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MACROFAUNA DIVERSITY AND ABUNDANCE ACROSS DIFFERENT LAND USE SYSTEMS IN EMBU, KENYA

[DIVERSIDAD Y ABUNDANCIA DE MACROFAUNA EN DIFERENTES SISTEMAS DE USO DEL SUELO EN EMBU, KENIA]

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SUMMARY

This paper presents data on diversity and abundance of soil macrofauna of various land use systems in Embu, Kenya (natural forest, plantation forest, fallow, coffee, tea, napier, and maize). Each was sampled for macrofauna using three sampling methods (monolith, transect and pitfall traps). Thirty four (34) genera/species of soil macrofauna were recorded, the highest number (27) being observed in napier. Majority of these genera/species being Coleoptera. Rényi diversity profile indicated that in terms of species richness (α at 0), maize was the richest of all the land use systems, but plantation forest the least. It was however not possible to clearly order or rank the land use system in terms of diversity because of the bias of each of the two diversity indices as indicated by the numerous crossings observed for the diversity profiles/curves. Shannon index of diversity (α = 1) indicated that coffee was the most diverse of the land use systems followed by plantation forest > natural forest > napier > maize > tea, while fallow/pasture was the least diverse (Figure 1). On the other hand, Simpson's diversity (α = 2) indicated that plantation forest was the most diverse followed by fallowed by coffee > natural forest > napier > maize >tea > fallow/pasture. Rényi evenness profile indicated that the plantation forest was most even in terms of species distribution followed by natural forest and coffee > napier > tea > maize but least even in the fallow/pasture. Hymenoptera were most abundant of the macrofauna groups constituting about 45% of the total followed by Isoptera (39%), Coleoptera (6%), Oligochaeta (5%), Orthoptera (3%) and Arenae (2%). The other groups that comprised of Hemiptera, Diptera, Phasmidae and Blattelidae each constituted <1% of the total marofauna recorded. Highest macrofauna density (1566) was recorded in the napier followed by fallow (1356) > coffee (1170) > natural forest (1110) > tea (755), but lowest in plantation forest (309), although analysis of variance indicated no significant variation among the land use systems. This study however, demonstrates that quantitative changes in diversity and density of soil fauna communities occur when various land use systems are subjected to varying levels of intensification. These changes appear to be associated with management practices such as use of agrochemicals, consequent destruction of nesting habitats, modification of soil microclimate within habitats, 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.

Key words: Macrofauna; diversity; abundance; land use systems.

INTRODUCTION

Soil macrofauna (organisms above 2000μm) are an important component of the biodiversity of many ecosystems and their populations require proper management for sustainable land use. They include

primarily invertebrates such as ants, earthworms, termites, amphipods, centipedes, millipedes, snails and slugs. These organisms are affected by anthropogenic activities such as agriculture, forestry and disturbance. Other threats to macrofauna include climate change, invasive species, genetically modified organisms, bush fires, landslides and toxic wastes.

Soil macrofauna are key organisms influencing decomposition and biodegradation of organic residues, soil organic matter dynamics, humification, nutrient release and soil physical characteristics such as bulk density, porosity and water availability (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). In general, soil macrofauna breakdown and redistribute organic residues in the soil profile, increasing their surface area for microbial activity. The subsequent deposition of faecal pellets also has important ecological implications (Lavelle *et al.,* 1992). Certain groups of macrofauna, particularly termites and earthworms, can substantially modify soil structure through formation of macropores and aggregates (Lee and Foster, 1991). The influence of soil fauna on soil structural properties has been considered to be the best long-term indicator of soil quality (Linden *et al.,* 1994). Yet despite their role in maintenance of structure and function of the belowground ecosystems, their importance is often overlooked (Crossley *et al.,* 1992). For instance, termites are often regarded as serious pests and most of studies conducted on termite have focused on pest species, yet of the more than 2,500 species, only 10% are agricultural pests.

In Kenya, limited research on soil fauna has been done. Some of the well studied macrofauna groups include termites, with most of the work concentrated in more or less natural habitats. Few quantitative studies have investigated changes in diversity and abundance of subterranean species and their response to land-use intensification. Work done by Koyman and Onck (1987) in western Kenya showed the importance of termites in soil formation, but it was not clear how land-use practices influenced the distribution of termite species and their impacts on soil quality.

This study set out to determine the taxa/groups of macrofauna in different land-use systems and their trends in relation to changes in land use intensification, aimed at obtaining an understanding of how faunal dynamics are affected by factors besides land-use intensification.

MATERIALS AND METHODS

Study area

The study was conducted in Mount Kenya region of Embu District. Embu District is in the Eastern Province of Kenya (latitude: 03º 30′ S, longitude: 37º 30′ E), at altitude of 1480 m above sea level. The area receives a total annual rainfall of between 1200 and 1500 mm in two rainy seasons, 'long rains' (March to June) and 'short rains' (mid October to December). Mean monthly temperature ranges from 14º C to 19.5º C. The soils are mainly Humic Nitisols (FAO, 1989) derived from basic volcanic rocks (Jaetzold and Schmidt, 1982). They are deep, well weathered with friable clay texture and moderate to high inherent fertility.

The benchmark site of Mt Kenya-Embu 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" (Hotspots Book, Conservation International, 2005). The site cuts 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 macrofaunal ecological studies.

Soil sampling and analysis

In order to characterize 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 Embu, 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 60 monoliths cutting across the different land use systems (natural forest-8, plantation forest-9, fallow-8, coffee-9, tea-10, napier-8, and maize-8) were excavated in Embu during the period of January/February 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 Zoology department Invertebrate section of 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 (Shannon and Wiener, 1949 in Maguran, 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 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.

Soil pH levels in Embu benchmark ranged between 3.5 and 4.2. It was highest in fallow/pasture (4.2), but lowest in the natural forest (3.5) (Table 1). The highest level of acidity was realized in the natural forest (2.8), while the lowest was measured under napier (1.1). The highest level of % organic carbon was realized in the plantation forest (6.55), but lowest under coffee. Nitrogen was highest N in plantation forest (0.88) but again lowest in coffee (0.33). The level of phosphorous was lowest in coffee (10.83) with the highest level being realized in the natural forest (21.13). Exchangeable cations were generally higher in both the natural and plantation forests than the agroeosystems (Table 1).

Table 1. Selected soil properties for the different land use systems of Embu.

	Land use systems						
Parameters	Coffee	Fallow /pasture	Maize	Napier	Natural forest	Tea	Planted forest
$pH_{(1:2.5\ H2O)}$	4.03	4.19	3.88	4.14	3.54	3.86	4.18
Acidity (%)	1.49	1.36	2.19	1.05	2.75	2.05	1.65
N (%)	0.32	0.74	0.37	0.33	0.56	0.44	0.88
C (%)	3.43	5.81	3.70	3.87	5.43	4.69	6.55
C:N	10.71	7.87	10.02	11.85	9.73	10.58	7.45
P(ppm)	10.83	16.63	16.13	14.75	21.13	14.60	12.38
$K_{\ cmolc\ kg^{-1}\ soil}$	0.33	0.19	0.27	0.31	0.28	0.38	0.19
$Ca_{\ cmolc\ kg^{-1}\ soil}$	1.75	1.99	2.15	2.63	3.35	2.01	1.64
$Mg_{\ cmolc\ kg^{-1}\ soil}$	0.56	1.46	0.45	0.91	0.17	0.73	1.92
$Mn_{\ cmolc\ kg^{-1}\ soil}$	0.64	0.56	0.51	0.74	0.42	0.39	0.15
$Cu_{\ cmolc\ kg^{-1}\ soil}$	10.25	1.13	7.40	4.09	0.82	2.60	3.05
$Fe_{\ cmolc\ kg^{-1}\ soil}$	35.51	27.19	41.46	41.84	82.55	58.29	43.34
$Zn_{\ cmolc\ kg^{-1}\ soil}$	7.97	16.89	6.54	8.54	5.77	5.29	6.24
$Na_{\ cmolc\ kg^{-1}\ soil}$	0.20	0.29	0.26	0.28	0.33	0.22	0.26

Macrofauna diversity across land use systems of the Embu

Soil macrofauna diversity occurring in the different habitats studied is shown in Table 2. Following sorting and taxonomic identification, thirty four (34) genera/species were recorded; the majority (10 genera/species) belonging 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, most earthworms collected were juveniles hence could not be identified.

Rényi diversity profile indicated that in terms of species richness (α at 0), maize was the richest of all the land use systems, but plantation forest the least (Figure 1). It was however not possible to clearly order or rank the land use system in terms of diversity because of the bias of each of the two diversity indices as indicated by the numerous crossings observed for the diversity profiles/curves. Shannon index of diversity (α=1) indicated that coffee was the most diverse of the land use systems followed by plantation forest > natural forest > napier > maize > tea, while fallow/pasture was the least diverse (Figure 1). On the other hand, Simpson's diversity (α = 2) indicated that plantation forest was the most diverse followed by fallowed by coffee > natural forest > napier > maize > tea > fallow/pasture (Figure 1).

Rényi evenness profile indicated that the plantation forest was most even in terms of species distribution followed by natural forest and coffee > napier > tea > maize but least even in the fallow/pasture (Figure 2). However because profiles for all land use systems decline from left to right such that they are less horizontal, this indicates that species are not evenly distributed.

Table 2. Macrofauna diversity collected across different land use systems of Embu, Kenya.

Macrofauna Diversity				Land use systems						
Class	Order	Family	Genus/sp	T	C	N	F	M	IF	PF
Insecta	Blattelidea	Blattoidea	*Sp1*	+	-	-	+	+	-	-
	Orthoptera	Hetrodidae	*Sp1*	+	-	+	-	+	-	-
		Acrididae	*Sp2*	+	-	+	+	+	-	+
		Gryllidae?	*Sp3*	+	-	+	+	+	-	-
		Gryllidae	*Gymnogryllus sp*[4]	-	+	+	-	-	-	-
	Diptera	Muscidae	*Sp1*	-	+	+	-	+	-	-
	Isoptera	Termitidae	*Odontotermes sp*[2]	+	+	+	+	+	+	+
		Termitidae	*Sp3*	+	+	+	+	+	+	+
		Alates	*Sp4*	+	-	+	+	-	+	-
	Hymenoptera	Sphecidae	*Sp1*	-	+	+	-	+	-	-
		Formicidae	*Crematogaster sp*[2]*.*	-	+	+	+	+	+	+
			Tetramorium sp[3]	-	+	+	+	+	+	+
		Halcitidae	*Sp4*	-	-	+	-	+	-	+
		Bethylidae	*Sp5*	-	-	+	-	-	-	-
	Phasmatodea	Phasmidae	*Gratidia sp*[1]	-	-	-	-	-	+	-
	Coleoptera	Rhizophagidae	*Sp1*	+	+	-	+	-	+	-
		Tenebrionidae	*Gonocephalum sp*[2]	+	+	+	-	+	+	+
		Staphylinidae	*Sp3*	+	-	+	-	+	+	+
		Curculionidae	*Sitophilus sp*[4]	-	-	+	+	-	+	+
			Sciobius sp[5]	-	+	+	-	-	+	+
		Scarabaeidae	*Acanthocerodes sp*[6]	-	-	+	-	+	-	-
		Scarabaeidae?	*Sp7*	-	-	+	+	-	+	+
		Carabidae	*Cyphloba sp*[8]	+	-	+	-	-	-	-
			Menigius sp[9]	-	-	-	-	-	+	-
		Ellateridae	*Conodenus sp*[10]	-	-	+	+	-	-	-
	Hemiptera	Coreidae	*Sp1*	-	-	+	+	+	-	+
		Coreidae	*Anoplocnemis sp*[2]	-	+	-	-	-	-	-
		Aphraphoridae	*Sp3*	+	+	+	-	-	-	-
		Cydnidae	*Sp4*	-	-	+	+	+	-	-
		Lygaeidae	*Sp5*	-	-	+	-	+	-	+
		Pentatomidae	*Sp6*	-	-	-	-	+	-	-
		Aphididae	*Sp7*	-	-	-	-	-	+	-
Arachnida	Araneae		*Sp1*	+	-	+	+	+	+	+
Oligochaeta			*Sp1*	+	+	+	+	+	+	+

Key: T-Tea; C-Coffee; N-Napier grass; F-Fallow; M-Maize; IF-Indigenous Forest; PF-Plantation Forest. Data is pooled from all the three methods. Signs (+/-) indicate presence or absence of a genera/species.

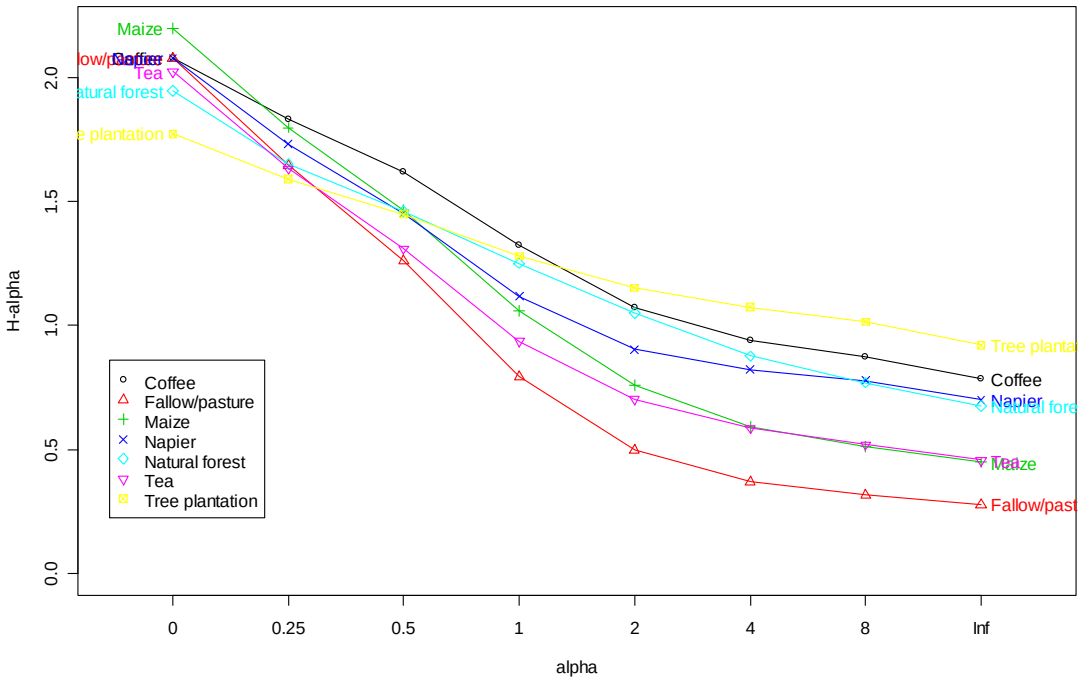

Figure 1. Rényi diversity profiles for different land use systems of Embu, Kenya.

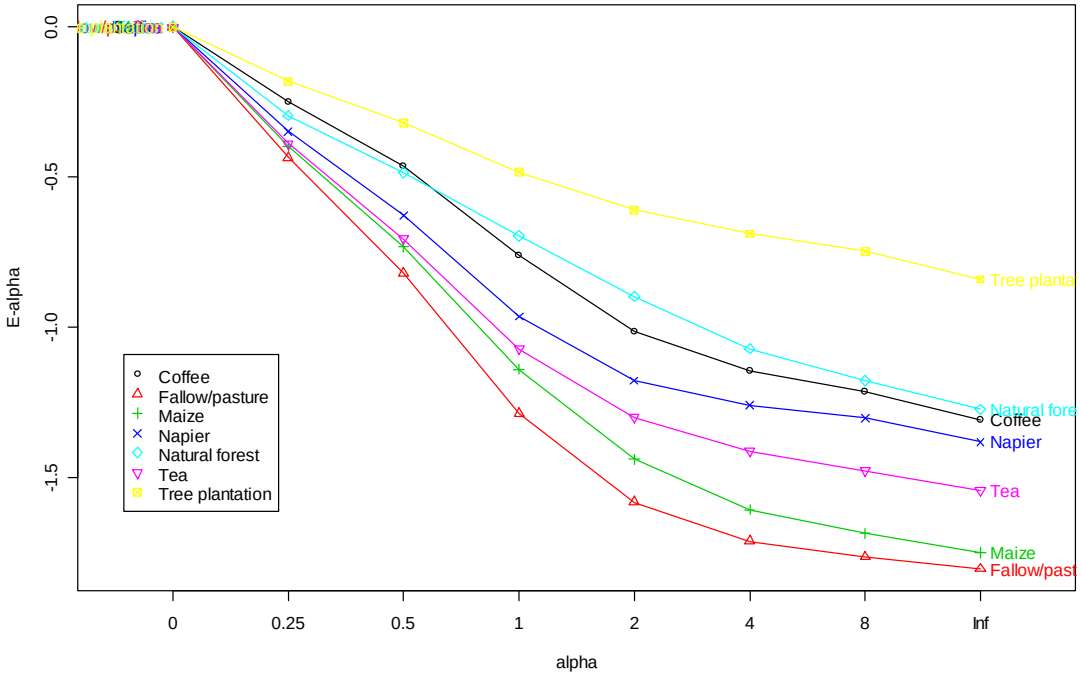

Figure 2. Rényi evenness profile across the different land use systems of Embu, Kenya.

Macrofauna abundance across land use systems of Embu

The major groups recorded in the Embu benchmark site included: Hymenoptera, Isoptera, Coleoptera, Oligochaeta and Orthoptera and Arenae (Table 3). Generally Hymenoptera were the most abundant of the macrofauna groups constituting about 45% of the total followed by Isoptera (39%), Coleoptera (6%), Oligochaeta (5%), Orthoptera (3%) and Arenae (2%). The other macrofauna groups that comprised Hemiptera, Diptera, Phasmidae and Blattelidae each constituted <1% of the total macrofauna recorded (Table 3).

Hymenoptera was ranked 1st as this macrofauna group had the largest total abundance (26,576 individuals m^{-2}), while Phasmidae was ranked 10^{th} since it had the lowest total abundance (16 individuals m^{-2}).

Macrofauna density (number of individuals m^{-2}) was highly variable across the land use systems (Table 4). Highest mean macrofauna density (1566) was recorded in the napier followed by fallow (1356) > coffee (1170) > natural forest (1110) > tea (755), but lowest in the plantation forest (309), although (ANOVA) indicated no significant variation among the land use systems. However, significant differences were noted for some of the macrofauna groups such as Hymenoptera, Coleoptera, Oligochaeta and Orthoptera (Table 3). Hymenoptera were significantly higher in the fallow (1028) followed by napier (778) > maize (524) > coffee (414), but lowest in plantation forest (110) < natural forest (132) < tea (216). Coleoptera on the other hand were significantly highest in the natural forest (286) than in all the other treatments. The densities of Oligochaeta were significantly highest in both the primary forest (108 m^{-2}) and secondary (108), followed by maize (62), but significantly lowest in fallow and napier (28) > coffee (23) > tea (18). Orthoptera were significantly highest in coffee (107) than in all the other treatments. However the density in coffee was not significantly different from that observed in napier. Some groups such as Isoptera, Arenae, Hemiptera, Diptera, Phasmidae and Blattelidae were not significantly different across the land use systems (Table 4).

Relationship between soil properties and macrofauna abundance

Redundancy analysis (RDA) plots were fitted to the constrained environmental variables (Table 5). The RDA table shows 5.6 from the total 34.8 variance or 16.1% of variance. Eigenvalues of the RDA axes constrained to environmental parameters indicates that soil parameters explain 16.1% of the observed variance on macrofauna abundance.

GLM equally fitted for some macrofauna groups indicated significantly stronger relationships between some soil parameters versus some soil macrofauna groups (Table 6). Significantly stronger correlations were observed between pH, % soil C and N and Hymenoptera group, explaining between 7.5 and 8.7% deviance (Table 6). The other soil parameters (acidity, P and K) had no significant correlation with the macrofauna group. Whereas a strong significant correlation was observed between soil N and Isoptera group, no correlation was observed between this macrofauna group and the other soil parameters (pH, acidity, soil C, P and K). However, Coleoptera was not significantly correlated with any of the soil parameters (Table 4). Whereas a significant correlation was observed between % N and Oligochaeta group explaining 7.5% of the deviance, the other soil parameters were not significantly correlated (Table 6).

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

Group	Rank	Abundance	Proportion (%)	P-lower	P-upper	Accumfreq	Logabund	Rankfreq
Hymenoptera	1	26576	44.5	31.9	57.1	44.5	4.4	10
Isoptera	2	23104	38.7	26.9	50.5	83.2	4.4	20
Coleoptera	3	3600	6.0	1.1	10.9	89.3	3.6	30
Oligochaeta	4	3168	5.3	2.7	7.9	94.6	3.5	40
Orthoptera	5	1712	2.9	0.9	4.9	97.5	3.2	50
Arenae	6	912	1.5	0.5	2.6	99.0	3.0	60
Hemiptera	7	464	0.8	0.3	1.2	98.8	2.7	70
Diptera	8	64	0.1	0.0	0.2	99.9	1.8	80
Blattodea	9	64	0.1	0.0	0.2	100.0	1.8	90
Phasmidae	10	16	0.0	0.0	0.1	100.0	1.2	100

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

Macrofauna group	Land use systems							Mean	P value
	NF	PF	C	F	M	N	T		
	----------Number m^{-2}----------								
Hymenoptera	132b	110b	414ab	1028a	524ab	778ab	216b	457	0.05*
Isoptera	566a	69a	524a	242a	190a	618a	483a	385	0.44 ns
Coleoptera	286a	14b	34b	24b	10b	58b	14b	63	0.04*
Oligochaeta	108a	108a	23b	28b	62ab	28b	18b	51	0.05*
Orthoptera	0b	0b	107a	8b	18b	52ab	13b	22	0.05*
Arenae	14a	4a	43a	14a	4a	22a	6a	15	0.42 ns
Hemiptera	2a	4a	21a	8a	8a	8a	3a	8	0.23 ns
Diptera	0a	0a	4a	0a	2a	2a	0a	2	0.35 ns
Phasmidae	2a	0a	0a	0a	0a	0a	0a	1	0.38 ns
Blattelidae	0a	0a	0a	4a	2a	0a	2a	2	0.30 ns
Mean total	1110	309	1170	1356	820	1566	755		0.21ns

NF-Natural forest; PF-Plantation forest; C-Coffee; F-Fallow; M-Maize; N-Napier; T-Tea
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: 34.83
Constrained: 5.61 (16.12%)
Unconstrained: 29.22 (83.88%)
Eigenvalues and their contribution to the variance

Axes	RD1	RD2	RD3	RD4	RD5	RD6	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Lambda	2.77	1.75	0.63	0.33	0.11	0.02	9.29	8.34	3.06	2.65	2.36	1.40	1.20	0.43	0.38	0.11
Accounted (%)	7.90	13.0	14.8	15.8	16.1	16.1	26.7	50.6	59.4	67.0	73.8	77.8	81.2	82.6	83.7	83.9

Macrofauna reacted differently to the probable influence of soil chemical properties. Strongest and significantly correlating variables were soil C, Mn and N (<0.01). The other variables weakly correlated with the soil macrofauna group. The macrofauna groups (Coleoptera, Hymenoptera, Oligochaeta and Orthoptera) that varied significantly across the land use systems were traced and assessment made on how they correlated with these variables. Oligochaeta positively correlated with both C and N, but negatively with Mn. Orthoptera positively correlated with Mn, but negatively to C and N. On the other hand, Hymenoptera negatively correlated with soil C and N but positively with Mn. Coleoptera weakly correlated with these soil variables (Figure 3).

Hymenoptera group was negatively correlated with soil pH, % C and N (Figure 4A-C) explaining why they were probably highest in the natural forest but lowest in the plantation forest. Probability of finding Hymenoptera in soils with high soil pH, C and N decreased with increase in these variables. Isoptera group were also negatively correlated with soil N (Figure 5A). Probability of finding Isoptera in soils with high soil N decreased with increase in N. They were highest in maize but lowest in plantation forest. On the other hand, Oligochaeta were positively correlated with soil N (Figure 5B). Probability of finding Oligochaeta in soils with high N increased with increase in N. They were highest in natural forest but lowest in tea.

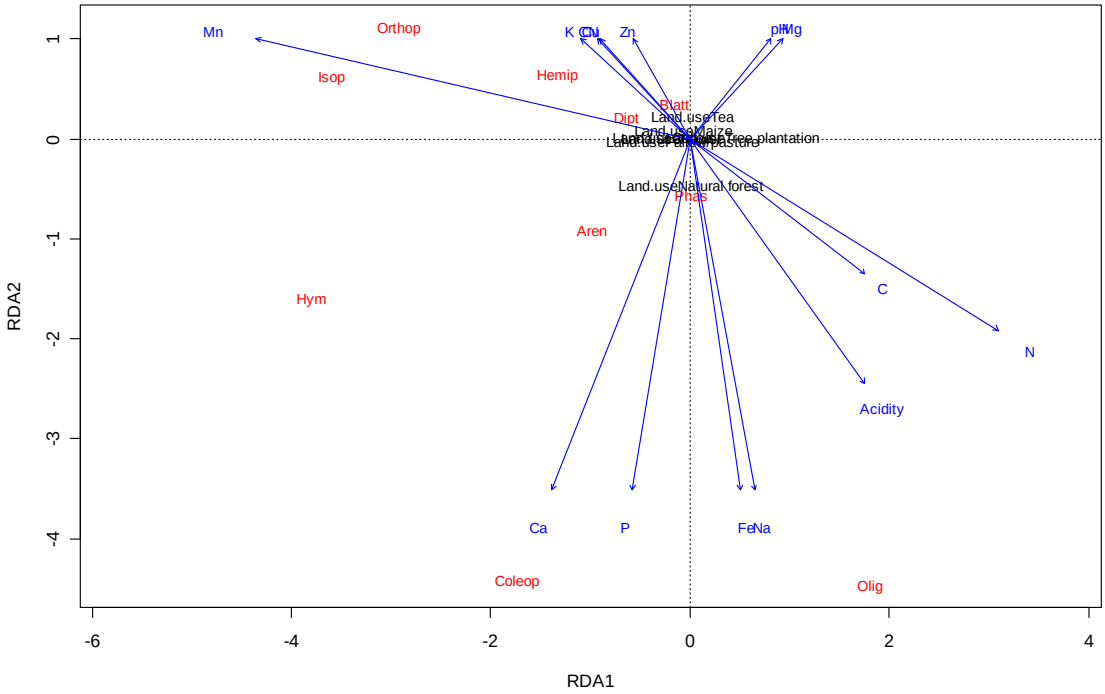

Figure 3. RDA biplot showing correlation between soil macrofauna groups and all the soil parameters as constraining variables. Soil characteristics are represented by arrows.

Table 6. Correlation between selected soil properties and macrofauna abundance.

	Macrofauna group							
	Hymenoptera		Oligochaeta		Coleoptera		Isoptera	
Selected soil parameters	F-test	Deviance explained (%)	F-test	Deviance explained (%)	F-test	Deviance explained (%)	F-test	Deviance explained (%)
$pH_{(1:2.5\ H2O)}$	0.02*	8.74	0.37ns	1.09	0.41ns	0.87	0.16ns	2.62
Acidity (%)	0.16ns	3.86	0.50ns	0.59	0.64ns	0.28	0.75ns	0.13
N (%)	0.03*	7.93	0.03*	7.49	0.14ns	2.81	0.03*	6.36
C (%)	0.03*	7.54	0.08ns	4.13	0.28ns	1.48	0.23ns	1.89
C:N	0.80ns	0.10	0.06ns	4.96	0.08ns	3.89	0.12ns	3.16
P(ppm)	0.25ns	2.06	0.42ns	0.87	0.58ns	0.40	0.30ns	1.43
$K_{\ cmolc\ kg^{-1}\ soil}$	0.90ns	0.02	0.60ns	0.36	0.98ns	0.00	0.14ns	2.83

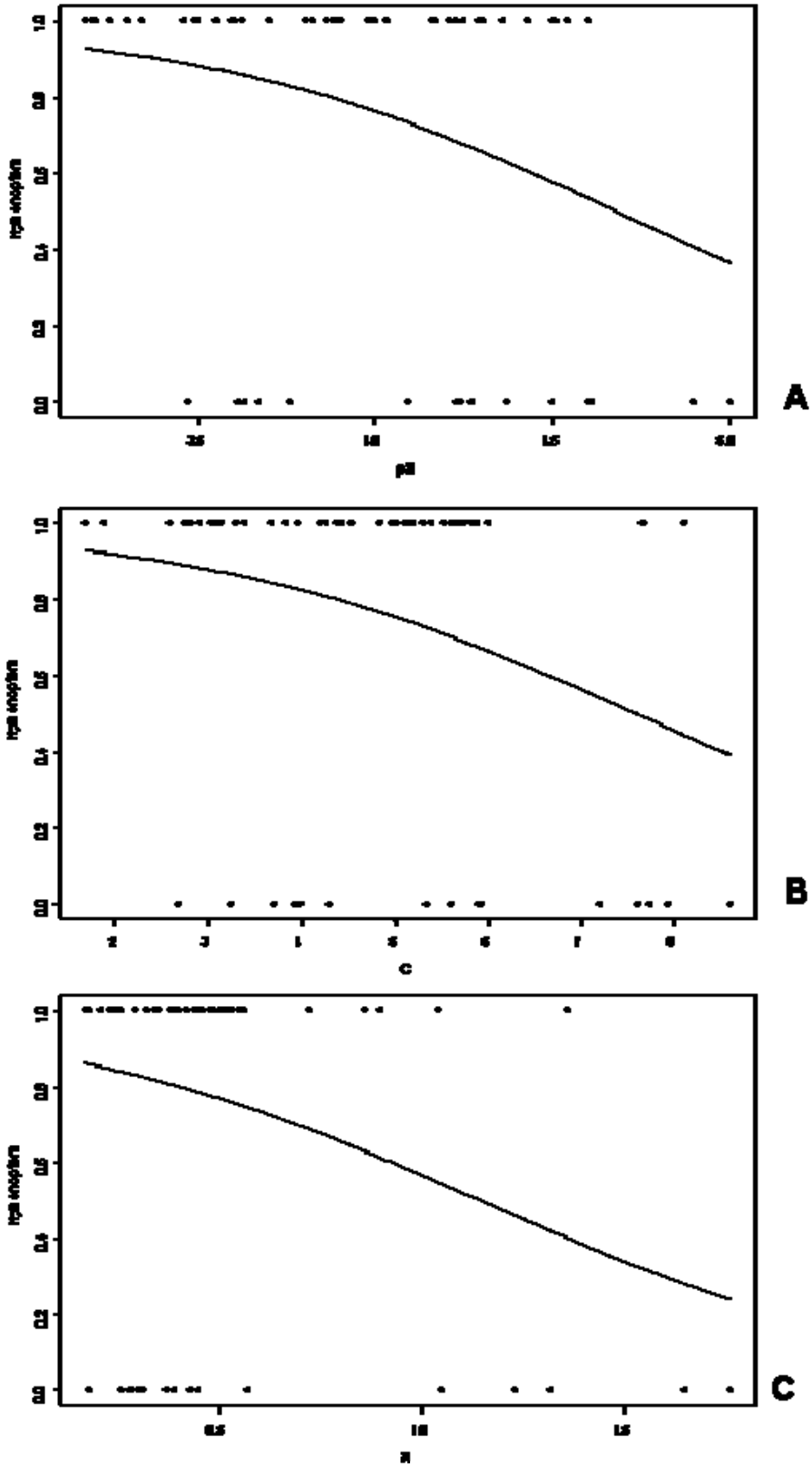

Figure 4. Correlations between soil characteristics and Hymenoptera group.

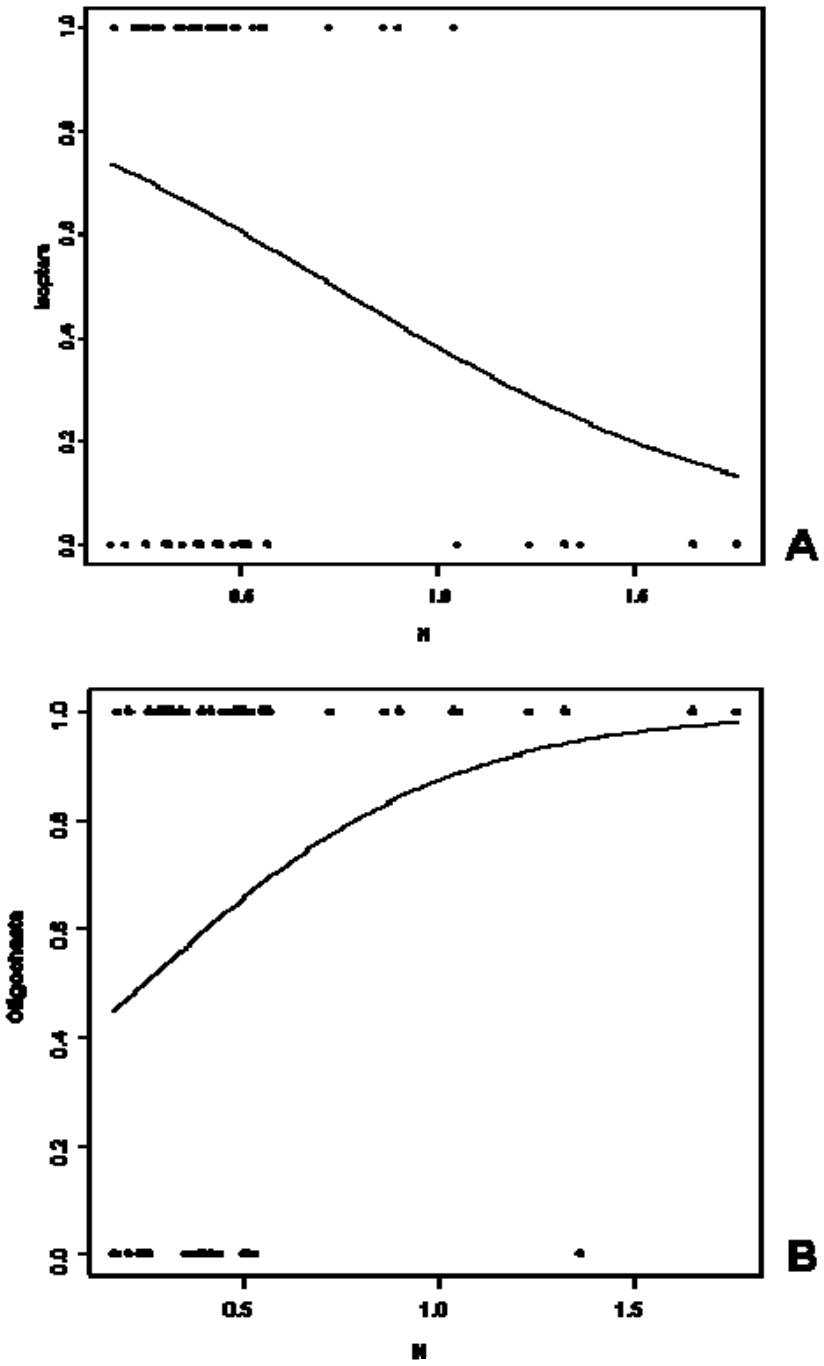

Figure 5. Correlation between soil N and Isoptera group; soil N and Oligochaeta.

DISCUSSION

Impact of land-use intensification on macrofauna diversity and abundance

Results of this study have shown that plantation forest was rich in macrofauna species and that the forests had higher species distribution or evenness than the agroecosystems. Natural forest too harboured higher Coleoptera and Oligochaeta density than the agroecosystems. These observed variations in macrofauna diversity and density appear to be associated with management practices such as use of agrochemicals, consequent 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 shown 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). These observations are consistent with results of our study, in which some groups such as Oligochaeta, Coleoptera were found to be more abundant in the forests but low in the other land use systems such as coffee and tea. In these land use systems, farmers use both inorganic fertilizers and pesticides to increase yields and pest control. Consequently these practices could have contributed to the low diversity and abundance observed. Fallow/napier a land use system in transition between use and recovery had lowest species richness and were less even. The findings of higher species richness in the plantation forest, higher species distribution or evenness in the forests, higher Coleoptera and Oligochaeta abundance, particularly in the natural forest are consistent with that reported by Okwakol, (2005) in that, natural forest was found to be richer than the agroecosytems and that forest clearance and subsequent cultivations resulted in drastic reduction of the number of species to about 40% of the original diversity in forest soils. In most cases forest disturbance, clearance and cultivation creates a harsh environment intolerable to a number of soil organisms.

It has been suggested that those animals with cryptic behaviours, those capable of vertical migration or nest building such as termites may overcome temporary adverse consitions. Although the observed density of 1110 individuals m^{-2} reported for the natural forest of Embu measures to that between 1333 and 3061 individuals m^{-2} reported by Rossi and Blanchart (2005), some tropical forests such as those of Mexico and Cote d'Ivoire are known to host higher soil macrofauna densities (up to 10,000 individuals m^{-2}) than intensively cultivated lands. Studies by results therefore do not corroborate those reported elsewhere.

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 Oligochaeta were positively correlated to N and were found to be abundant in the forests. This observation corroborates findings by Newman, 1988 who observed a strong positive correlation between amount of inorganic nitrogen applied and population of earthworms. Other groups such as Hymenoptera and Isoptera negatively correlated soil pH, C and N. The forests contained a thick 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 however appeared not to favour Hymenoptera who in most cases feed on other groups such as the Isoptera. Consequently these groups were observed in low numbers in the forest ecosystems than in the agroecosystems. 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 systems are subjected to varying levels of intensification. These changes appear to be associated with management practices such as use of agrochemicals, consequent 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 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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