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COLLEMBOLA DENSITY AND DIVERSITY ALONG A GRADIENT OF LAND- USE TYPES IN EMBU DISTRICT, EASTERN KENYA

[DENSIDAD Y DIVERSIDAD DE COLLEMBOLA EN UN GRADIENTE DE USO DE SUELO EN EL DISTRITO DE EMBU, KENIA]

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SUMMARY

Populations of soil-dwelling Collembola were monitored on a land use gradient ranging from Natural forests to intensively cultivated land during the wet season October-November, 2007 and dry season February-March, 2008. Eight land use types (LUTs) which included stands of; *Eucalyptus saligna*, *Vitex keniensis*, *Pennisetum purpureum*, indigenous forest, fallow fields, *Cammelia sinensis*, *Coffea africana* and *Zea mays* intercropped with *Phaseolus vulgaris* were sampled for Collembola in Embu district. Collembola population densities of (15,111 M^2) were collected in the study area. The Collembolan populations were lower in all sites during the dry season (5,445 M^2), compared to those of wet season (9,666 M^2). However, the highest Collembolan population was observed in undisturbed indigenous forest (38,089 M^2) during the dry season. A total of seventeen genera in seven families were recorded. The genus *Isotomiella* was the most abundant followed by *Cryptopygus, Folsomina* and *Parisotoma* respectively. Results from this study revealed that abundance, diversity and species richness decreased along land use gradient with agro-based LUTs presenting an impoverished community. The level of organic matter as indicated by proportion of Carbon and Nitrogen in LUTs such as Indigenous forest, *Eucalyptus* forest and *Cammelia sinensis* seemed to influence highly Collembolan assemblages. The study concludes that land use intensification (land disturbance) negatively influences the abundance and species richness of soil Collembolan communities.

Key words: Mesofauna; land intensification; Collembola and land use types.

INTRODUCTION

Soil conditions and vegetation cover influence the activities of diverse soil organisms including Collembola (Hansen, 2001). Collembolan communities have been shown to vary in abundance and diversity negatively according to changes in vegetation, quality of litter materials, habitat structure and human induced disturbances related to land use practices (Bengtsson, 2000, Ponge *et al*., 2003, Sousa *et al*., 2003 and Jose *et al*., 2004, 2005). Agricultural intensification leads to alteration of soil pH which disrupts niches of soil fauna (Moreira *et al*., 2006). Previous studies on effect of soil disturbances on the abundance and diversity of mites and Collembola showed that soil disturbance negatively affects their diversity (Bedano *et al*., 2006). Berch *et al*., 2007 have showed that molding and burning of surface plant litter reduces populations of Acari and Collembola. Understanding the impact of disturbance on abundance and diversity due to changes in land use practices is important for development and implementation of effective measures to preserve biodiversity of Collembolans in human-disturbed land uses. Previous studies have shown that high concentration of cadmium in the soil, accumulation of heavy metals in the soil and type of vegetation cover as well as chemical conditions in the soil affect reproduction, survival and abundance of Collembola (Langa-Reyrel and Deconchat, 1999, Ponge *et al*., 2003, Menta *et al*., 2006 and Syrek *et al*., 2006). The high sensitivity of Collembolans to microclimatic changes makes them very important bio-indicators of land degradation (Stork, 1995). Studies aiming to evaluate the degree of change in Collembola diversity patterns induced by land use intensification are scarce Ponge *et al*., 2003.

Previous studies on effect of land use types on biodiversity of Collembola in Europe exist but, little work has been done in Africa. In Kenya, little data exists on soil Collembola biodiversity despite its diverse assemblages and importance (Coimbra, 1983, Deharveng, 1984 and Moreira *et al*., 2006). The agro-ecosystem of Embu district is characterized by intensified agricultural activities creating a unique ecological zone especially along the slopes of Mount Kenya whose biodiversity has been poorly studied. As a part of Global below Ground Biodiversity project funded by Global Environmental Facility (GEF) in eight countries including Kenya, the study aimed at analyzing the response of Collembolan communities along a gradient of LUTs, ranging from undisturbed forests to disturbed agricultural-dominated biogeography regions. The paper specifically analyses (i) the abundance and diversity of Collembolan communities in different LUTs, and (ii) the effect of seasons and soil physical parameters to Collembola abundance and distribution in different LUTs.

MATERIAL AND METHODS

The study was conducted in Embu district in Eastern Province during the wet and dry season of October 2007 and February 2008 respectively. Embu, bench mark site is on the slopes of Mount Kenya at altitude of 1480m above sea level. The site lies along a gradient from Irangi forest to Kibugu sub-location with intensified agricultural activities. The area lies along longitude 0 37° 30´E and latitude 0 3° 32´S. Soils are deep, well weathered with friable texture, with moderate to high fertility. They are mainly Humic Nitisols (Jeatzold and Schmidt, 1983). A total of eight land use types located using GPS system (Swift and Bignell, 2000) were sampled in the study site. The LUTs comprised of *Eucalyptus saligna* (Myrtaceae), *Vitex keniensis* (Verbenceae)), indigenous forest (predominated by *Trichilia emelica* (Meliaceae), *Podocarpus falcalus* (Podocarpaceae), *Cordia africana* (Boraginaceae)), fallow (predominated by *Lantana camara* (Verbebaceae), *Trema orientalis* (Ulmaceae), *Rubus steudneri* (Rosaceae), *Pennisetum clandestinum* (Poaceae), *Conyza bonariensis* (Compositae)), *Camellia sinensis* (Theaceae), *Coffea arabica* (Rubiaceae) *Pennisetum purpureum* (Poaceae) and *Zea mays* (Poaceae) intercropped with *Phaseolus* vulgaris (Fabaceae). The LUTs in the study site range from undisturbed forest land use type (LUTs) to disturbed agricultural LUTs.

The sampling points were established at fixed intervals of 200 m apart along the selected transects. At each LUT, twelve sub-samples were collected from each sampling point and composed into three samples (Figure 1). There were four replications in each LUT. At each sampling point, Collembola were sampled by taking a soil core of 5 cm wide and at a depth of 5 cm including the organic horizon. Collembola were extracted using dynamic behavioral modified Berlese funnel and were identified to the genus level due to taxonomic impediment. Sampling was done in the wet season (October – November, 2007) and dry season (February – March, 2008).

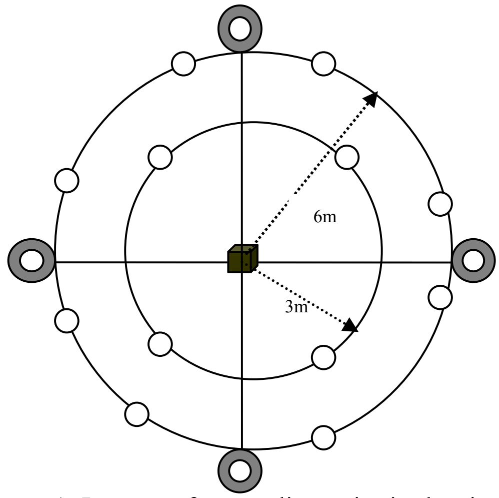

Figure 1. Lay out of a sampling point in the site. The sampling point in the middle of the circles shows the location of the monolith where other data on below ground biodiversity were collected. The lighter circles outside the monolith show the points at which core samples of both mites and Collembola were sampled.

Data analysis

Data collected was averaged per sampling point and land use types, analyzed using analysis of variance (ANOVA). Prior to analysis, data were normalized using log transformation. Biodiversity descriptions estimated; genera abundance, richness, Shannon, Renyi index, and Principal Component Analysis. The mean values were compared using the Fisher test when ANOVAs where significant.

RESULTS

We recorded 2847 soil dwelling Collembolan represented in 8 families and 17 genera. The family *Isotomidae* was the most frequently sampled, with a cumulative frequency of 82.6%. The most abundant genera were as follows: *Isotomiella, Cryptopygus, Folsomina and Parisotoma*. The rest of the genera had an accumulative frequency of less than one. *Isotomiell*a had the highest frequency of occurrence, followed by *Cryptopygus*, *Folsomina* and *Parisotoma* (Table 1). The rest of the genera had a frequency of less than 1% (Table 1). However, six of the eight families sampled belonged to the Order Athropleona while, the rest belonged to the Order Symphypleona.

The eight land uses were significantly different in terms of mean densities in year 2007 wet season (p=0.0004). The highest mean density recorded in indigenous was 163.25 and lowest in maize based LUT was 6.75. There was no significant difference in mean richness (P<0.156) and mean Shannon (P<0.100) between LUTs except between indigenous forest and maize, tea and maize, *Vitex* and maize, *Eucalyptus* and maize as revealed by the P-values (p=0.004, p=0.019, p=0.015, p=0.024 respectively). The highest mean densities were recorded in indigenous forest, followed by tea plots (Table 2). The eight LUTs showed significant differences in their mean density in year 2008 dry season (p<0.001). The highest density was recorded in *Eucalyptus* forests (101.000) and lowest in fallow (6.5000) in the same period. Both mean richness and mean Shannon did not show significant difference although there was mean difference between Indigenous forest and Maize, Indigenous forest and Coffee (p=0.007, p=0.013 respectively (Table 3)).

Table 1: Frequency of occurrence of soil dwelling Collembola in different LUTs in Embu, Kenya.

Genera	No of Collembola	Frequency	Cumm.Frequency
Isotomiella	1020	35.8	35.8
Cryptopygus	682	24.0	59.8
Folsomina	339	11.9	71.7
Parisotoma	299	10.5	82.2
Ceratophysella	218	7.7	89.8
Lepidocyrtus	140	4.9	94.8
Tullbergia	48	1.7	96.5
Psuedosinella	41	1.4	97.9
Sminthurinus	20	0.7	98.6
Hypogastrura	12	0.4	99.0
*Folsomide*s	10	0.4	99.4
Sminthurus	8	0.3	99.6
Odontella	5	0.2	99.8
Xynella	2	0.1	99.9
Subisotoma	1	0.0	99.9
Folsomia	1	0.0	100.0
Friesea	1	0.0	100.0
Total	2847	100.0	

Table 2. Effect of land use on density, richness and diversity of Collembola in the wet season 2007 in Embu, Kenya.

LUT	Mean Density	Mean Richness	Mean Shannon
Indigenous	163.25±22.41a	5.750±0.479a	1.370±0.0935a
Tea	120.50±46.92ab	4.750±0.479a	1.196±0.1335a
Eucalyptus	75.50±26.81bc	4.500±0.289a	1.164±0.0626a
Napier	39.50±17.60cd	4.000±0.913ab	1.076±0.1801a
Vitex	39.00±8.00cd	4.667±0.333a	1.278±0.1361a
Coffee	19.50±6.51cd	4.000±1.732ab	0.858±0.3552b
Fallow	19.00±9.08cd	3.750±0.750ab	1.104±0.1740a
Maize	6.75±1.250d	2.000±0.408b	0.531±0.1907b
F-value	6.04	1.713	1.998
Df	7.23	7.23	7.23
P-value	0.0004	0.156	0.1

Means in the same column followed by the same lower case letter are not significantly different (Fisher test, p≤0.05), LUT = Land Use Type

Table 2. Effect of land use on density, richness and diversity of Collembola in the dry season 2008 in Embu Kenya

LUT	Mean Density	Mean Richness	Mean Shannon
Eucalyptus	101.000±28.47a	4.500±0.289a	1.125±0.1099ab
Indigenous	74.000±25.36ab	4.250±0.629b	1.266±0.1450a
Tea	33.750±8.47bc	2.750±0.629ab	0.579±0.2356bc
Maize	17.000±7.23c	2.750±1.250ab	0.718±0.3866abc
Vitex	16.667±13.32c	2.333±1.202ab	0.664±0.3330abc
Napier	16.250±4.50c	3.250±0.479ab	1.032±0.1640abc
Coffee	7.50±4.628c	1.500±0.645b	0.391±0.2334c
Fallow	6.500±2.102c	2.000±0.408b	0.578±0.2154bc
F-value	5.355	2.082	1.723
Df	7,23	7,23	7,23
P-value	0.001	0.087	0.153

Means in the same column followed by the same lower case letter are not significantly different (Fisher test, p≤0.05), LUT = Land Use Type

The diversity profiles of soil dwelling Collembolan in the five LUTs show that coffee and indigenous forest exhibited the highest diversity, followed by napier and Eucalyptus. The least diversity was observed in maize plots (Fig. 1). Forest ecosystems recorded the highest diversity with least recorded diversity recorded in agro-based ecosystem. The genera *Isotomiella*, *Lepidocyrtus*, *Parisotoma*, *Tullbergia*, *Odontella*, *Hypogastrura*, *Folsomina* and *Cryptopygus* were the most common in forest ecosystems while *Xynella*, *Subisotoma*, *Ceratophysella* were more abundant in agro-based ecosystems. The evenness profiles show that the fallow was the most even followed by coffee, napier, *Eucalyptus*, maize, *Vitex* and indigenous forest respectfully (Figure 2).

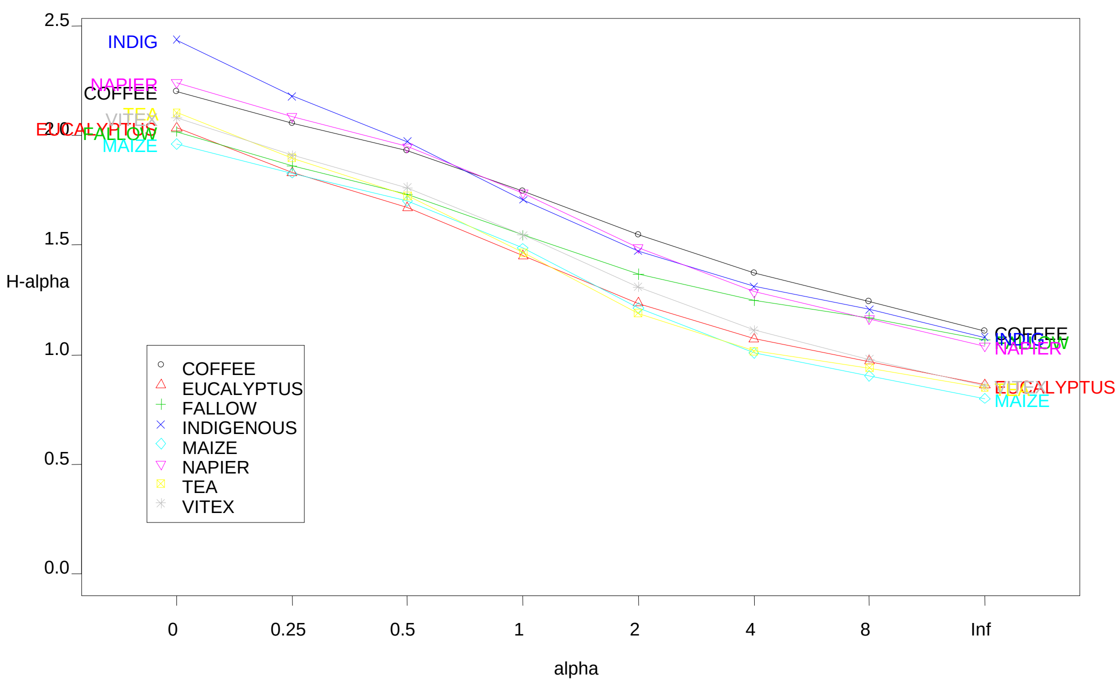

Figure 1. Land use diversity profiles for Embu (Renyi diversity profiles)

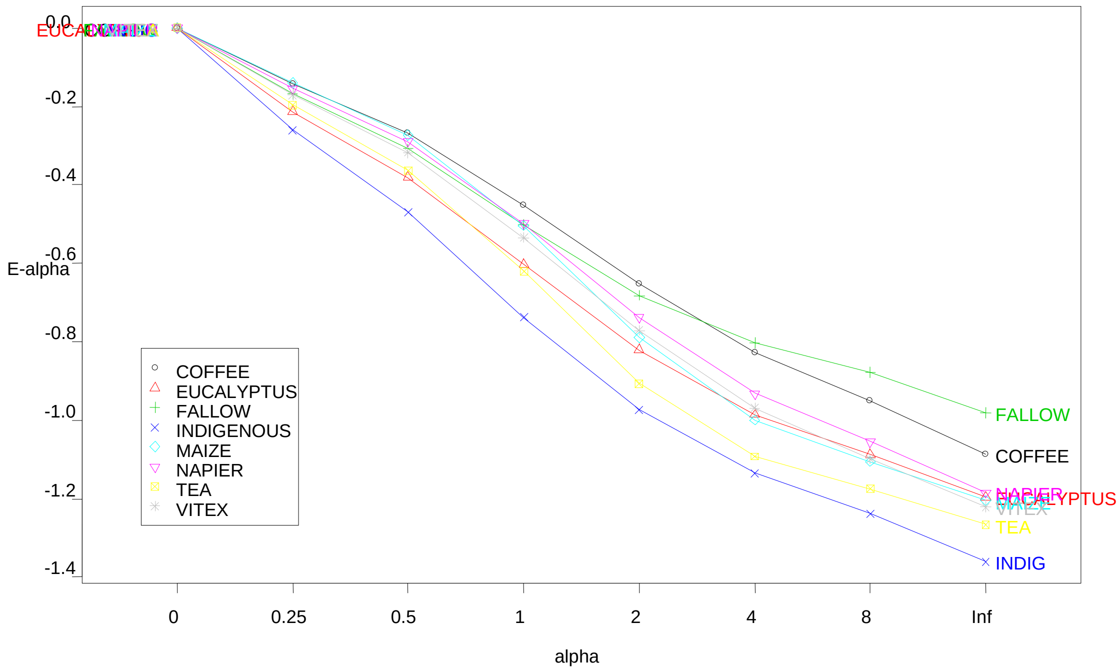

Figure 2. Land use evenness profiles for Embu (Renyi Eveness profiles)

The relationship between biodiversity descriptors, soil chemical parameters and LUTs were determined using Principal Component Analysis (PCA). It was observed that the acidity was high in *Eucalyptus*, indigenous forest and tea plots while Carbon and Nitrogen were high in *Vitex*. The results suggested that LUT was a significant factor in influencing the abundance and richness of Collembola. High abundance of the soil Collembola communities was observed in forested sites such as *Eucalyptus*, indigenous forest, and *Vitex* where there was high acidity and humus (organic matter). Difference observed between LUT could be attributed to disturbance effect which influenced soil compaction, organic matter content (food base), shade and moisture hence the creation of a microclimate. There was both low abundance and high diversity recorded in agro-based (disturbed) land uses like coffee, napier and young fallow. This may be due to removal of organic matter, burning of trash/plant materials, and high application of inorganic fertilizers and continuous turning of soil during tillage. Collembola have a soft cuticle and less pigmented compared to soil mites and hence less adapted to withstand direct suns heat.

DISCUSSION

Worldwide over 7500 species of Collembola have been identified (Hopkin, 1997). Unfortunately, Collembolan communities have not been studied in Kenya. The past data on Collembola study shows only four species belonging to genera *Xynella* and two species of Hypogastruridae (Coimbra, 1983 and Deharveng, 1984). In the current study, fifteen new records of Collembolan genera have been documented. They included *Isotomiella*, *Cryptopygus*, *Folsomina*, *Parisotoma*, *Ceratophysella*, *Lepidocyrtus Tullbergia*, *Psuedosinella*, *Sminthurinus*, *Hypogastrura*, *Folsomides*, *Sminthurus*, *Odontella*, *Xynella*, *Subisotoma*, *Folsomia* and *Friesea*. The study of these soil mesofauna is of interest because of their potential in improving soil conditions as well as act as indicators of land degradation. The edafica mesofauna (Acari and Collembola) play important roles, such as a catalyzer in the microbial activity, organic matter decomposition, moistening process, mechanical disintegration of the decomposing vegetable matter, 'soil respiration', formation and maintenance of the soil structure (Langerlóf and Andrén, 1991, Ponge *et al*., 2003). Plants and plants diversity determine functioning of below ground ecosystems via factors like plant litter quality and quantity.

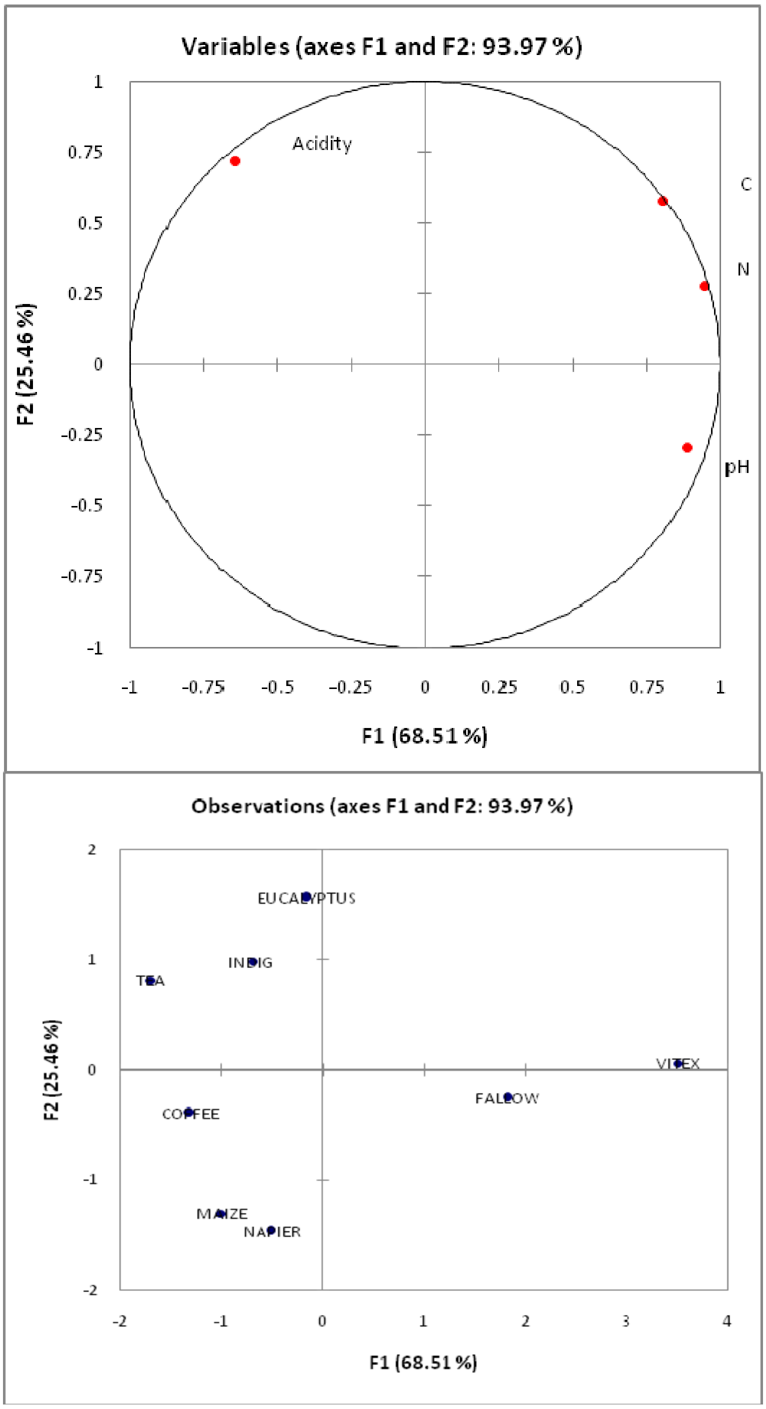

Figure 3 (a and b). Principal component analysis representing soil chemical parameter descriptors and land-use metrics.

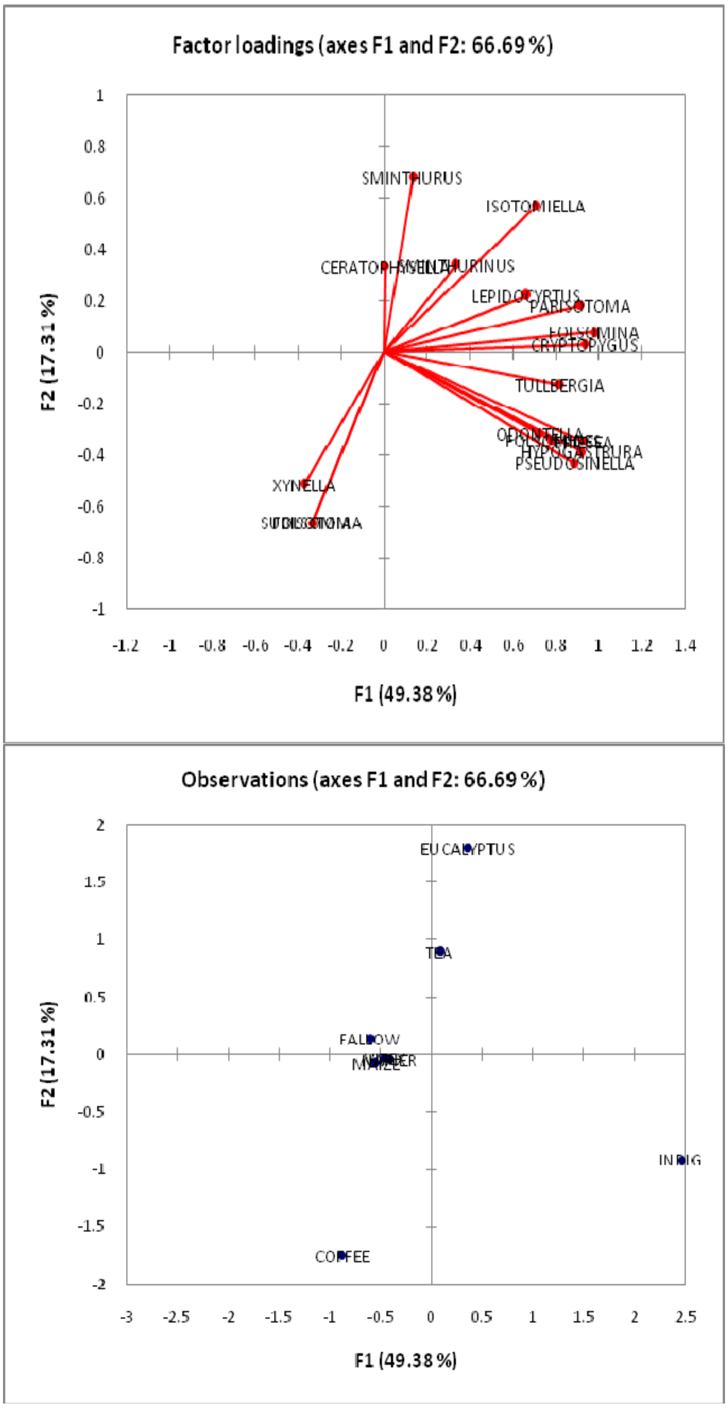

Figure 4 (a and b). Principal component analysis representing biodiversity descriptors and land-use metrics.

Although no comparative data on soil Collembolan community exists in East Africa, results from this study suggest that the agro-ecosystem of Mount Kenya region is rich in springtails. The Collembolan community in the study area was strongly dominated by Isotomidae accounting for 82.6 %. A similar pattern is reported by Lauga-Reyrel and Deconchat (1999) for oak coppice forests in France. Dominant Isotomidae species represented high reproductive rate and adaptive ability. The feature has allowed some of the genera to colonize forests and open micro-habitats. However, species dominance, diversity and richness were more in the forested habitats and impoverished in agricultural LUTs. This concurs with the results obtained by Alvarez *et al* (2001) who found a decline in richness and diversity of Collembolan community in crop systems. From the current study, it is evident that in all the sampled LUTs there was a difference in occurrence of soil Collembolan. The study also revealed that decreased disturbance resulted in increased occurrence and diversity of soil Collembolan. These findings are consistent with the previous reports indicating that soil Collembola are present in all habitats but at different densities and diversity as this group of organisms are known to react to changes in land use (Lauga-Reyrel and Deconchat, 1999 and Rosilda *et al*., 2002). The difference in landscape configuration as well land use cover types have an effect in species richness with low numbers of species recorded in arable land (Alvarez *et al*., 2000, 2001).

In general, the high numbers of Collembola sampled were epedaphic type because sampling was done on the upper 5 cm depth of the top soil with litter. The undisturbed relatively stable LUTs like indigenous forest, tea and Eucalyptus forests recorded high numbers of soil Collembola in both seasons. This may be explained by the presence of high organic matter, humid soils, acidity, nitrogen and presence of shade. Collembola are less pigmented and have soft cuticle hence are poorly adapted to withstand direct sunbeams, decreasing consequently in open, disturbed lands (Hopkin 1997). Low numbers recorded in disturbed and less stable land uses like maize based LUT may be due to decreased organic matter, soil compaction, lack of shade and agricultural intensification which may have led to deterioration of soil physical and chemical conditions (Lauga-Reyrel and Deconchat, 1999). The most impoverished LUTs included vegetable gardens and maize-based LUTs. The population difference was attributed to the impact of land management practices such as intensive use of fertilizers and agro-chemicals (Gudleifsson & Bjarnadottir, 2008). According to Syrek *et al* (2006) and Ponge *et al* (2003) accumulation of certain mineral elements and variation of certain vegetation cover and soil chemical conditions negatively affect Collembolan communities.

The highest abundance of the soil Collembola communities was observed in forested sites such as *Eucalyptus*, indigenous forest, and *Vitex* which were characterized by high acidity and humus levels (organic matter). Difference observed between LUT could be attributed to disturbance effect which influenced soil compaction, organic matter content (food base), shade and moisture hence the creation of a microclimate. There was both low abundance and high diversity recorded in agro-based (disturbed) land uses like coffee, napier and young fallow. This may be due to removal of organic matter, burning of trash/plant materials, and high application of inorganic fertilizers and continuous turning of soil during tillage. Collembola have a soft cuticle and less pigmented compared to soil mites and hence less adapted to withstand direct suns heat.

In conclusion, this study has provided additional information on the abundance and richness of Collembola in Kenya. The results obtained can be used to formulate alternative methods of land use practices that, will support the below ground fauna which are very important in improving soil fertility. From the current study it is evident that Collembola communities are good indicators of land use intensity but more research efforts and taxonomic training are needed in overcoming their taxonomic impediment in East Africa.

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REFERENCES

Alvarez, T., Frampton, G.K., Goulson, D. 2000. The role of hedgerows in the recolonisation of arable fields by epigeal Collembola. Pedobiologia 44: 516-526.

Alvarez, T., Frampton, G.K., Goulson, D. 2001. Epigeic Collembola in winter wheat under organic, integrated and conventional farm management regimes. Agricuture Ecosystems Environment. 83: 95-110.

Bedano, J.C., Cantu, M.P., Doucet, M.E. 2006. Influence of three different land management practices on soil mite (Arachnida: Acari) densities in relation to a natural soil. Applied Soil Ecology 32: 293 – 304.

Bengtsson, J., Nilson, S.G., Franc, A., Menozzi, P. 2002. Biodiversity, Disturbances, ecosystem function and Management of European forests. Forest Ecology Management 132: 39-50.

Berch, S.M., Battigelli, J.P., Hope, G.D. 2007. Response of Soil mesofauna communities and oribatid mite species to site preparation treatment in high elevation cutblocks in

Southern British Columbia. Pedobiologia 51: 23-32.

Coimbra, 1983. Systématique Évolutive Des Xenylla. XIII. Espéces Provenant Du Kenya (Insecta: Collembola). Revista da Universidale de Coibrya Vol XXIX-Ano 1981 pp: 249-257.

Deharveng, L., Diaz, A. 1984. Collembola du Kenya. Bulletin Museum Natural History. Paris, 4[e] Sér., 6: 335-348.

Gudleifsson, B.E., B. Bjarnadottir 2008. Springtail (Collembola) populations in hayfields and pastures in northern Iceland. Icelandic Agricultural Sciences. 21: 49-59.

Hansen, R.A. 2000. Effects of habitat complexity and composition on a diverse litter micro arthropod assemblage. Ecology. 81: 1120 - 1132.

Hopkin, S.A. 1997. Biology of the springtails (Insect: Collembola) Oxford University Press, Cambridge, UK.

Jeatzold, R., Schmidt, H. 1983. Farm Management Handbook of Kenya. Vol. II/L. East Kenya. Ministry of Agriculture. Nairobi, Kenya.

José, P.S., Maria, M.G., Cristina, P., Anto'nio, K., Filipa C., Marco, L., Catarina, C., Taigo, L., Pedro, L., Susana, D. 2004. Effect of land use on Collembola diversity patterns in a Mediterranean landscape. Pedobiologia. 48: 609-622.

José, P.S., Thomas, B., Maria, M.M., Thomas, L., Jean-Francios, P., Carlos, S., Georgy, T., Adam, J. V., Aoife, B., Florence, D. Eva, I., Anto'nio, K., Silvia, S., Allan, D. W. 2005. Changes in Collembola richness and diversity along a gradient of land-use intensity: A pan European study. Pedobiologia. 50: 147-156.

Lagerlóf, J., Andrén, O. 1991. Abundance and activity of Collembola, Protura and Diplura (Insecta, Apterygota) in four cropping systems. Pedobiologia, 35: 337-50.

Luanga-Reyrel, F., Deconchat, M. 1999. Diversity within the Collembolan community in fragmented coppice forests in South-Western France. European journal of Soil Biology 35: 177-187.

Menta, C., Maggiani, A., Vattuone, N. 2006. Effects of Cd and Pd on the survival of Juvenile production of *Sinella coeca* and *Folsomia candida*. European Journal of Soil Biology. 42:181-189.

Moriera, F. M. S., Iquera, J. O., Brussard, L. 2006. Soil organisms in Tropical Ecosystems: a key role for Brazil in the Global quest for the Conservation and sustainable use of Biodiversity. Soil Biodiversity in Amazonian and other Brazilian Ecosystems, CAB International, Wallingfork, UK. pp: 1-12.

Ponge, J.F., Gillet, S., Dubs, F., Fedoroff, E., Haese, L., Sousa, P.J., Lavelle, P. 2003. Collembola communities as bioindicators of land use intensification. Soil Biology Biochemistry. 35: 813-826.

Rosilda, M.M., Silvana de Paula, Q.S., Sandra, V., Valdirene, R.S. 2002. Study of Acari and Collembola Populations in Four Cultivation systems in Dourados-MS. Brazilian Archives Biology Technology. 45(3).

Stork, N.E. 1995. Measuring and Monitoring arthropod Biodiversity in Tropical and Temperate Forests. Centre for International Forests Research, Bogor, Indonesia. pp: 257-270.

Swift, M.J., Bignell, D. (eds), 2000. Standard methods for assessment of soil biodiversity and land use practice. Alternatives to Slash and Burn Project. ICRAF, Nairobi, Kenya. 41 pp.

Syrek, D., Wiener, W.M.., Wolty, M. Olszowska, G., Kwapis, Z. 2006. Species abundance distribution of Collembolan communities in forest soils polluted with heavy metals. Agriculture, ecosystems and environment. Applied soil ecology. 31: 239-250

Van Noordwijk, M., Swift, M.J. 1999. Belowground biodiversity and sustainability of complex agro ecosystems. In: A. Gafur, FX Susilo, M Utomo and M van Noordwijk (eds). Proceedings of a workshop on Management of Agrobiodiversity in Indonesia for Sustainable Land Use and Global Environment Benefits. UNILA/ PUSLIBANGTAN, Bogor, Indonesia. 19-20 August 1999. Pp: 8-28.

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