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SOIL MACROFAUNA COMMUNITY STRUCTURE ACROSS LAND USE SYSTEMS OF TAITA, KENYA

[ESTRUCTURA DE LA COMUNIDAD DE LA MACROFAUNA DEL SUELO EN DIVERSOS SISTEMAS DE USOS DE SUELO DE TAITA, KENIA]

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SUMMARY

This paper presents data on diversity and abundance of soil macrofauna in various land use systems in Taita (natural forest, plantation forest, fallow, coffee, napier, and maize, Horticulture. Each was sampled for macrofauna using three sampling methods (monolith, transect and pitfall trapping). Seventy eight (78) genera/species were recorded across the different land use systems of Taita. Rényi diversity profile indicated no significant differences in species richness across land use systems as reflected by the very close diversity profiles at $\alpha = 0$. However, the two diversity indices (Shannon index: $\alpha = 1$ and Simpson's index: $\alpha = 2$) indicated that plantation forest was the most diverse of the land use systems, while fallow and maize were least diverse. Rényi evenness profile indicated that the plantation forest was most even in terms of species distribution which was least in maize. However because some of the profiles for some land use systems cross each other, they could not be ranked. The major macrofauna groups recorded in the Taita benchmark site included: Hymenoptera, Isoptera, Coleoptera, Oligochaeta and Orthoptera and Arenae. Generally Hymenoptera were the most abundant of the macrofauna groups constituting about 36% of the total followed by Isoptera (22%), Oligochaeta (16%), Coleoptera (10%). The other macrofauna (Arenae, Diplopoda, Diptera, Orthoptera, Blattidae, Isopoda, Chilopoda- Geopholomorpha, Hemiptera, Opiliones,Chiopoda-Scolopendromorpha, Lepidoptera, Dermaptera, Phasmidae, Blattelidae and Mantodea each constituted <10% of the total macrofauna recorded. Hymenoptera was ranked 1st as it had the highest total abundance (59,440 individuals m^{-2}), while Mantodea was ranked 18th and had the lowest total abundance (6 individuals m^{-2}). Generally macrofauna density was higher in arable systems than forests, although the differences were not always significant. Except for Chilopoda-Geopholomorpha, Chilopoda-Scolopendromorpha and Isopoda, all the other macroafauna groups were not significantly different across land use systems. The three groups (Chilopoda-Geopholomorpha, Chilopoda- Scolopendromorpha and Isopoda) were significantly highest in the forests than in all the other land use systems. These variation appear to be associated with management practices that consequently results in the destruction of nesting habitats, modification of soil microclimate within these habitats and removal of substrate, low diversity and availability of food sources for the associated macrofauna groups. The significant correlations between some soil macrofauna groups with selected soil chemical properties too show that, soil chemical characteristics may indirectly play a role in influencing the density, distribution and structure of macrofauna communities. This indicates the potential of using these fauna groups as bio-indicators of soil productivity.

Key words*:* Macrofauna; community structure; diversity; abundance; land use systems.

INTRODUCTION

Biodiversity became a central concept in agronomical research since the Rio de Janeiro summit in 1992. This event indicated a world consciousness of the importance of biodiversity protection for sustainable development (Brundtland, 1987; CBD, 2001; Clergue *et al.,* 2005). Among reasons advanced for the need for biodiversity protection is that: biodiversity represents a potential reserve of new compounds for medicine, interesting genes for plant breeding and services for

agriculture (Paoletti *et al.,* 1992; Alteri, 1999; Duelli *et al.,* 2003). Biodiversity is also considered as mankind's heritage and human beings cannot decide on the existence or not of a species (Cairns, 1997).

Although biodiversity loss has been given prominence all over the world in the last 2-3 decades, most of the conservation efforts have been directed to above ground and in particular large plant and animal species of economic and aesthetic value while smaller animals and lower plants and below ground organisms such as earthworms, termites, bacteria and fungi have seldom been considered among endangered species. Biodiversity loss therefore, seems to attract public attention only when large charismatic, species are endangered or romantic habitats are threatened while hotspots of biodiversity are chosen based on above ground species (Vandermeer and Perfecto, 1998).

Soil (belowground) biodiversity has, particularly received little attention despite them having high functional significance. This is not surprising given poor understanding and misconception by many that soil is a 'lifeless' substrate, yet soil constitutes a complex maze of microhabitats and contains some of the most diverse assemblages of organisms whose crucial functions contribute to maintain life on earth (Lavelle, 1996; Giller *et al.,* 1997; CBD, 2001). The relevance of using soil organisms e.g. earthworms and termites to monitor soil ecosystem health is validated by the recognition that they are essential to ecological processes and they also depend on soil as habitat (Doran and Parkin, 1994; Blair *et al.,* 1996; Elliot, 1997). Studies have shown that soil fauna improve agricultural productivity through their activities on soil (Vikram, 1994; Wood, 1996; Lee and Foster, 1991; Brussaard *et al.,* 1993; Lavelle *et al.,* 1992*;* TSBF, 1994; Tinzara and Tukahirwa, 1995; Black and Okwakol, 1997; Beare *et al.,* 1997). Basically, biological processes (decomposition, soil structure modification and bioaccumulation) are intimately linked with the maintenance of soil structure and fertility and are potentially more sensitive to changes than indicators based on the physical and chemical characteristics of the soil such as soil texture, bulk density, infiltration, moisture content, water retention characteristics, soil temperature, water holding capacity and total carbon, nitrogen, pH, mineral nitrogen, phosphorus and potassium respectively. Bioassessment techniques use these attributes of soil biota through monitoring high-order shifts in biodiversity to infer environmental conditions (Cairns *et al.,* 1993). This can be used as early warning signs of ecosystem dysfunction, which may allow appropriate intervention before irreversible effects on the soil physical and chemical characteristics, and biodiversity occur.

Research has continued to show the value of soil organisms to the biological control of human and agricultural pests, in biotechnology, and for remediation of hazardous wastes. However, soil organisms remain among the vast unknown life on our planet despite their critical importance to understanding ecosystem function. Thousands of species of microbes and invertebrates inhabit just a square meter of soil yet their identities and contributions to sustaining our biosphere are largely undiscovered. Little is known about the spatial distribution of different groups of soil macrofauna across different land use systems of Kenya and of the management practices that stimulate their activity. The elucidation of species diversity of soils in conjunction with sustainability assessments of soil fauna-mediated ecosystem processes must be a high priority in global biodiversity efforts. It is against this background that a GEF-UNEP funded global project on the conservation and management of belowground biodiversity (CSM-BGBD) was conceived. This study therefore (1) determined soil macrofauna taxa and groups macrofauna in selected land-use systems, and (2) evaluated abiotic factors that influence the distribution patterns of macrofauna in (1) above.

MATERIAL AND METHODS

Study area

The study was conducted in Taita Hills of Taita Taveta District, located Southeastern Kenya (latitude: 03º 20′ S, longitude: 38º 15′ E), at an altitude of 2228 m above sea level). The climate of the area is under the influence of Inter-Tropical Convergence Zone (ITCZ), receiving an average annual rainfall of 1500 mm in the highlands and 250 mm in the lowlands and the mean monthly temperature ranges from 17.4º C and 34.5º C. The soils are primarily sandy loam with high infiltration rates, low pH, low water holding capacity, and low nutrient contents due to excessive leaching. The soils are also characterized by the presence of high aluminium, low calcium and potassium, leading to a low cation exchange capacity (TSBF-CIAT BGBD GEF-UNEP Project, 2002). The benchmark site of Taita Hills has high biodiversity, and is known to contain a large number of endemic plant and animal species. It is designated among the twenty-five globally recognized biodiversity "hotspots" (Mittermeier *et al.,* 2005). The communities in this study area are mainly smallholder subsistence farmers. The two sites cut across areas of varied land use intensification including undisturbed and disturbed forests, cropping systems, pastures or grazing lands, shrublands and fallow ecosystems. Therefore the site provides an interesting framework for the proposed macrofaunal ecological studies.

Soil sampling and analysis

In order to characterize the soils in the study area, six 2-metre deep representative profile pits were dug in each of the land use systems and these were described by Kenya Soil Survey in collaboration with Kenya Agricultural Research Institute (KARI).

From each site, soil samples were taken randomly from each plot and transported to the laboratory in a cool box for analyses. Total carbon (C) was determined by Heanes' improved chromic digestion and spectrophotometric procedure (Heanes, 1984); total nitrogen (N) by micro-Kjeldahl digestion followed by distillation. Using the same digestion solution used for N extraction, phosphorus (P) was measured colorimetrically by a spectrophotometer while potassium (K) was measured by flame photometry. Exchangeable acidity, CEC, exchangeable calcium (Ca) and magnesium (Mg) were extracted by the Mehlich-3 procedure (Mehlich, 1984) and then measured using atomic absorption spectrophotometry (Okalebo *et al.,* 1993). The soil pH was measured in water using a pH meter in a soil: water ratio of 1:2.5 (Asawalam *et al.,* 1999) while surface (0-20 cm) soil moisture was measured gravimetrically during each study period from composite samples. Other environmental parameters such as rainfall and temperature were obtained from secondary data.

Macrofauna sampling designs

Three different sampling methods were employed for macrofauna and they are described below.

(a) Monolith sampling method
At the benchmark site of Taita, macrofauna were sampled by excavating one soil monoliths of 25 cm x 25 cm x 30 cm per sampling site of the land use systems (Anderson and Ingram, 1993; Swift and Bignell, 2001). Each sample was further divided in 3 layers (0-10 cm, 10-20 cm and 20-30 cm) taken to the sampling base and hand sorted, removing all the animals >2mm in diameter. A total of 42 monoliths cutting across the different land use systems (natural forest-6, plantation forest-3, fallow-12, coffee-5, napier-4, and maize-7, Horticulture-5) were excavated in Taita during the period of April/May 2005.

(b) Transect sampling for termites
At each sample point (above), a 20 x 2 m transect was laid about 8 metres from the monolith. Within each transect, 5 x 2 sections were randomly excavated for termites using shovels up to a 5 cm depth. In each section the collectors searched the following microhabitats common sites for termites: surface soil to 5 cm depth; accumulations of litter and humus at the base of trees; the inside of branches and twigs; all subterranean nests, mounds, carton sheeting and runways on vegetation, and arboreal nests up to 2 m above ground level.

(c) Pitfall method
Alongside each transect laid, three unbaited pitfall traps filled wit 70% alcohol were laid and checked for macrofauna after 24 hours. Samples were trapped in 70% alcohol.

Termites and all the other macrofauna groups were put in McCartney bottles and then fixed in 70% alcohol, while earthworms were first killed in 70% alcohol, then fixed in 4% formaldehyde. All the macrofauna samples collected taken to the Entomological Department at the National Museums of Kenya, Nairobi for enumeration and taxonomic identification. Biological assessment included macrofauna populations, numbers or abundance, diversity at species, genus and species level richness. The following aspects of diversity were evaluated for each type of land-use using R′enyi diversity profiles (Kindt and Coe, 2005): (1) richness (*S*), (2) diversity (*H′*), and (3) evenness (*J*). Richness (*S*) was estimated as the number of taxa per sample. Diversity (*H′*) was estimated using the Shannon-Wiener index (Magurran, 1988): $H' = -\sum(p_i \ln P_i)$ Where H′ is the Shannon-Wiener index and pi is the proportion of the *i*th taxonomic group, estimated as n*i*/N; where n*i* is the number of individuals of the *i*th species and N the total number of individuals within the sample. The Simpson's index of diversity (D) was used on the same data to reduce the bias that may arise from the interpretation of a single diversity index (Magurran, 1988). $D=1-\sum n_i(n_i/N(N-1)$ where n*i*=number of individuals in the *i*th species, and N=the total number of individuals (Magurran, 1988). Evenness (*J*) was estimated as follows: $J = H'/\ln S$.

Data from the transects and pitfall traps were pooled and combined with monoliths to estimate species richness in each land use system, but statistical analyses were based on monolith data only.

Statistical analysis

Given the multiplicity of sites, management and environmental factors and macrofauna data, multivariate statistics was carried using Biodiversity-R (Kindt and Coe, 2005). Level of significance among the interactions was performed by a Post Hoc Multiple comparisons test (Tukey's significant difference test).

To assess the strength and statistical significance of relationship between soil fauna density versus soil chemical parameters, ordination constrained to the environmental variables and general linear model (GLM) were performed.

RESULTS

Soil Characterization

Results of selected soil properties under different land use systems are presented in Table 1. They are important, not only for explaining the changes in biological communities and the functions they perform in different ecosystems, but also for identifying the biophysical constraints to agricultural production. These form the basis for identifying the appropriate management technologies and their implementation strategies. The soils are generally acidic with the pH ranging between 3.06 and 4.93 (Table 1). Relatively lower pH values were recorded in the forests. The lowest pH level was observed in plantation forest (3.06) but highest in napier (4.93). However acidity was high in the forest than in the arable systems (Table 1). Nitrogen ranged between 0.2% and 0.42. Higher levels were recorded in the forests. Similarly higher levels of soil C were also observed in the forests. The highest level of organic carbon was observed in the plantation forest (2.88) and lowest level in horticulture (1.57) (Table 1). In general, the level of phosphorous varied across sites, being lowest in the plantation forest (5.33) but highest in napier (58.25).

Macrofauna diversity across land use systems of the Taita and Taita Hills

Soil macrofauna diversity occurring in the different habitats studied is shown in Table 2. Following sorting and taxonomic identification, seventy eight (78) genera/species were collected (Table 3) respectively. Majority of these genera/species belonged to the order Coleoptera. It is important to note that some macrofauna groups could not be identified beyond order and families due to lack of identification keys.

Rényi diversity profile indicated that in terms of species richness, no significant differences were observed as reflected by the very close diversity profiles at $\alpha = 0$ (Figure 1). However, the two diversity indices (Shannon index: $\alpha = 1$ and Simpson's index: $\alpha = 2$) indicated that plantation forest was the most diverse of the land use systems, while fallow and maize were least diverse (Figure 1).

Rényi evenness profile indicated that the plantation forest was most even in terms of species distribution, but least even in maize (Figure 2). However because the other profiles for some land use systems cross each other, they could not be ranked.

Table 1. Selected soil properties for the different benchmark site of Taita

	Land use systems						
Soil parameters	Natural forest	Planted forest	Fallow	Horticulture	Maize	Napier	Coffee
$pH_{(1:2.5\ H2O)}$	3.72	3.06	4.27	4.78	4.59	4.93	4.79
Acidity (%)	1.19	2.38	0.77	0.33	0.31	0.34	0.39
N (%)	0.42	0.38	0.26	0.20	0.20	0.28	0.20
C (%)	2.55	2.88	1.98	1.57	1.68	1.89	1.78
C:N	39.42	22.68	97.48	41.14	61.04	27.16	46.31
P(ppm)	27.17	5.33	13.96	53.40	12.50	58.25	14.40
$K_{cmolc\ kg^{-1}\ soil}$	0.23	0.10	0.49	0.31	0.38	0.76	0.25
$Ca_{cmolc\ kg^{-1}\ soil}$	2.72	3.40	3.35	2.18	2.57	3.40	2.06
$Mg_{cmolc\ kg^{-1}\ soil}$	1.71	0.58	2.15	2.66	2.19	3.71	2.98
$Mn_{cmolc\ kg^{-1}\ soil}$	0.61	0.20	0.42	0.81	0.70	0.53	0.34
$Cu_{cmolc\ kg^{-1}\ soil}$	1.55	0.92	0.74	1.08	1.90	1.76	0.68
$Fe_{cmolc\ kg^{-1}\ soil}$	81.85	161.60	49.39	52.32	31.13	44.13	41.06
$Zn_{cmolc\ kg^{-1}\ soil}$	3.40	0.74	1.95	3.42	4.50	6.16	3.77
$Na_{cmolc\ kg^{-1}\ soil}$	0.27	0.36	0.26	0.36	0.20	0.25	0.19

Table 2. Macrofauna diversity across different land use systems in Taita Hills, Kenya

Macrofauna Diversity				Land use systems						
Class	Order	Family	Genus/sp	M	C	Ht	F	N	NF	PF
Insecta	Blattelidae	Pseudoderopeltis	*Sp[1]*	+	-	+	+	-	+	+
		Blattoidea/Blattidae	*Blattella sp[2]*	-	-	+	+	+	+	+
	Orthoptera	Gryllidae	*Gryllus sp[1]*	+	-	+	+	+	+	+
			Phaeophilaeris sp[2]	-	-	-	+	+	-	-
		Acrididae	*Sp[3]*	+	+	+	+	+	+	-
		Tettigonidae	*Sp[4]*	-	+	-	-	+	+	-
	Dermaptera	Forficulidae	*Sp[1]*	+	+	+	+	+	-	-
	Diptera	Muscidae	*Orthelis sp1*	+	+	+	+	+	+	-
		Calliphoridae	*Rhinia sp[2]*	+	-	+	+	+	-	-
		Drosophilidae	*Sp[3]*	+	+	+	+	+	+	-
		Anthomyiidae	*Sp[4]*	-	+	-	+	+	+	-
		Muscidae	*Sp[5]*	-	+	-	+	+	+	-
		Calliphoridae?	*Sp[6]*	+	-	-	+	+	+	-
		Cecidomyiidae	*Sp[7]*	+	-	+	+	+	+	-
		Platystomatidae	*Sp[8]*	-	-	-	+	-	-	-
		Asilidae	*Sp[9]*	-	+	-	+	-	-	-
		Chloropidae	*Sp[10]*	-	+	-	-	+	-	-
	Isoptera	Termitidae	*Odontermes sp[1]*	+	-	+	+	+	-	-
		Termitidae	*Sp[2]*	+	-	+	+	+	+	+
		Rhinotermitidae	*Sp[3]*	+	+	-	-	+	-	-
		Alates	*Sp[4]*	+	-	+	+	+	+	+
	Hymenoptera	Formicidae	*Tetramorium sp[1]*	+	-	+	+	+	+	+
			Camponatris sp[2]	+	-	+	+	+	-	+
			Paltothyreus tartus[3]	+	-	+	+	-	-	-
		Sphecidae	*Ammorphila sp[4]*	+	-	+	+	+	-	-
			Liris sp[5]	+	-	-	+	+	-	-
		Scolidae	*Campsomeris sp[6]*	-	+	-	+	-	-	-
		Halicitidae	*Sp[7]*	-	+	+	+	+	-	-
		Pompiloicidae	*Crytocheilus sp[8]*	+	-	-	-	+	-	-
		Rhopalasomatidae	*Panascomima sp[9]*	+	-	+	-	+	-	+
		Apidae	*Apis sp[10]*	+	-	+	-	-	-	-
	Phasmatodea	Gratididae	*Sp[1]*	-	-	-	-	-	-	+
	Coleoptera	Larvae	*Sp[1]*	+	-	+	+	+	+	+
		Geotripidae	*Bobocerus sp[2]*	-	+	-	+	+	-	-
		Anthribidae	*Xylinada sp[3]*	+	-	-	+	-	-	-
		Scarabaeidae	*Schizomycha sp[4]*	-	+	+	+	+	-	-
			Clitopa sp[5]	-	+	-	-	+	+	-
			Gymnoplueurus sp[6]	-	+	-	+	+	-	-
		Tenebrionidae	*Selinus sp[7]*	+	+	+	+	+	+	-
			Leichenum sp[8]	+	+	+	+	+	+	-
			Phryanacolus sp[9]	+	+	-	-	+	-	-
			Psamodes sp[10]	-	+	-	+	+	-	-
			Sepidum sp[11]	+	+	-	-	+	-	-
		Cryptocephalidae	*Cryptocephalus sp[12]*	+	+	-	-	+	-	-
		Colydidae	*Metacerylon sp[13]*	-	+	-	-	+	+	-
		Curculionidae	*Borthus sp[14]*	-	+	-	+	+	+	+
			Gypomychus sp[15]	-	+	-	-	+	+	-
			Systates sp[16]	+	+	+	+	+	+	+
		Carabidae	*Chlaenus sp[17]*	+	-	-	+	-	+	-
			Tachys sp[18]	+	-	+	+	-	-	-
			Bembidion sp[19]	+	+	+	+	+	+	-
			Scarites sp[20]	-	+	-	-	+	+	-
			Agonum sp[21]	-	+	-	-	+	+	-
			Zophosis sp[22]	+	+	-	+	+	+	-
			Amophomerus sp[23]	+	+	-	-	+	-	-
			Plocamotrechus sp[24]	+	+	-	+	+	-	-
		Carabidae?	*Sp[25]*	-	+	-	+	+	-	-
		Lagrididae	*Aeritolagria sp[26]*	+	-	-	-	-	-	-
		Bostrychidae	*Bosstrycharis sp[27]*	+	+	-	+	+	-	-
		Paussidae	*Paussus sp[28]*	+	+	-	-	+	-	-

Macrofauna Diversity				Land use systems						
Class	Order	Family	Genus/sp	M	C	Ht	F	N	NF	PF
		Staphylinidae?	*Sp*[28]	+	-	-	-	-	-	-
		Staphylinidae	*Staphylinus sp*[29]	+	+	+	-	+	+	-
			Aleochara sp[30]	+	+	+	+	+	-	-
			Tachinomorphus s[31]	+	+	+	+	+	+	-
			Pinophilus sp[32]	+	-	+	-	-	+	-
			Moecerus sp[33]	-	-	-	+	-	-	-
	Lepidoptera		*Sp*[1]	+	+	+	+	+	-	-
	Hemiptera		*Sp*[2]	+	+	+	+	+	+	-
	Mantodea		*Sp*[3]	-	-	-	-	-	+	-
Malacostraca	Isopoda		*Sp*[1]	+	+	+	+	+	+	+
	Amphipoda		*Sp*[2]	-	+	-	-	+	+	-
Diplopoda			*Sp*[1]	+	+	+	+	+	+	+
Arachnida	Aranea		*Sp*[1]	+	+	+	+	+	+	+
	Opiliones		*Sp*[2]	+	+	+	+	+	+	+
Chilopoda	Geopholomorpha		*Sp*[1]	+	+	+	+	+	+	+
	Scolopendromorpha		*Sp*[2]	+	+	+	-	+	+	+
Oligochaeta		Eudrilidae	*Polytereutus sp*[1]	-	-	-	+	+	+	-
			Sp [2]	+	+	+	+	+	+	+

Key: C-Coffee; F-Fallow; H-Horticulture; M-Maize; NF-Natural forest; PF-Plantation forest; N-Napier
Data is pooled from all the three methods. Signs (+/-) indicate presence or absence of the genera/species.

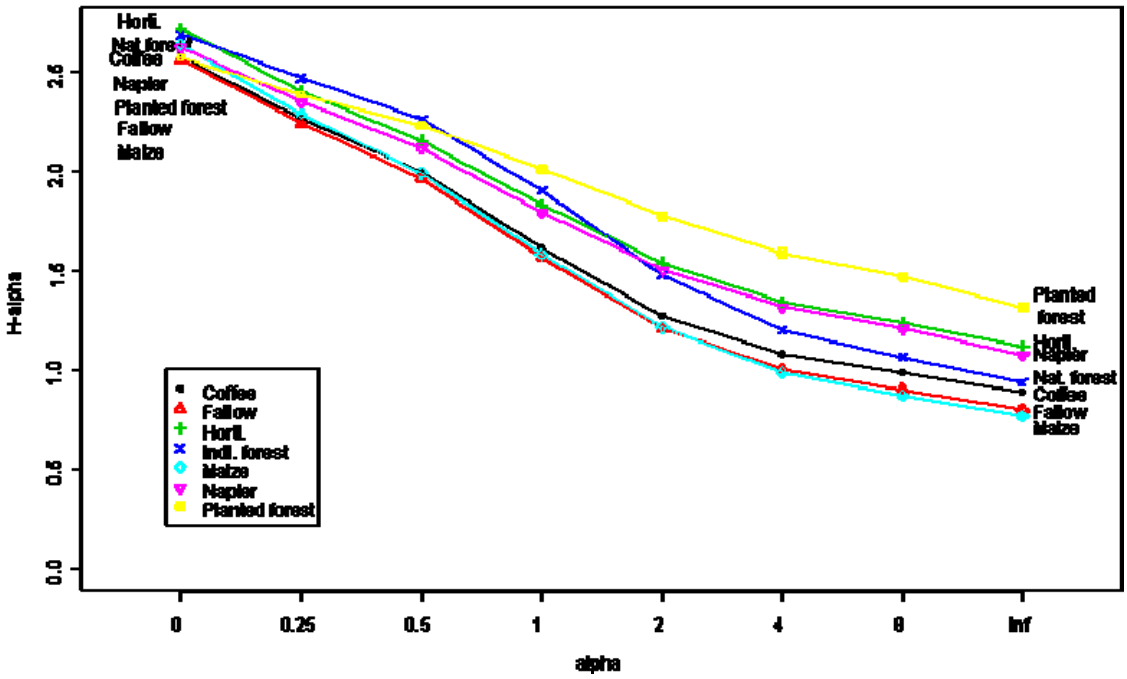

Figure 1. Rényi diversity profiles for different land use systems of Taita, Kenya.

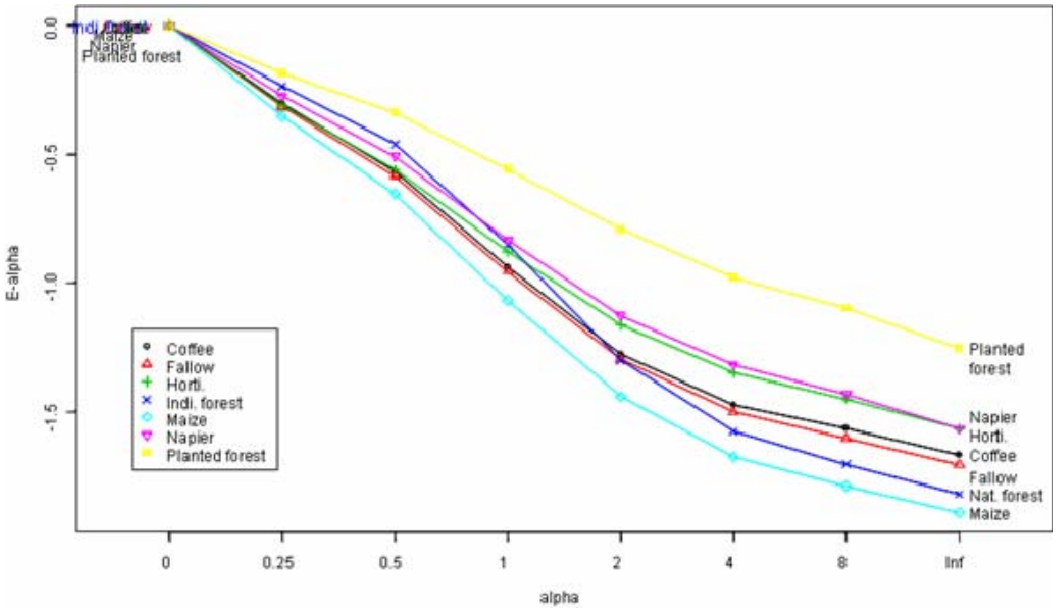

Figure 2. Rényi evenness profile across the different land use systems of Taita, Kenya.

Macrofauna abundance across land use systems of Taita

The major groups recorded in the Taita benchmark site included: Hymenoptera, Isoptera, Coleoptera, Oligochaeta and Orthoptera and Arenae (Table 4). Generally Hymenoptera were the most abundant of the macrofauna groups constituting about 36% of the total followed by Isoptera (22%), Oligochaeta (16%), Coleoptera (10%). The other macrofauna (Arenae, Diplopoda, Diptera, Orthoptera, Blattidae, Isopoda, Chilopoda- Geopholomorpha, Hemiptera, Opiliones,Chiopoda-Scolopendromorpha, Lepidoptera, Dermaptera, Phasmidae, Blattelidae and Mantodea each constituted <10% of the total macrofauna recorded (Table 3).Hymenoptera was ranked 1st as it had the highest total abundance (59,440 individuals m^{-2}), while Mantodea was ranked 18th and had the lowest total abundance (16 individuals m^{-2}).

Table 3. Macrofauna composition and rank abundance, Taita, Kenya.

Group	Rank	Abundance	Proportion (%)	P-lower	P-upper	Accumfreq	Logabund	Rankfreq
Hymenoptera	1	59440	35.7	28.0	43.5	35.7	4.8	5.6
Isoptera	2	36416	21.9	14.1	29.7	57.6	4.6	11.1
Oligochaeta	3	26160	15.7	8.7	22.7	73.3	4.4	16.7
Coleoptera	4	16080	9.7	8.2	11.1	83.0	4.2	22.2
Arenae	5	8208	4.9	3.3	6.6	87.9	3.9	27.8
Diplopoda	6	4384	2.6	1.7	3.6	90.6	3.6	33.3
Diptera	7	3840	2.3	1.4	3.3	92.9	3.6	38.9
Orthoptera	8	3408	2.0	1.4	2.7	94.9	3.5	44.4
Blattelidae	9	2208	1.3	0.8	1.9	96.3	3.3	50.0
Isopoda	10	1792	1.1	0.1	2.1	97.3	3.3	55.6
ChiolpodaG	11	1712	1.0	0.5	1.6	98.4	3.2	61.1
Hemiptera	12	1040	0.6	0.4	0.9	99.0	3.0	66.7
Opiliones	13	656	0.4	0.1	0.7	99.4	2.8	72.2
ChilopodaS	14	528	0.3	0.1	0.5	99.7	2.7	77.8
Lepidoptera	15	336	0.2	0.1	0.3	99.9	2.5	83.3
Dermaptera	16	112	0.1	0.0	0.1	100.0	2.0	88.9
Phasmidae	17	32	0.0	0.0	0.0	100.0	1.5	94.4
Mantodea	18	16	0.0	0.0	0.0	100.0	1.2	100.0

Macrofauna density (number of individuals m^{-2}) was highly variable across the land use systems (Table 4). Generally macrofauna density was higher in the arable systems than in the forests, although the differences were not always significant. Except for Chilopoda-Geopholomorpha, Chilopoda- Scolopendromorpha and Isopoda, all the other macroafauna groups were not significantly different across the land use systems (Table 4). The three groups (Chilopoda-Geopholomorpha, Chilopoda- Scolopendromorpha and Isopoda) were significantly highest in the forests than in all the other land use systems.

Relationship between soil properties and macrofauna abundance

Redundancy analysis (RDA) plots were fitted to the constrained environmental variables (Table 5). The RDA table shows 17.6 from the total 58.72 variance or 29.89% of variance. Eigenvalues of the RDA axes constrained to environmental parameters indicates that soil parameters explain 29.89% of the observed variance on macrofauna abundance. The remaining PCA axes contributed to the remaining variance (70.11%).

Table 4.Soil Macrofauna abundance (number m^{-2}) across different land use systems of Taita.

	Land use systems ----------**Number m^{-2}**----------								
Macrofauna group	**C**	**F**	**H**	**M**	**NF**	**PF**	**N**	**Mean**	**P value**
Isoptera	115a	1275a	291a	354a	762a	256a	656a	530	0.38ns
Hymenoptera	1341a	2051a	921a	1472a	80a	123a	1144a	1019	0.18ns
Oligochaeta	838a	524a	1056a	756a	384a	37a	508a	586	0.40ns
Coleoptera	204a	465a	326a	297a	224a	21a	344ba	269	0.08ns
Phasmidae	0a	0a	0a	8a	3a	5a	0a	2	0.18ns
Dermaptera	3a	0a	0a	5a	3a	0a	4a	2	0.73ns
Diplopoda	115a	127a	32a	98a	61a	11a	48a	70	0.50ns
Diptera	163a	121a	86a	14a	27a	0a	12a	60	0.09ns
Hemiptera	26a	29a	13a	37a	5a	0a	12a	17	0.58ns
Arenae	323a	135a	122a	112a	107a	80a	184a	152	0.28ns
Lepidoptera	10a	8a	13a	5a	0a	0a	0a	5	0.49ns
Mantodea	0a	0a	0a	0a	0a	0a	4a	1	0.10ns
Blattellidae	77a	45a	12a	14a	56a	53a	88a	49	0.48ns
Opiliones	19a	29a	10a	9a	5a	5a	0a	11	0.62ns
Orthoptera	67a	89a	58a	48a	85a	5a	4a	51	0.47ns
ChilopodaG	6c	13c	3c	25cb	83b	171a	36b	48	<0.001***
ChilopodaS	0b	4b	3b	7b	35a	59a	0b	15	<0.001***
ChilopodaS	0b	4b	3b	7b	35a	59a	0b	15	<0.001***
Isopoda	6b	13b	3b	5b	99a	304a	8b	63	<0.001***
Mean total	3315	4929	2950	3257	2019	1131	3088		0.09ns

Key: C-Coffee; F-Fallow; H-Horticulture; M-Maize; NF-Natural forest; PF-Plantation forest; N-Napier
Values followed by the same letters within rows are not significantly different at P<0.05.

Table 5.Hybrid RDA constrained to the environmental parameters (soil characteristics) showing their correlation with soil macrofauna.

Total: 58.72						
Constrained: 17.55 (29.89%)						
Unconstrained: 29.22 (70.11%)						
Eigenvalues and their contribution to the variance						
Axes	RD1	RD2	RD3	RD4	RD5	RD6
Lambda	10.84	2.87	1.96	1.13	0.50	0.24
Accounted (%)	0.18	0.23	0.27	0.29	0.29	0.30

Macrofauna reacted differently to influence of soil chemical properties. Soil parameters such as acidity, C, N, Fe, pH (<0.001), Mg (p=0.02) strongly and significantly (p<0.05) correlated with some of the macrofauna groups while other variables (Ca, Cu,K, Mn, Na,P and Zn) were weakly and insignificantly correlated with the macrofauna groups at P<0.05. The macrofauna groups (Chilopoda-Geopholomorpha, Chilopoda- Scolopendromorpha and Isopoda,) varying significantly across the land use systems were traced and assessment made on how they correlated with these variables. All these groups positively correlated with acidity, C, N, Fe, but negatively with pH (Figure 3).

The two orders of Chilopoda and Isopoda favoured by forest environment and were higher in the forests than in arable systems. The forest ecosystem had low pH (high acidity), high C and N and Fe whereas the arable (agroecosystems) had relatively higher pH but lower C, N and Fe.

DISCUSSION

Results of this study have shown that plantation forest within Taita was rich in macrofauna species and had higher species distribution or evenness than the agroecosystems. Although most of the macrofauna groups did not differ significantly across the land use systems, the forests harbored higher Chilopoda and Isopoda density than the agroecosystems. Results of our study also indicated that most of macrofauna groups such as Hymenoptera, Oligochaeta, Coleoptera, Diplopoda, Diptera, Arenae, Blattelidae, Hemiptera were found to be more abundant in arable systems but low in the forest ecosystems. However the insignificant variations for some groups across the different land use systems shows management practices did not influence macrofauna density.

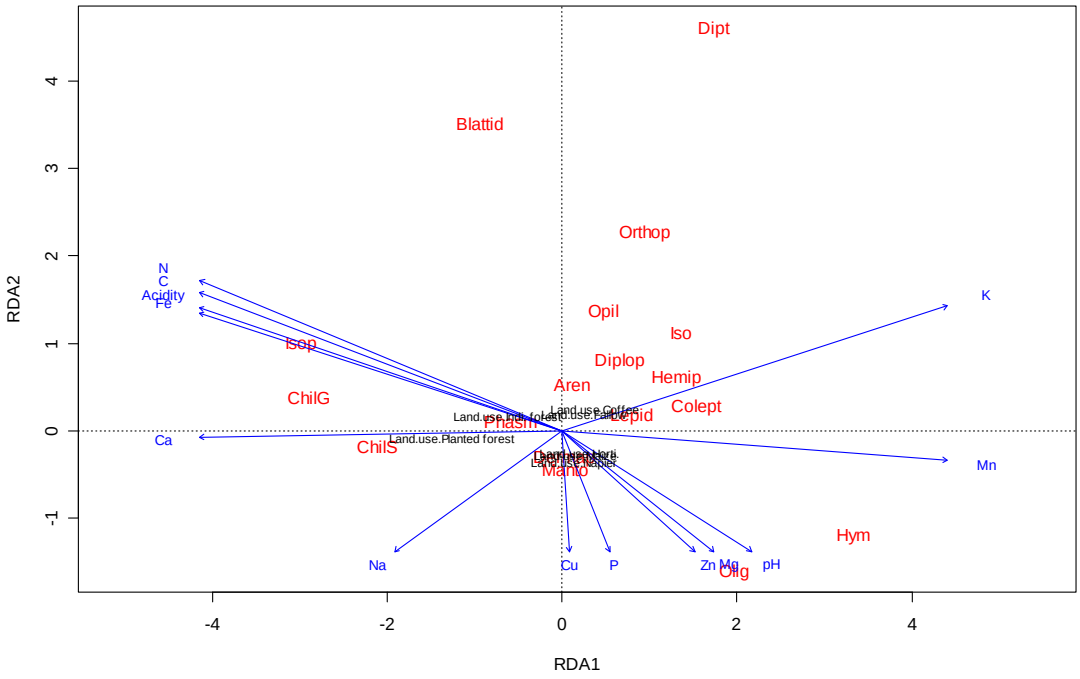

Figure 3. RDA biplot showing correlation between soil macrofauna groups and all the soil parameters as constraining variables. Soil characteristics are represented by arrows.

Other factors such as food availability and habitat preference explain differences in abundance and species composition of soil organisms (Castellarini *et al.,* 2002; Uhia and Briones, 2002). In this study, macrofauna groups such as Chilopoda and Isopoda were positively correlated to C, N, and acidity but negatively to pH and were found to be abundant in the forests. The two orders of Chilopoda and Isopoda were favoured by forest environment and were higher in the forests than in arable systems. The forest ecosystem

had low pH but high acidity, high C and N and Fe whereas the arable (agroecosystems) had relatively higher pH but lower C, N and Fe. Besides, plantation forests, particularly that of *Pinus patula* in Taita contained a thick (about 10 cm) continuous litter layer often permeated with fungal mycelia resulting in higher acidity and higher amounts of soil carbon and organic matter, the main energy source for soil organism metabolism. These conditions appeared to favour the two macrofauna groups. Lower density of Chilopoda and Isopoda in the arable ecosystems could be associated with management practices that consequently results in the destruction of nesting habitats, modification of soil microclimate within these habitat and removal of substrate, low diversity and availability of food sources for the associated macrofauna groups.

Management practices such as mechanized land clearing and burning, continuous tillage, monoculture, crop rotation, organic residue inputs, retention and removal and use of agrochemicals have been demonstrated to be among the causes of the alterations of soil fauna population structure, disappearance or reduction of key species and in some cases extremely low abundances or biomass (Warren *et al.,* 1987; Dangerfield, 1993; Roper and Gupta, 1995; Brown *et al*., 1996). Eigenvalues of the RDA axes constrained to environmental parameters indicates that soil parameters explain 29.89% of the observed variance on macrofauna abundance. The significant correlations between some soil fauna groups to soil chemical properties indicate that, apart from the direct influence of ecosystem disturbance, cultivation and soil fertility management practices, soil characteristics may indirectly play a role in influencing the density, distribution and structure of macrofauna communities. This indicates the potential of using these fauna groups as bio-indicators of soil productivity.

CONCLUSION

The study demonstrates that quantitative changes in diversity and density of soil fauna communities occur when various land use is subjected to varying levels of intensification. These changes could be associated with management practices that consequently results in destruction of nesting habitats, modification of soil microclimate within these habitat and removal of substrate, low diversity and availability of food sources for the associated macrofauna groups. The significant correlations between some soil macrofauna groups with selected soil chemical properties shows that, soil chemical characteristics may indirectly play a role in influencing the density, distribution and structure of macrofauna communities. However there is need to demonstrate how changes in macrofauna diversity and abundance associated with land use changes affect ecosystem functions and how such functions are beneficial at farm level.

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