.29	0.64±0.15	6.44±1.14	1±0.2	0.68±0.2	0.96±0.22
Dichogaster terrae	0.72±0.22	1.56±0.3	0.96±0.24	0.4±0.13	1.72±0.32	1.36±0.32
Dichogaster baeri	0.92±0.25	3.28±0.78	3.4±1	0	0.16±0.09	0.24±0.2
Dichogaster agilis	3.56±0.65	11.44±1.32	27.88±2.19	3.32±0.45	5±0.6	9.44±0.92
Agastrodrilus opistogynus	0.88±0.4	0.76±0.46	0.72±0.34	0	0	0
Millsonia sp1	0.2±0.08	0.32±0.21	0.52±0.15	0	0	0.16±1.11
Chuniodrilus sp1	9.16±2.15	4.44±1.26	8.96±1.56	0	0	0
Millsonia lamtoiana	0	0.88±0.2	1.28±0.27	0.08±0.56	0.88±0.22	1.2±0.29
Hyperiodrilus africanus	0	0.08±0.56	0	0	0	0
Dichogaster eburnea	0	1.04±0.65	2.24±2.1	0	0	0
Dichogaster sp2	0	0.84±0.37	0	0	0	0
Chuniodrilus sp2	0	4.44±1.26	2.76±0.94	0	0	0
Dichogaster sp3	0	0.52±0.41	0.64±0.52	0	0	0
Millsonia ghaneensis	0	0	0	2.20±0.21	0	0
Total	**96.48±12.6**	**75.36±12.55**	**90.88±15.72**	**44.08±4.68**	**25.68±2.89**	**28±3.76**
Number of species	**12**	**17**	**16**	**9**	**9**	**9**

Table 2: Density of plants families in the three stands of vegetation (grassy savannah, woody savannah and forest) across seasons (mean±SE, n=100)

	Rainy season			Dry season		
Plant families	**Grassy savannah**	**Woody savannah**	**Forest**	**Grassy savannah**	**Woody savannah**	**Forest**
Ampelidaceae	-	2.12±0.71	0.01±0.16	-	2.27±0.75	0.02±0.02
Anacacardiaceae	-	0.1±0.03	0.88±0.61	-	0.49±0.18	1.54±0.63
Annonaceae	0.79±0.10	0.47±0.26	5.18±0.56	0.77±0.15	0.56±0.27	5.16±0.79
Apocynaceae	-	0.46±0.08	1.95± 0.73	-	1.26±0.30	3.2±0.44
Araliaceae	-	0.17±0.04	0.03±0.42	-	1.11±0.11	-
Arecaceae	0.2±0.07	0.19±0.04	0.22±0.09	0.01±0.01	0.06±0.04	0.18±0.09
Asclepediaceae	0.01±0.01	0.13±0.05	-	-	0.16±0.09	-
Asteraceae	0.08±0.03	40.74±3.48	17.05±3.43	-	41.64±377	17.97±3.98
Bignogonaceae	-	0.02±0.02	-	-	-	-
Bombacaceae	-	0.05±0.02	0.2±0.04	-	-	0.38±0.12
Cesalpiniaceae	-	2.3±0.74	0.06±0.23	-	2.18±0.75	0.18±0.11
Cochlospermaceae	0.18±0.05	0.03±0.03	-	0.1±0.04	-	-
Combretaceae	-	0.49±0.10	-	-	0.86± 0.18	1.28±0.30
Commelinaceae	-	5.04±1.17	0.25±0.11	-	0.89±0.39	-
Connaraceae	-	2.8±0.57	0.02±0.37	-	2.46±0.48	0.09±0.06
Convolvulaceae	-	-	-	-	-	1.02±0.29
Cyperaceae	0.88±0.49	6.57±0.94	-	0.8±047	4.52±0.89	-
Ebenenaceae	-	0.28±0.06	0.45±0.20	-	1.63±0.52	0.63±0.17
Erythroxylaceae	-	0.01±0.01	0.27±0.095	-	0.02±0.02	0.6±0.22
Euphorbiaceae	-	0.49±0.08	0.09±0.07	0.01±0.01	1.04±0.23	0.53±0.17
Hyppocastanaceae	-	0.76±0.31	0.15±0.29	-	0.71±0.26	0.65±0.60
Labiaceae	-	-	1.26±0.69	-	-	1.82±0.88
Leguminoseae	-	0.06±0.03	1.68±0.60	-	0.15±0.08	2.04±0.41
Logoniaceae	-	-	0.02±0.07	-	0.06±0.06	-
Meliaceae	-	0.01±0.01	0.04±0.01	-	0.03±0.03	0.05±0.06
Mimosaceae	-	-	0.02±0.02	-	-	-
Moraceae	0.01±0.01	0.5±0.29	0.09±0.02	-	0.55±0.24	0.41±0.12
Ochnaceae	-	-	0.09±0.02	-	-	0.25±0.11
Olacaceae	-	0.96±0.33	0.51±0.09	-	1.32±0.39	0.65±0.16
Poaceae	218.37±10.25	2.5±1.08	0.14±0.134	193.42±9.50	2.39±1.25	-
Papilionaceae	22.28±2.49	3±0.53	0.18±3.39	18.82±2.19	3.39±0.59	0.4±0.14
Poygonaceae	-	0.09±0.04	0.01±0.03	-	0.22±0.10	-
Rhamnaceae	-	-	0.56±0.14	-	-	0.53±0.20
Rubiaceae	0.15±0.15	0.07±0.02	-	0.2±0.2	0.14±0.06	-
Sapindaceae	-	3.59±0.95	3.73±0.50	0.78±0.51	3.52±0.66	4.3±0.55
Sapotaceae	-	1.21±0.34	1.13±0.36	-	1.79±0.53	2.28±0.49
Simarombaceae	-	0.03±0.01	-	-	0.1±0.06	0.09±0.06
Sterculiaceae	-	3.91±0.92	2.23±0.12	-	4.24±0.90	3.49±0.70
Tiliaceae	-	0.2±0.10	0.31±0.07	-	0.11±0.08	0.47±0.13
Verbenaceae	0.06±0.03	0.26±0.05	-	0.01±0.01	0.6±0.15	0.17±0.06
Zingiberaceae	1.19±0.62	34.02±3.62	2.77±0.97	-	28.9±3.64	2.57±1.01

(-) denote lack of plants families in the site

Environmental parameters: Three environmental parameters were measured (soil organic carbon, Soil moisture and pH) (table 3).This study revealed that soil organic carbon was poor in the three types of vegetation. The mean value was 5.6%. The pH was similar in all types of vegetation (pH = 6). Then the soil moisture was 23.14% in rainy season and 8.85% in dry season.

Table 3: Environmental parameters (Ph), soil moisture (%), organic carbon (%) in the three vegetation types across seasons

Soil parameters	Rainy season			Dry season		
	Grassy savannah	Woody savannah	Forest	Grassy savannah	Woody savannah	Forest
Ph	5.68	6.18	6.08	6.13	5.94	5.98
Soil moisture	21.98	22.44	25.02	9.09	10.6	6.86
Organic carbon	5.25	2.47	10.01	3.94	5.04	7.66

Multivariate analysis

Forest data - Rainy season: The first four axes of the Correspondence analysis (CA) accounted for 56.9% of the total variance within earthworm data set. The canonical correspondence analysis (CCA) indicated that the variance explained by the four axes was 25.6%. The eigenvalues dropped for the first two axes, from 0.73 to 0.36 in CA to 0.29 to 0.22 in CCA. But the variance explained by relationships between earthworm species and plants families for the four first axes was nearly 70% (Table 4a). Apparently, the plant families are not sufficient to predict the main variation in earthworm species dispersion extracted by CA, but they do predict a substantial part of the remaining variation. The multiple correlations from CCA were 0.66 from axis 1 to 0.62 on axis 4. Axes 2 and 3 were strongly correlated with the plants variables, respectively 0.87 and 0.75. From canonical coefficients (Table 4b), axis 1 is a Bombacaceae and a Tiliaceae gradient and the second axis is a Connaraceae family gradient. CCA with these plants families produced an ordination in which the first and all canonical axes were not significant ($P > 0.05$)

Forest data -Dry season: The first four axes of the CA accounted for approximately 70% of the total variance within data set (Table 4a). From CCA, the plants families explained 38.8% of earthworm's variance for the first four axes. The variance explained by relationships between earthworm species and plant families for the first four axes nearly 80%. The first two axes of CCA were strongly correlated (respectively 0.92 and 0.72) to plants families. From canonical coefficients (Table 4b), the first axis is a Simarombaceae, an Asteraceae and a Connaraceae gradient. The second axis is a Hyppocastanaceae gradient. CCA with these plants families produced an ordination in which the first and all canonical axes were significant ($p < 0.005$).

Table 4a: Correspondence analysis (CA) and canonical correspondence analysis (CCA) results for forest data

	Rainy season				Dry season			
	Axis 1	Axis 2	Axis 3	Axis 4	Axis 1	Axis 2	Axis 3	Axis 4
CA								
Eigenvalues	0.737	0.368	0.294	0.269	0.444	0.378	0.335	0.300
Cumulative percentage variance of earthworms data	25.1	37.7	47.7	56.9	20.7	38.3	54.0	67.9
CCA								
Eigenvalues	0.290	0.229	0.125	0.108	0.376	0.175	0.163	0.117
Cumulative percentage variance of earthworms data - plants families	9.9	17.7	21.9	25.6	17.5	25.7	33.3	38.8
Eigenvalues	0.138	0.034	0.011	0.680	0.046	0.036	0.007	0.420
Cumulative percentage variance of earthworms data – environmental parameters	4.7	5.9	6.3	29.4	2.2	3.8	4.2	23.8

Table 4b: Canonical coefficients of plants families with the first four axes of CCA for forest data.

	Rainy season				Dry season			
	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**
Earthworms-plants correlations	0.657	0.878	0.756	0.624	0.925	0.724	0.731	0.603
Ampelidaceae								0.2150
Anacardiaceae			0.3226					
Annonaceae							**0.5086**	
Apocynaceae						0.2644		
Araliaceae			0.2421					
Arecaceae			-0.2334			0.2566		0.3717
Asteraceae			-0.2499		**0.7883**			
Bombacaceae	**0.4925**	0.2422			**0.6780**			0.3045
Combretaceae					0.2634	0.3077		
Connaraceae		**0.7886**	-0.2209				0.2274	
Ebenaceae								0.2409
Poaceae			-0.2623					
Hyppocastanaceae			**0.4685**	**0.3014**		**0.4054**	0.2861	**0.4607**
Leguminoseae				**-0.3778**				
Mimosaceae				0.2150				
Moraceae					0.2840			0.2467
Ochnaceae		0.3081		**0.3579**				0.2093
Olacaceae	-0.2116	0.2190	0.2541			0.2480	**0.4499**	0.2568
Papilionaceae				-0.2204				
Rhamnaceae				-0.2588				
Sapindaceae	0.2338	0.2850					0.2657	
Sapotaceae				-0.2021			0.2240	
Simarombaceae					**0.8946**			
Sterculiaceae			-0.3527					
Tiliaceae	**0.4367**		-0.2526	0.2530				

Empty cell denote canonical coefficient ($R<|0.2|$)

Woody savannah data- rainy season: The first four axes of the CA accounted for approximately 52.2% of the total variance within earthworm data set. The variance explained by the four axes of CCA was 25.5%. Within this variance, relation earthworms-plants variables explained nearly 60% (Table 5a). The first four axes of CCA were best correlated with plants variables, from 0.87 on axis 1 to 0.66 on axis 4 (Table 5b). From canonical coefficients (Table 5b), it can be seen that the axis 1 is a Commelinaceae family and Tiliaceae gradient. The second axis is a Bombacaceae gradient. The Monte Carlo permutation test was not significant for the first four axes ($p>0.05$).

Woody savannah data- dry season: The eigenvalues dropped from CA to CCA (Table 5a) from 67.2% for the first four axes of the total variance within earthworms data in CA to 28.9% when we have chosen the axes in the light of plants variables by means of CCA. The variance explained by relationships between earthworm species and plant families for the first four axes was 75%. The Monte Carlo permutation test showed that the first four canonical axes were not significant (p□0.05). Nevertheless these first four canonical axes were best correlated with plants variables from 0.8 on axis 1 to 0.66 on axis 4. From canonical coefficients (Table 5b) the first axis is a Zingiberaceae gradient and the second canonical axis is Anacardiaceae and Hyppocastanaceae gradient.

Table 5a: Correspondence analysis (CA) and canonical correspondence analysis (CCA) results for woody savannah data

	Rainy season				Dry season			
	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**
CA								
Eigenvalues	0.512	0.446	0.343	0.295	0.622	0.337	0.297	0.252
Cumulative percentage variance of earthworms data	16.7	31.3	42.6	52.2	27.7	42.7	56.0	67.2
CCA								
Eigenvalues	0.266	0.233	0.151	0.129	0.290	0.138	0.119	0.100
Cumulative percentage variance of earthworms data – plants families	8.7	16.3	21.3	25.5	12.9	19.1	24.4	28.9
Eigenvalues	0.093	0.061	0.033	0.507	0.049	0.027	0.018	0.609
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 5b: Canonical coefficients of plants families with the first four axes of CCA woody savannah data.

	Rainy season				Dry season			
	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**
Earthworms-plants correlations	0.871	0.775	0.731	0.657	0.801	0.717	0.722	0.664
Ampelidaceae		0.3308	0.3636	0.2681				
Anacardiaceae			0.3158	0.2693		**0.3510**		0.2970
Annonaceae					0.4533		0.2297	
Apocynaceae			0.3213	0.3404			**0.3923**	
Araliaceae						0.2676	0.2422	0.2283
Arecaceae		0.3040			0.3654		0.2757	
Asclepediaceae					0.4306			
Asteraceae	0.3944	0.2568	0.2916		0.2111			
Bombacaceae	0.3852	**0.6494**						
Cesalpiniaceae			0.2300					
Combretaceae	0.3955							
Commelinaceae	**0.5643**				0.2689			
Connaraceae						0.2218	0.2238	
Cyperaceae			0.3412					
Ebenaceae				0.2499				
Erythroxylaceae							**0.3163**	
Poaceae						0.2873		0.3233
Hyppocastanaceae						**0.3513**		0.2093
Leguminoseae						0.2407		
Meliaceae			0.3598	**0.4750**				
Olacaceae			0.2191					
Papilionaceae			0.2118	0.2743				
Poygonaceae								0.2589
Rubiaceae			0.3269				0.2072	
Sapotaceae			0.2782			0.2236	0.2085	
Simarombaceae				0.2310				
Sterculiaceae			**0.4484**	0				0.2045
Tiliaceae	**0.5435**		0.3339	0.2867				
Verbenaceae	0.3542			0.2618				**0.4448**
Zingiberaceae	0.3741		0.2702		**0.6356**			

Empty cell denote canonical coefficient < |0.2|

Grassy savannah data- rainy season: The first four axes of the Correspondence (CA) accounted for 61.3% of the total variance within data set. The canonical correspondence analysis (CCA) performed on the data set indicated that the variance explained by the first four axes was 17.6%. But the variance explained by the relationship between earthworms species and plants families for the first four axes was 85.3%.The eigenvalues dropped for the first two axes, from 0.37and 0.27 in CA to 0.12 to 0.08 in CCA (Table 6a). Apparently the plants families were not sufficient to predict the main variation in earthworms species composition extracted by CA, but they do predict a substantial part of the remaining variation. The first two axes of CCA were moderately related to plants variables (multiple correlation was 0.61 in axis 1 and 0.66 in axis 2) (Table 6b). From canonical coefficients (Table 5b), the first axis is Papilionnaceae, Asteraceae and Poaceae gradient and the second axis is a Cyperaceae gradient. CCA with plants families produced an ordination in which the first and all canonical axes were significant (P< 0.05 for axis 1 and, p< 0.05 for all axes).

Grassy savannah data -dry season: The first four axes of CA accounted for 66.5% of the total variance within data set and the CCA performed on the data set indicated that the variance explained by the first four axes was 10.5%. Within this variance the relationship between earthworm species and plants families explained 85.6% (Table 6a). From the canonical coefficients (Table 6b), the first canonical axis is Annonaceae and Poaceae gradient. The second canonical axis is a Cyperaceae gradient. The multiple correlations between earthworm species and plants variables were relatively weak. Monte Carlo permutation test showed that the first and all canonical axes were not significant (P> 0.05 for the axis 1 and, p>0.05 for all axes).

Table 6a: Correspondence analysis (CA) and canonical correspondence analysis (CCA) results for grassy savannah data

	Rainy season				Dry season			
	Axis1 1	Axis2 2	Axis3 3	Axis4 4	Axis1 1	Axis2 2	Axis3 3	Axis 4
CA								
Eigenvalues	0.369	0.272	0.187	0.179	0.211	0.192	0.179	0.150
Cumulative percentage variance of earthworms data	22.5	39.0	50.4	61.3	19.1	36.6	52.8	66.5
CCA								
Eigenvalues	0.121	0.082	0.058	0.028	0.046	0.029	0.022	0.018
Cumulative percentage variance of earthworms data – plants families	7.4	12.3	15.9	17.6	4.2	6.8	8.8	10.5
Eigenvalues	0.064	0.024	0.006	0.332	0.024	0.008	0.005	0.205
Cumulative percentage variance of earthworms data-environmental parameters	3.9	5.4	5.7	25.9	2.2	2.9	3.3	21.9

Table 6b: Canonical coefficients of plants families with the first four axes of CCA (grassy savannah data).

	Rainy season				Dry season			
	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**
Earthworms-plants correlations	0.612	0.664	0.460	0.496	0.532	0.407	0.479	0.343
Annonaceae					**0.6697**			0.3077
Arecaceae			**0.4591**					
Asclepediaceae			**0.5679**					
Asteraceae	**-0.4929**	-0.3331	**-0.4752**					
Cochlospermaceae			0.2190					

Cyperaceae		**0.9503**			0.2746	**0.6737**	-0.2097	-0.4324
Euphorbiaceae							**0.9104**	0.3696
Poaceae	**-0.4294**			0.3762	**-0.7511**		-0.2800	
Papilionnaceae	**0.5590**			0.3406	0.4569			
Rubiaceae								-0.2027
Verbenaceae		0.2690	0.2331		0.3638			**0.5731**
Zingiberaceae	0.3359			**0.7312**				

Empty cell denote canonical coefficient < |0.2|

Variance partitioning: The total amount of variance explained by plant familieses data matrices and environmental parameters (C, pH, Soil moisture) data in forest in rainy season was 96.66% (Table 7). Plant families account for 45% whereas environmental parameters indicated 51.66%. The undetermined variance was 3.34%. But in dry season the variance was best explained by plant families in earthworm species data (57.14%). The unexplained variance was 7.81%. The variance partitioned in woody savannah showed that the variation in earthworm structure was best explained by plants family in rainy season. The variance was nearly 50%. But in dry season the variance was fairly partitioned (40%) between both plants family variables and environmental parameters. Then the undetermined variance was 10.43%. The structure of earthworms was best explained by environmental parameters in grassy savannah during rainy and dry season. The variance accounted respectively for 42.25% and 32.93%. The undetermined variance is more significant than others (51.29%).

Table 7: Partitioning variance (%) in the three sites of vegetation (forest, woody savannah, and grassy savannah)

Vegetation type	**Rainy season**				**Dry season**			
	P	**EP**	**T**	**UEPV**	**P**	**EP**	**T**	**UEPV**
Forest	45	51.66	96.66	3.34	57.14	35.05	92.19	7.81
Woody savannah	49	43.58	92.33	7.67	43	46.57	89.57	10.43
Grassy savannah	28.71	42.25	70.96	29.04	15.78	32.93	48.71	51.29

P = plants, EP = environmental parameters, T = total variance, UEPV = Unexplained variance

DISCUSSION

One view of ordination technique, assumes that there is an underlying (or latent) structure in the data, i.e. that the occurrence of earthworm species in the different habitats, is determined by a few unknown environmental variables (latent or explanatory variables) according to a response model. It was assumed in this study that plants in Lamto savannah could be these latent variables. Thus canonical ordination combined both aspects of regular ordination and aspects of regression. The eigenvalues in CCA usually were smaller than those in CA because of the restrictions imposed on the site scores to be linear combination of explanatory variables (Jongman et *al*., 1995). By comparing the eigenvalues of CA with those in CCA, the magnitude of variance accounted for plants families can be inferred to predict the main variation in earthworms species composition extracted by CA. Whatever the season, the variance accounted for plant families was nearly half of total variance extracted by CA in earthworms' species dispersion (45 to 57% in forest and from 43 to 49% in woody savannah). Moreover, the first four axes in these two sites were strongly correlated with plant families. In grassy savannah, the variance accounted for plant families was a weak portion (29% in rainy season and 16% in dry season) of total variance extracted by CA. And the multiple correlations between the first four axes and plants were fairly weak particularly in dry season. Plant families apparently were not sufficient to predict the main variation in earthworm species composition and dispersion, but they do predict a substantial part of the total variance. The remaining variance was due to environment parameters such as abiotic parameters (i.e. soil moisture, Ph, soil organic carbon) (Tiho, 2001; Hernandez et *al*., 2003). It may also be due to interactions of other soil organisms with earthworms or a probable stochastic process that create a sampling error (Gauch, 1982). Although high correlation between earthworm species and plant families was observed in forest and woody savannah, the plant families identified as main gradients had low densities. These plants were rare. This might show that earthworm distribution was not due to the density of litter but possibly to its quality. Hättenschwiler et *al*., (2005) have reported that there was a close correlation between litter quality and decomposition; however these correlations were commonly determined from single-species litters in experimental conditions. Moreover (Abbadie et *al*., 2006) in their study on leaves of the most common tree in Lamto savannahs, have reported that the most decomposable materials were obviously the *Indigofera polysphaera* (herbaceous legume) leaves. In these species, 17.1% of the carbon was mineralized in 14 days (vs. 2.5% in control soil). Grass roots and tree leaves were also decomposed rapidly (6.9% to 12.8% of their carbon mineralized in 14 days). The most resistant to biodegradation were the grasses (5.9% to 6.5%). In the current study, the different gradients might act in synergy to influence earthworm distribution in forest and woody savannah. Plant families Bombacaceae and Tiliaceae might be part of this combination in rainy season. The fact that we did not record the same plants gradients in dry season plots indicated that earthworms might not rely on a particular plant family, but rather on litter quality. Among factors that cause high correlation between earthworms and plants families in woody sites, canopy cover of tree could created suitable environmental conditions in surrounding soil that maintained earthworms and other litter decomposition organisms. The weak correlation in grassy savannah between earthworms and plants variables might be due to the management system of Lamto savannah. Grassy savannahs were maintained by annual fire. In this savannah the organic matter cycling might be due mostly to the fire system (Abbadie et *al*., 2006) and environmental conditions but more rarely to activity of earthworms.

Despite the lack of high correlation between earthworms and plants in herbaceous site and its lowest species richness, grassy savannah was home to the highest density of earthworms of the three sites. This high density was due to four species belonging to two functional groups. (1) the litter-dwelling or epi-endogeic earthworms (*Chuniodrilus zielae, Sthulmania porifera, Chuniodrilus palustris*) which live in the soil litter and (2) the anecic *Millsonia omodeoi* that stay most of their life within the soil and come out to feed on litter. In the rainy season (occurrence of little leaf shoot), these groups feed preferentially on grass root in grassy savannah (Eisenhauer et *al*., 2009). Moreover root exudates which were secondary source of organic matter, facilitated decomposition (Laossi et *al*., 2009). In dry season *Millsonia omodeoi* was the single species which contributed to total density. The soil surface might become too dry for epigeic earthworm to survive. Many earthworm species that normally live near the surface of the ground move from the top layers of the soil and become comparatively inactive in deeper soil during adverse periods (Edwards & Lofty, 1977). In grassy savannah the grass roots might dominate the diet of earthworms because above ground production was yearly burned.

CONCLUSION

In conclusion CCA showed that in forest and woody savannah, the variance accounted for plants variables was nearly half of total variance extracted by CA. Apparently, the plant families were not sufficient to predict the main variation in earthworm species distribution extracted by CA, but they do predict a substantial part of the remaining variation. The remaining variation was environmental parameters such as pH, soil moisture and soil organic carbon and undetermined variance due to other parameters or organisms. Nevertheless this study observed high correlations between earthworm species and plants variables in these vegetation types. In grassy savannah, the variance accounted for plants variables was a weak portion and the multiple correlations between the axes and plants were fairly weak.

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