LAND USE CHANGE AND INTENSIFICATION: IMPACTS ON SOIL MACROFAUNA WITH EMPHASIS ON EARTHWORMS IN LAND USE MOSAICS IN EMBU AND TAITA-TAVETA DISTRICTS, KENYA

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DECLARATION AND RECOMMENDATION

Declaration

I declare that this thesis is my original work and has not been presented previously, in part or whole, to any university for a diploma, degree or any other qualification.

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Recommendation

This Thesis has been submitted with my permission and approval as university supervisor

Professor G.H.N. Nyamasyo.. Date 04|11|2012 ....

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DEDICATION

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ACRONYMS

ANOVA	Analysis of Variance
ASB	Alternatives to Slash and Burn Agriculture
ATP	Adenosine tri phosphate
BGBD	Below-Ground Biological Diversity
CEC	Cation Exchange Capacity
CAN	Calcium Ammonium Nitrate
CBD	Convention on Biological Diversity
CIAT	International Center for Tropical Agriculture
COP	Conference of Parties
CSIRO	The Commonwealth Scientific and Industrial Research Organization
DNA	Deoxyribonucleic acid
DRSRS	Department of Resource Surveys and Remote Sensing
FAO	Food and Agriculture Organization
FF	Farmer Fields
FTC	Farmers Training Center
GCTE	Global Change and Terrestrial Ecosystems
GEF	Global Environmental Facility
GIS	Geographical Information Systems
GLM	General Linear Model
GPS	Global Positioning System
ICRAF	International Center for Research in Agro-Forestry (World Agro-Forestry Center)

ITCZ	Inter Tropical Convergence Zone
KARI	Kenya Agricultural Research Institute
KEFRI	Kenya Forestry Research Institute
KREMU	Kenya Rangeland Ecological Monitoring Unit
KSS	Kenya Soil Survey
LUI	Land use intensity
LUT	Land use types
NMK	National Museums of Kenya
NPK	Nitrogen Phosphate and Potassium
NARL	National Agricultural Research Laboratories (Kenya)
pH	Measure of acidity or alkalinity
PI	Productivity index
RDA	Redundancy analysis
SOM	Soil Organic Matter
TSBF	Tropical Soil Biology and Fertility
TSP	Triple Super Phosphate
UN	United Nations
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UoN	University of Nairobi
USIU	United States International University
VAM	Vesicular arbuscular mycorrhizae
OTU's	Operational taxonomic units

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ABSTRACT

The study set out to determine, characterize and compare geomorphologic, physiographic land use types and agroecosystem intensification, assess physicochemical nature of soil at benchmark study sites of Embu and Taita Kenya. Then determine macrofauna occurrence, abundance and diversity along a land use intensification chronosequence and explore their relations with soil characteristics, and impacts of land use and agricultural intensification on diversity and abundance of soil macrofauna. Then finally determine effects of soil fertility amendments on earthworms in a maize based agroecosystem.

Specific stages within of study included site characterization, stratified sampling of macrofauna and estimation their abundance, biomass and diversity in land use mosaics subjected to varying degrees of anthropogenic intensification and determination of within and between land use mosaic macrofauna diversity.

The study synthesized and appraised importance of macrofauna in soil structure stability and quality, soil organic matter translocations, decomposition and inorganic soil components. Findings from this study provide baseline data and information on use of macrofauna in evaluating potential consequences of anthropogenic management practices as global change drivers of ecosystem processes responsible for loss or maintenance of soil productivity.

Key words: Macrofauna biodiversity, Earthworms, Geomorphology, Physiography, Land use, Soil fertility, Soil degradation, Agricultural intensification, Kenya

CHAPTER ONE

BACKGROUND TO RESEARCH ON BELOW GROUND BIOLOGICAL DIVERSITY: SOIL MACROFAUNA

1.0 General introduction

The study on below ground (soil dwelling) macrofauna in Kenya was part of a larger (global) research project on Conservation and Sustainable Management (CSM) of Below Ground Biological Diversity (CSM-BGBD) co-funded by the Global Environment Facility (GEF) with implementation support from the United Nations Environment programme (UNEP) and executed by Tropical Soil Biology and Fertility of the International Center for Tropical Agriculture (TSBF-CIAT).

The project was a multi-national undertaking carried out simultaneously in seven countries within the tropics, namely Kenya, Uganda, Cote d'Ivoire, India, Indonesia, Brazil, and México. It was also a multi-institutional research project. In Kenya, there were six participating institutions including The University of Nairobi (UoN), The National Museums of Kenya (NMK), The Kenya Agricultural Research Institute (KARI), The Kenya Forestry Research Institute (KEFRI), The United States international University (USIU) and The Department of Resource Surveys and Remote Sensing (DRSRS).

The project was multidisciplinary involving more than 300 researchers from various disciplines covering soil biology of several (micro, meso, and macro-fauna) "functional groups", soil and social scientists. Within this study, soil macrofauna like other soil dwelling biota are characterized by their role in soil functional processes, since there is a limited knowledge of their taxonomy as of most below ground soil biota.

The aim of research was to survey, document and develop an understanding of Below Ground Biological Diversity (BGBD) at plot, farm and landscape level, along with standardizing field sampling methods globally that can be used to assess and quantify BGBD. Since there is no single situation where a full inventory of soil biodiversity can be achieved, as different fauna groups require different methods for collection and extraction from soil that are often destructive to the soil habitat.

Further, methods of identification and quantification also require using a variety of methods. The study aimed at elucidated BGBD and enumerating ecological services that maintain soil productivity under prevailing circumstances of dwindling resources and increase in farm input costs in the face of rising human populations and reducing farm yields.

The soil is a dynamic, living matrix containing a variety of micro, meso and macrofauna that interact within and between themselves, and the soil, forming a web of biological activities that maintain soil quality. Soil is an essential part of the terrestrial ecosystem and is a significant finite resource not only to agricultural production and food security but also to maintenance of most life processes. However, wide knowledge gaps make it difficult to predict effects of land-use change on ecosystem processes as well as to evaluate other situations, such as effects of climate change or agricultural intensification on soil ecosystems.

Under the programme of work on agricultural biodiversity, the Conference of Parties (COP) to the Convention on Biological Diversity (CBD), initiated at COP-3 (decision III/11, of Buenos Aires, 1996), soil biodiversity was identified as an area requiring particular attention aimed at promoting positive and mitigating negative impacts of agricultural activities on soil biological diversity.

This led to the launch of conservation and sustainable use of genetic resources of actual or potential value for food and agriculture and promoting the fair and equitable sharing of benefits arising out of use of genetic resources at COP-5 (decision V/5, Nairobi, 2000, (UNEP, 2001). COP 3.

The parties recognized need to improve understanding of multiple goods and services provided by different levels and functions of soil biodiversity, appreciate relations between soil biodiversity, resilience and productivity in agro-ecosystems and of impacts of traditional and modern farming practices and technologies on soil biodiversity, sustainability and productivity of agricultural eco-systems. Special attention was to be paid to role of soil macrofauna and other below-ground biodiversity organisms in supporting agricultural production systems (UNEP, 2001).

Land use change and rate at which it is occurring, is of great global concern in the tropics, as is evidenced by extensive deforestation and conversion to agriculture in the initial stages, with subsequent agricultural intensification when land becomes limiting, resulting in a gradient of land use intensification (Ruthenberg, 1980; Swift, 1997).

In Kenya land use intensification gradients range from shifting cultivation, that is non-existent today with reduced land size and an ever increasing population. To reduced fallow systems, that is rare due to unrelenting population increases, with subsequent increase in demand for food, fiber and shelter distorting sustainability of shifting cultivation systems (Eyasu and Scoones, 1998). Ultimately continual unrelenting land utilization subjected to diverse management practices of varying intensities that is currently predominant.

In shifting cultivation, soil can fully recover if left long enough for many years. However this is not possible with increase in human populations and corresponding food demand that has resulted in short fallow periods (Lavelle *et al.,* 1998; Malton and Spencer, 1984), or improved fallow systems (Ahn, 1979), during which there is some restoration towards an equilibrium that existed before conversion of forest habitats.

Thus while shifting cultivation was for long considered the most adoptable farming system in the humid tropics, particularly in low populated areas (Bandy *et al.,* 1993, Nye and Greenland, 1960). Soil sustenance by a nutrient flux during slash and burn with ash residues being incorporated to increase fertility is no longer tenable, need therefore exists for external inputs to sustain or improve the soil productivity through various intensification strategies.

However, existing intensification levels are unsustainable under the prevailing economic meltdown in most developing countries within the tropics. Intensification has been shown to severely compromise soil quality (Lal, 1997), its capacity to be productive (Jeffery, 2000) and resilience (Fresco and Kroonenberg, 1992; Lal, 1993), as agricultural practices employed stress and perturb the soil environment.

Processes of land use change and agricultural intensification are significant factors contributing to soil biodiversity loss with considerable impact on ecosystem services that BGBD provides and concomitant soil productivity (Hairiah *et al.*, 2001). Decline in soil biological diversity impairs essential ecosystem functions reducing ability of agricultural systems to withstand unfavourable periods of stress.

1.1 Problem statement

It is acknowledged that intensified land use in agriculture and forestry is a major cause of global climate change and biodiversity loss, through elevated levels of green house gases (methane, carbon dioxide, and nitrous oxide) associated with decline in forest cover and that agriculture substantially contributes to their emission through unsustainable slash and burn agriculture and intensive agriculture through high use of fertilizers and fossil fuels (Smaling *et al.*, 1999). Nevertheless low-intensity land-use systems may be important elements of large-scale conservation programmes.

Degradation of soil structure, through natural or human-induced processes negatively impacts on vegetation diversity and landscape vegetation patterns (Young *et al.*, 1991). Soil biota are negatively impacted on when vegetative cover is removed, leading to dramatic decrease in crop yields.

Over time degradation of soil evidenced by declining stability, increased erosion, decreasing sequestered carbon levels (Holland and Coleman, 1987; Ladd *et al.*, 1994), and low microbial activity is masked by use of inorganic chemical inputs (Greig-Smith, 1990). This contrasts to farming under natural conditions, where resource inputs to the soil are derived from plants, either through root exudation and root turnover during active growth, or from dead plant material following senescence or tillage.

Disturbances to soil systems arising from direct action on soil, or indirectly from effects on above-ground plant community, induce changes in plant community composition that change soil food web composition and soil organisms involved in direct interactions with plants, as has been depicted that plant detritus composition impacts on feeding behaviour of macrofauna. Agricultural fields are subjected to frequent disturbances of ploughing, harrowing, fertilizing and pesticide applications, among other inorganic amendments and soils are often left bare over periods of time in between seasons.

Agroecosystems therefore differ from perennial habitats such as forests, plantations, grasslands and hedgerow field boundaries, which act as refugia for macrofauna, as has been established that arable fields are regularly re-colonized from these perennial habitats (Holland & Reynolds, 2003; Samu *et al.*, 1999; Schmidt & Tscharntke, 2005b). Consequently, local farming systems and factors within the landscape may have significant effects on biodiversity within arable fields (Schmidt *et al.*, 2004).

It has for long been presumed that high diversity and endemism of below ground macrofauna is found in the humid tropics However these environments are subject to most rapid change, increasing concern and interest to study below ground biological diversity, as limited data is available on taxonomy, ecology, geographic distribution and critical roles macrofauna play in driving ecosystem services within the tropics (Wells, 1986).

As landscape use changes shift, so do species compositions and distributions. It is therefore anticipated that food web patterns will shift according to changes in community composition of above as well as below ground organisms. Intensification of cropping systems by increased inorganic inputs and reduced crop diversity exerts small and differential effects on different soil biota groups, as intensification affects abundances diversity and composition of functional taxonomic groups with larger body size (earthworms) more negatively than smaller-sized taxonomic groups by short-term consequences of conversion (disturbance, loss of habitat), (Hauser, 1993; Lavelle *et al*., 1998).

One important reason for studying and measuring diversity is to measure the impact of projects or interventions planned to achieve landscape domestication, To be able to demonstrate such impacts, one needs to measure diversity before and after the interventions hence the importance of biodiversity indices.

1.2 Justification

Agriculture in Africa is both a source of food and income; it is a way of life. Most of the human population in Africa live and subsist on farming with the poorest of the poor being most dependent on agriculture for food and income. However food consumption exceeds production and despite increase in farming area, food production continues to decline.

With over eighty percent (80%) of the population in tropical Africa residing in rural areas engaging in subsistence rain fed arable agriculture from which they derive their livelihoods, that depend on level and structure of agricultural production and land use management practices that in turn affect spatial and temporal distribution of ecosystem resources.

Small holder farmers who constitute bulk of the farming community have limited resources to access inorganic inputs to sustain food production (Tian *et al.,* 1997). Currently most agricultural practices in the tropics result in loss or degradation of non-crop habitats, through clearing of forests and shrubs and draining of wetlands. Similarly removal of weeds from within farmed land, enlargement of field sizes reducing hedge-rows, tillage frequency and intensity, use of inorganic fertilizers and chemicals to enhance production, control pests and weeds to increase crop yield (Gurr *et al.*, 2003), are all impacting on soil ecosystems.

With widespread food shortages, there is growing apprehension over undesirable effects of agricultural intensification on macrofauna diversity, as increase in global food production is perceived to be dependent on agricultural intensification. However, resorting to agricultural intensification to remedy food shortages raises concern over adverse effects such intensification has on soil macrofauna biodiversity in agricultural areas (Krebs *et al.*, 1999 Swift *et al.*, 1996).

Soil biodiversity has been greatly influenced by these changes on various spatial scales ranging from plot, landscape and regional levels. At field scale, shift from fallow and organic inputs to inorganic synthetic fertilizers, and introduction of pesticides has had a negative impact on fauna and flora (Greig-Smith, 1990; Matson *et al.*, 1997). While mono-cropping has resulted in greatly simplified agroecosystems (Swift *et al.*, 1996).

On landscape scale within some regions, fields have been amalgamated, consolidated and enlarged to enhance farming efficiency resulting in homogeneously farmed landscapes with little non-crop areas, as is witnessed in developed countries and large scale farms in developing economies. On the other hand, fragmentation of land and removal of scant natural habitat (hedgerows) because of expanding human populations, with concomitant increase in intensity of agricultural practice as is observed in developing countries (Tilman *et al.*, 2002), is significantly impacting on soil macrofauna biodiversity.

Expansion and intensification of cultivation are among predominant global changes evidence in the 20th century. While intensification of agriculture by use of high-yielding crop varieties, soil fertilization, irrigation, and pesticides has contributed substantially to tremendous increases in food production over the past 50 years, land conversion and intensification. It has however altered biotic interaction and patterns of resource availability in soil ecosystems with grave environmental consequences at plot, landscape, regional and global levels. Therefore, need to use ecologically sound management strategies that contribute to sustainable agricultural production and simultaneously reduce negative impacts on soil biodiversity is imperative.

During the last few decades, worldwide losses of biodiversity have occurred at an unprecedented scale and agricultural intensification has been a major driver of this global change (Matson *et al.*, 1997; Tilman *et al.*, 2002). With dramatic land use change including conversion of complex natural ecosystems into simplified managed ecosystems and intensification of resource use (including application of agrochemicals at a generally higher input than output and reduced fallow periods that were typical for traditional agroecosystems).

Not only has biodiversity of pristine habitats and traditional, low-intensity agroecosystems been greatly reduced, but also that of intensively used agroecosystems during this period with increased species loss resulting from agricultural intensification happening at two spatial scales, landscape and local intensified farming practices.

It is presumed that by appropriate management of above and belowground biodiversity, coupled with optimal biodiversity conservation, benefits could be derived in mosaics of land-use with differing intensities of management. There is limited knowledge on the amount of below ground biological diversity and roles the functional groups perform, though it was known that soil and above ground biodiversity were interdependent. Findings obtained can be taken up to demonstrate methods for conservation and sustainable management of soil biological diversity within the study areas and beyond.

While the per capita food production has declined over the last 20 years in sub-Saharan Africa (Ehui and Spencer, 1990, 1992, Woomer and Swift, 1994), increase in human population has led to a corresponding increase in food demand and short fallow periods (Lavelle, *et al.*, 1998), and increase in proportion of cultivated land with the view of bridging the gap in food production. This has led to encroaching and destroying natural habitats for plant and animal species, causing a decline in natural resource bases (Ehui and Hertel, 1989; Ehui *et al.*, 1990 Wolters *et al.*, 2000), oblivious of impact on BGBD and its intricate relation with above ground productivity.

This in turn has resulted in soil degradation and decline in crop yields (Malton and Spencer, 1984, Tian *et al.*, 1997). The situation is further confounded by soil related constraints of inherent low soil fertility and small holder farmers with limited resources to access inorganic inputs and pesticides to sustain food production.

Farmers in the tropics are challenged by the need of intensifying their production to meet food demands while sustaining or improving soil fertility and productivity, when the only available resources available locally to achieve this are waste products of plant and animal production. For this reason understanding of diversity and role of soil macrofauna communities in regulating structure and function of soil is paramount in efficient use and management of these resources by farmers. Furthermore, development of agricultural practices that promote beneficial attributes of soil macrofauna biota is essential to sustaining productivity and environmental integrity of tropical agriculture (Beare *et al.,* 1997).

Organic farming systems while having a lower nutrient and pesticide input into soil, have an improved biological activity, with natural and anthropogenic factors acting at various scales affecting soil biodiversity in various ways. Local land management practices (planned agro diversity), thus shape and influence landscape heterogeneity and in the process impact on species occurrence, density, composition and richness of macrofauna in such land use mosaics. However, some of these management practices have caused serious ecological problems including water contamination, habitat degradation and biodiversity loss (Krebs *et al.*, 1999; Matson *et al.*, 1997; Tilman, *et al.*, 2002), also affecting ecological biological control (Didham *et al.*, 1996; Kruess and Tscharntke, 1994, 2000; Matthies, *et al.*, 1995).

Mulch systems can contribute significant quantities of nutrients (Kang *et al.*, 1990; Mulongoy, 1986; Tian *et al.*, 1993b). To avail nutrients, plant residues have to decompose. This is achieved by commutation, catabolism and leaching of water soluble materials from organic matter (Swift *et al.*, 1979). Inherently crop nutrition relies on biological processes mediated by soil macrofauna including earthworms and termites.

Earthworms stimulate microbial action by increasing surface area for microbial colonization and enzymatic action, commuting organic residues into smaller particles (Anderson and Ineson, 1983), while fungi and bacteria are responsible for major chemical transformations during plant decomposition and nutrient release.

Since agricultural land use affects large parts of the world's land surface area, its influence on soil biodiversity is critical for successful conservation and sustainable utilization of below ground biological diversity in the future. Hence need exists to understand why agricultural land use has to a great extent resulted in more negative rather than positive effects on soil biodiversity and concomitant loss of ecosystem goods and services that soil biodiversity provides.

Agricultural land use and biodiversity conservation have traditionally been viewed as incompatible, with ecologists and conservationists focusing on pristine or little interfered habitats to save remnants of wild nature and only recently acknowledging that such conservation focus on presumed pristine habitats is of limited value (Bengtsson *et al.*, 2003; Collins and Qualset, 1999; Schroth *et al.*, 2004).

Currently ecological conservators appreciate and acknowledge importance of population exchange between areas of different disturbance regimes, among variable habitats for sustainable utilization of soil and its associated biodiversity for agricultural production.

Land use dynamics are intricately linked to climate change globally (Bruijnzeel and Critchley 1994). For example land use influences capacity of soils to consume and produce atmospheric gases of Carbon, Nitrogen and Methane, whose changes influence atmospheric quality.

1.3 Objectives

2. To determine, characterize and compare geomorphologic, physical, vegetative and land use types and intensification patterns In Embu and Taita Agro landscapes.
3. To determine macrofauna occurrence, abundance and diversity along a land use intensification gradient and impact of soil physicochemical on soil macrofauna.
4. To determine effects of soil fertility amendments on earthworm densities and biomass.

1.4 Hypothesis

1. Macrofauna occurrence, density, distribution in land use mosaics and biogeochemical services they provide are influenced by soil physicochemical characteristics.
2. Macrofauna occurrence, abundance and diversity are lower in managed agricultural lands than in undisturbed ecosystems and fallows.
3. Soil management practices such as use of soil amendments to improve crop production negatively impact on earthworm population densities and biomass.

CHAPTER TWO

LITERATURE REVIEW

2.0 Importance of soil fauna

Globally, Below Ground Biological (BGBD) in agroecosystems can be grouped into three categories: 1) Productive biodiversity made up of crops and livestock that produce food, fibre and related by products is mainly above ground, 2) destructive biodiversity (pests and diseases) that causes lose of crops and 3) resource biodiversity that contributes directly or indirectly to agricultural productivity (Swift and Anderson, 1993).

It the third category that (BGBD) belongs to. Soil resource biodiversity community is extremely diverse and includes bacteria, fungi, protozoa and macrofauna. (BGBD) is a relatively new concept, which along with its methods of study requires substantial attention (Van Noordwijk and Swift 1999). Diversity of the microbial component might be greater than that of invertebrates and is being unravelled by phylogenetic and ecological studies using molecular methods (Torsvik *et al.*, 1996). Over 1000 species of micro invertebrates were identified in 1m^2 of soil in temperate forests in Germany (Schaefer and Schauermann, 1990; Torsvik *et al.*, 1994).

Conventional agriculture causes a great lose of Soil Organic Matter (SOM) from cultivated land worldwide that negatively impacts soil structure and fertility, resulting in global warming through increase in atmospheric concentration of carbon dioxide (Pulleman *et al.*, 2004). Soils are the major global storage reservoir for carbon in the form of organic matter with estimates of about 1500 X 10x15g C stored in soils.

Living microbes, fungi and macro invertebrates that comprise the soil food web are responsible for changing plant residue and atmospheric carbon and nitrogen through several steps to forms available for plant growth, while at the same time contributing to the rate of production and consumption of carbon dioxide (CO_2), methane, and nitrogen. Under given climatic conditions and soil type, factors controlling SOM concentrations are determined largely by land use management. SOM in agricultural soils can be increased through adoption of management systems that increase amount of organic inputs and slow down SOM turn over (Pulleman *et al.*, 2004).

Earthworms influence soil profile development and humification through casting, enhancing organic matter decomposition and incorporation into the soil (Lavelle *et al.*, 1988, 1989; Reddy *et al.*, 1997; Scheu, 1993; Springett, 1983; Swift, 1987) and restore soil properties (Blanchart *et al.*, 1992; Edwards & Lofty, 1977; Lee, 1985; Satchell, 1983;), increasing soil macro porosity that influences soil water infiltration properties and retention capacity (Blanchart *et al.*, 1999; Brussaard *et al.*, 1993; Casenave and Valentine, 1988; Douglas *et al.*, 1980; Ehlers, 1975; Lal, 1987; Lavelle, 1988; Marinissen and Dexter, 1990;) and enhance nutrient uptake by plants (Kladivko and Timmenga, 1990; Kladivko *et al.*, 21986; Logsdon and Linden, 1992; Wang *et al.*, 1986).

The combined effect of earthworms and organic animal manure has been shown to be a good source of nutrients to the soil (Mäder *et al.*, 2002; Maria *et al.*, 2011). It has been shown that addition of organic fertilizer (animal manure) has a positive effect on earthworm biomass, C and N mineralization and nutrient (Mg, K and assimilable (P) availability, unlike inclusion of nitrogen fixing legumes that do not confer similar positive effects on the soils, due to poor nodulation and limitation of assimilable (P. It was noted that up to 85% of the leached N consisted of organic nitrogen (N) a significant pool that could have both economic and environmental implications.

It is evident that, tillage, quality of manure and other organic residues returned to the soil affect activity of soil organisms, soil structural characteristics, the chemical and physical stabilization of SOM (Hendrix *et al.*, 1986) Organic matter and mineral particles bind together to form aggregates of different sizes and stability depending on SOM content and binding agents, whose model of aggregate hierarchy is as follows, micro aggregates which are less than <250 micrometers and organic residues are bound into stable macro aggregates greater than >250 micrometers, by roots and fungal hyphae (Tisdal and Oades, 1982).

New micro aggregates are formed preferentially within the stable macro aggregates, by mucilage produced during decomposition of organic fragments inside macro aggregates which interact with clay encrusting organic fragments to an extent that degradation of the organic material is retarded (Oades, 1984).

While overtime, as binding agents of macro aggregates degrade, resulting in loss of macro aggregate stability they release stable micro aggregates, that are building blocks for the next cycle of macro aggregate formation (Six *et al.*, 2000). Micro aggregates exhibit greater stability than macro aggregates and better protect SOM against microbial decay and slow down the rate of degradation of occluded SOM (Elliot, 1986; Six, *et al.*, 1998; Skjemstad *et al.*, 1990; Tisdal & Oades, 1982;).

Formation of micro aggregates within macro aggregates is negatively related to the rate of macro aggregate turnover that is strongly affected by management factors of tillage and residue management. Therefore, the degree of stable micro aggregation rather than stable macro aggregation might play an important and direct role in the relation between SOM sequestration and management of agricultural soils.

It has been shown that cultivation leads to a decline in water stable macro aggregates resulting in loss of SOM that binds the micro aggregates into macro aggregates (Tisdal and Oades, 1982; Elliot, 1986). Hence maintaining natural grasslands and no tillage systems lead to stable macro aggregates, of greater size and mean residence of times of mineralizable SOM pools (Gupta & Germida, 1988; Six *et al*., 1998).

It is important to note that enhancement of BGBD in soils may be accomplished by direct manipulation, of inoculation with desirable indigenous organisms such as nitrogen fixing bacteria, or agents such as the fungi trichoderma for biological control of plant diseases and indirectly through manipulation of cropping systems (e.g. by choice of plants, the cropping pattern in time and space, or management of organic and inorganic amendments added to or removed from soils.

Agricultural practices which provide good soil protection and maintain high levels of soil organic matter favour higher soil biota biodiversity, these include agroforestry systems, intercropping, rotational farming, conservation tillage, green cover cropping and integrated arable and livestock systems. Therefore actions that directly target conservation of both above and below-ground components of biological diversity will have environmental benefits at ecosystem, landscape and global scales. However, It remains a matter to be critically evaluated whether maintenance of higher diversity entails trade-offs between agricultural production and other ecosystem services (Swift, 1997).

Soil is one of the most diverse habitats on earth and contains a corresponding diverse assemblage of living organisms (Giller *et al.*, 1997). Hence, while biological diversity of organisms below ground is probably higher in most cases than that above-ground, it has generally been ignored in surveys of ecosystem biodiversity. Nowhere in nature are species so densely packed as in soil communities (Hågvar, 1998).

Since the industrial revolution, importance of soil biota in soil structure, fertility and resilience has been masked by technological developments of tiling, use of inorganic soil amendments and pesticides. Hence belowground biodiversity (macrofauna diversity included) has received little attention that has resulted in an acute lack or non existence of baseline data on most soil macrofauna taxa, their systematic positions, geographic occurrence and distribution, abundance and critical ecological roles soil fauna play in maintaining soil structure, soil fertility and in mediating important ecosystem processes such as decomposition and nutrient cycling.

Despite having high functional significance, studies on BGBD have been limited, mainly due to its inconspicuousness, poor understanding and misconception that the soil is a 'lifeless' substrate. Yet soil constitutes a complex maze of macro and microhabitats, containing some of the most diverse assemblages of organisms whose crucial functions contribute to maintain life on earth (Giller *et al.,* 1997; CBD, 2001; Lavelle, 1996).

2.1 Classification of soil fauna

Soil biota can be grouped into functional groups as follows:

1. Ecosystem Engineers are macrofauna e.g. earthworms termites and ants. Macrofauna have a major physical impact on soil and its pedogenesis through building of aggregate structures, formation of pores as well as influencing transport within the soil including nutrient cycling.

2. Decomposer micro-organisms e.g. cellulose degrading fungi or bacteria that possess polymer degrading enzymes are responsible for most of the energy flow within the decomposer food web.

3. Micro regulators e.g. nematodes which regulate nutrient cycles through grazing and other interactions with other decomposer microorganisms.

4. Micro-symbionts e.g. mycorrhizal fungi and rhizobia are associated with plant roots enhancing nutrient uptake.

5. Soil-borne pests and diseases e.g. fungal pathogens, invertebrate pests, biological control species are predators, parasitoids and hyper parasites of pests and diseases.

6. Bacterial transformers e.g. nitrifying bacteria that perform transformations of nutrient elements such as Nitrogen (N), carbon methanotrophy, Sulphate (S) or Phosphorous (P).

7. Soil biodiversity also includes plant roots in the soil that interact with other species above and below ground. (Giller *et al.,* 1997)

It is therefore evident that soil organisms provide a wide range of essential goods and services for sustainable function of soil ecosystems such as modifying soil physical structure and water regimes of percolation and retention (Beare *et al.*, 1995; Berry and Karlen, 1993; Hendrix *et al.*, 1992; Lavelle, 1994). Influence microbial composition and activity hence dynamics of soil organic matter decomposition (Beare *et al.*, 1992; Broder and Wagner, 1988;) and soil carbon sequestration (Holland and Coleman, 1987), greenhouse gas emissions (Beare *et al.*, 1993; Bowen and Harper, 1988; Doran, 1980).

Regulate nutrient cycles by enhancing amount and efficiency of nutrient acquisition by plants through mycorrhizal fungi and nitrogen fixing bacteria associations (Beare, *et al.*, 1992), and influencing plant health through interaction of pathogens and pests with their natural predators and parasites (Hendrix *et al.*, 1986 Sumner *et al.*, 1981,).

These goods and services are essential not only to functioning of natural ecosystems but constitute an important resource for sustainable management of agricultural ecosystems. The diversity of the microbial component may be greater than that of the invertebrates, with an estimate of 10,000 to 50,000 species per gram of soil (Hawksworth, 1991).

However, taxonomy of soil groups is wanting due to lack of taxonomic expertise, consequently complicating matters, because extremely few of these soil dwelling species have been described. Researchers have therefore resorted to group similar organisms within 'operational taxonomic units' (OTU's), or functional groups, since they cannot place them in precise species groups.

In the tropical regions, it is supposed that the highest levels of diversity may be found, available data is even more limited. Nonetheless rapid assessment methods have been proposed tried and tested, resulting in considerable progress towards development of soil biodiversity indicators. The most useful approach in this respect are studies based on a selective focus on key "functional" Groups namely the Micro, Meso and Macrofauna (Giller *et al.,* 1997).

2.1.1 *Soil macrofauna*

Soil macrofauna contribute greatly to biodiversity in agroecosystems and are important as effective components of natural soil ecosystems. Terrestrial ecosystems are divided into belowground and aboveground subsystems. These subsystems are intricately dependent upon one another since above the ground primary producers (plants) are the main source of organic carbon for sustenance of the belowground system, while below ground organisms are in charge of recycling organic matter and mineralization of nutrients therein resulting from above ground primary production (Scheu and Setälä, 2002, Wardle, 2002).

The decomposers are responsible for breakdown of organic matter, release, and cycling of nutrients (Haimi and Einbork 1992; Wardle, 2002). Hence activity of decomposers results in increased plant growth and plant nitrogen content (Bonkowski *et al.,* 2000, 2001; Scheu and Parkinson 1994, Wardle, 2002).

Soil macrofauna communities in landscapes are rapidly changing due to land use conversions and agricultural intensification, hence they (soil macrofauna communities) are highly transient systems, where interactions between species or trophic levels are being seriously disturbed or lost.

Influence of farming practices in modifying effects of soil organisms on aboveground systems is poorly understood, despite the fact that while these anthropogenic disturbances influence soil macrofauna communities at a local scale, they are a result of large-scale processes, such as increase in human population, change in land size by fragmentation or consolidation of original landscapes and use such as crop types.

Hence a change in distribution patterns of soil organisms (Brussaard *et al.*, 1997; Schröter *et al.*, 2004). These anthropogenic activities impact on spatial and temporal aspects of trophic interactions of soil biotic groups, such that if land changes and use intensification are severe enough to influence plant communities, it is likely that they trickle down to soil food webs and change linkages between above and below-ground communities (Wardle *et al.*, 2004).

Through feeding, locomotion, nesting and other functional activities soil macrofauna generate and maintain soil physical, chemical and biological characteristics within the ecosystems (Berry, 1994; Brussaard, 1994; Roy-Noel, 1979), hence activities in the soil affects its fertility.

Earthworms are known to directly or indirectly modify soil properties through feeding, burrowing and casting activities (Berry, 1994). However their populations are checked by soil parameters and land use practices, as well as climatic conditions that influence their food source (Hauser, 1993; Lavelle *et al.*, 1998). Such that when an ecosystem is altered through anthropogenic activities, there results a change in macrofauna occurrences, densities and diversities that in turn affect ecosystem functioning (Waid, 1999).

Basically all soil biological processes of decomposition, soil structure modification and bioaccumulation are intimately linked with maintenance of soil structure and fertility, and are potentially more sensitive to environmental changes than indicators based on physical and chemical characteristics of soil such as soil texture, bulk density, infiltration rate, moisture content, water holding capacity and retention, soil temperature, carbon, pH, mineral nitrogen, phosphorus and potassium respectively.

In this regard, soil macrofauna are an integral component of decomposing organic matter and nutrient cycling, as studies have shown that soil macrofauna improve agricultural productivity through their activities on soil (Beare *et al.,* 1997; Black and Okwakol, 1997; Brussaard *et al.,* 1993; Lavelle *et al.,* 1992; Lee and Foster, 1991; Tinzara and Tukahirwa, 1995; TSBF, 1994; Vikram, 1994; Wood, 1996).

Earthworms are macrofauna of great importance, belonging to Phylum Annelida class, Clitella and sub class Oligochaeta. They are species of segmented worms either aquatic or terrestrial, distributed worldwide. Their distribution, density and diversity are determined and influenced by soil type, organic matter availability and level of anthropogenic manipulations (Barley, 1961; Boag *et al.*, Edwards and Bohlen, 1996; Edward and Lofty, 1979; Evans and Guild, 1947; Didden, 2001; Fragoso and Lavelle, 1992; 1997; Hairiah, *et al.,* 2001; Lee, 1985; 1997; Norgrove *et al.,* 1988; Swift and Van Noordwijk 2001; Tischler, 1955).

Earthworms are sensitive to soil physicochemical changes (Blanchart, 1992; Blanchart *et al.*, 1999; Brussaard *et al.*, 1993; Doube and Schmidt, 1997; Hauser, 1994). Therefore they are potential candidates of soil quality indication (Oades and Walters, 1994). However few studies (Daugbjerg *et al.*, 1988; Hendrix, 1995; Koehler, 1992; Stork and Eggleton, 1992) have been undertaken to evaluate soil quality utilizing earthworms as indicators and impact of anthropogenic activity on earthworms. Earthworms are sensitive to anthropogenic disturbance thus natural and anthropogenic factors acting at various scales affect earthworm diversity. Land use change and agricultural intensification cause major changes in above ground vegetation soil structure, function and or loss of related soil biodiversity (Fragoso *et al.*, 1997; Giller *et al.*, 1997).

Earthworms play an important role in incorporation of organic matter into the soil matrix; they produce a wide range of organo-mineral structures such as casts in their feeding activities by formation of stable soil macro aggregates that are enriched in soil organic matter (SOM) compared to undigested soil. These biogenic structures (earthworm casts) resulting from soil and organic matter mixtures are impregnated with microflora mixed on intestinal transit and constitute micro sites where a number of particular physico-chemical changes occur (Mora *et al.*, 2003, 2005).

Ingestion and digestion of soil and litter by earthworms induces formation of micro aggregates. These micro aggregates are formed when organic particles are fragmented and pre-existing aggregates are dispersed in the earthworm gut. In the earthworm gut discrete clay particles are brought into intimate association with mucilage coated with decomposing organic fragments and rearranged into new micro aggregates are execrated as casts (Barois *et al.*, 1993; Shipitalo and Protz, 1989).

These earthworm organo-mineral structures affect fundamental processes of organic matter cycling (Brown *et al.*, 2000). Mixing in the earthworm gut activates microflora that accelerate organic matter decomposition (Barios and Lavelle, 1986; Scheu, 1987) and changes in structural properties of soil (Blanchart *et al.*, 1989, 1992). Ultimately, these organo-mineral structures disintegrate and integrate into the soil where they influence the physico-chemical and biological characteristics of soil.

2.2 Earthworm studies in Kenya

Studies on earthworms within the tropics have been fragmentary and incidental to other research, albeit being important belowground macrofauna influencing soil properties, quality and function (Ayuke, 2010; Ayuke *et al.*, 2009; Blanchart *et al.*, 1992; 1999; Brussaard *et al.*, 1993; Hauser, 1994; Karanja *et al.*, 2009). Most studies on earthworms within the tropics have been in the savannas hence limited information on their importance within the humid tropics (Henrot and Brussaard, 1997). This is confounded by few scientists with expertise in earthworm taxonomy or ecology available globally (Freckman *et al.*, 1997).

Since earthworms are important for soil development including its structure, recycling organic matter, release and of distribution nutrients and form a vital component within many food webs, earthworms are worthy of investigation for these and other reasons. While the impact of earthworms have been documented for over a century (Darwin, 1881), studies on earthworms are at infancy in Africa, with little known and understood about this group locally. Earthworm taxonomy is even more wanting, yet it is the most basic and inclusive study of living organisms since the biology and ecology of organisms are unique to their taxonomic entity and identification problems severely hamper understanding bionomics of any given species.

Earthworm studies in Kenya have all along been carried out casually in general biology and zoology lessons as part of invertebrate studies. The only notable extensive, dedicated and focused study on earthworms was done by (Oxtoby, 1975). Who developed a dissection guide describing the anatomy for the genus *Polytoreutus* but did not provide a species name, as the species was overdue for revision. The species was later identified as *Polytoreutus huebneri* (Michaelsen, 1913; Sims, 1982).

2.2.1 *Ecology of soil macrofauna*

Ecology is the scientific study of relations between living organisms in respect to each other and their natural environment. It is a sub discipline of biology that studies life and its environment (Allee *et al.*, 1949, Sahney *et al.*, 2010). Among other factors, ecological studies seek to explain life processes and adaptations, distribution and abundance of organisms in the context of their occurrence and interaction with their environment. Areas of specific interest to ecologists include occurrence, composition, distribution, density, biomass and changing states of organisms within and among ecosystems.

Ecosystems are biophysical feedback systems between (living) biotic and (nonliving) abiotic components that regulate and sustain the systems, they are also hierarchical systems organized into series interacting and semi-independent parts that aggregate into higher order of integrated wholes forming communities or functional systems with shifting equilibriums resulting from interaction between the components (Odum and Barret 2005). The soil ecosystem provides ecosystem goods and services that sustain productivity upon which humanity thrives, and sustains every life supporting function on earth including climate regulation, water filtration, soil formation and erosion, food and associated organic matter production (Begon *et al.*, 2005; de Grot, *et al,*. 2002; UN. 2005).

Ecosystems on the other hand are sustained by biodiversity, which is the full scale of life and its processes that integrate into complex interactions within and between them. Biodiversity is the variety of life and its processes, including the array of living organisms, the genetic differences among them, the communities and ecosystems in which they occur along with ecological and evolutionary processes that keep them functioning. Biodiversity includes species, ecosystem and genetic diversities, with complex processes operating within and between them at different levels (Purvis and Hector 2000; Scholes *et al.*, 2008; Wilson 2000), and plays an important role in ecological health (Tierney *et al.*, 2009).

Preventing species extinction or prioritizing species conservation is one way to preserve biodiversity as populations, their genetic diversity and ecological processes are threatened at both local and global scales and disappearing rapidly. Therefore within dissimilar settings, conservation priorities and management techniques require different approaches and considerations to address the ecological scope of biodiversity. An understanding of biodiversity has practical application for ecosystem-based conservation planners as it assists in making ecologically responsible recommendations and sound decisions in management of nature, as certain populations or species may be sensitive indicators of ecosystem services that sustain and contribute to natural capital (Svenning and Condi, 2008).

2.3 Ecological soil engineers

Soil engineering organisms' affect the soil and litter environment directly by commutating litter as well as burrowing and indirectly by accumulation of their biogenic structures (casts, pellets and galleries). Some species of earthworms being premier among, them are more highly regarded as they are endowed with ecosystem engineering capabilities.

Ecological engineers produce physical structures through their activities and directly influence the environment around themselves through which they can modify availability or accessibility of resources for other organisms (Jones *et al.*, 1994). Earthworms are among a group of macrofauna including termites and ants recognised as soil engineers (Lavelle *et al.*, 1994; 1997). Earthworms are able to pass vast quantities of soil through their guts creating an improved soil structure and incorporating mineral and organic elements essential for plant growth (Edwards and Bohlen, 1996). In addition, earthworms aerate soils and increase water infiltration rates, hence reducing soil erosion by burrow creation (Shipitalo *et al.*, 2004).

Few earthworm species (e.g., *Lumbricus terrestris*) show their presence by surface casting and middens (structures consisting of organic e.g., leaf and inorganic e.g., pebble material gathered together by earthworms and often cemented together with casts) which are normally engineered above the opening of the burrows used by earthworms. Though most earthworms require some digging to locate them, due to their subterranean existence, digging often detects only near surface (epigeic) earthworms and horizontal burrowing (endogeic) species, adults of deeper burrowing (anecic) species are missed unless excavation is to a depth of several metres.

Earthworms are therefore broadly classified into three ecological groups in relation to where they occur in the soil, these being Epigeic, Anecic, and Endogeic (Bouché, 1977; Lee, 1985). Anecic & epigeic earthworms are rapid moving and able to escape faster, than endogeic earthworms.

2.3.1 Epigeic earthworms

Epigeic earthworms dwell within moist decomposing litter at the soil surface/leaf litter interface. They feed on surface leaf litter where they may make shallow temporary burrows that they escape into from heat and disturbances. Their influence is felt in upper few centimeters just below the soil surface as they transform litter by commutation, modifying it physically and chemically.

They reduce the litter Carbon/Nitrogen ratio through respiration and assimilation, making it favorable for microbial activity and further decomposition by micro and mesofauna. Casts excreted by epigeic worms are rich in organic matter and nutrients, the nitrogen (N) tied up in the ingested food is released due to more efficient (C) than (N) utilization by this group of earthworms enhancing nutrient availability to plants (Norgrove and Hauser, 2000).

Few studies have been carried out on the role of epigeic earthworms on soil fertility and plant production in the tropics, as their populations (native species in natural forest ecosystems) disappear with clearing of forests surface litter. The fact being epigeics do not thrive in disturbed environments unless there is a significant litter component such as in plantations or permanent mulch systems, they are therefore not significant in agro ecosystems at a local or regional scale.

2.3.2 Anecic earthworms

Anecic earthworms, (Lavelle, 1994) exert a substantial impact on soils. Anecics worms reside in deep permanent vertical burrows that extend up to two meters in depth within some soils. The burrows are often lined with organic matter mixed with protein rich mucus and open on the surface where earthworms make casts. This group of earthworms is not easily sampled by the monolith method utilized in this study.

Burrows of Anecic earthworms act as bypasses for water flow into the soil and are also preferential paths for roots within the deep soil (Lee, 1985). Anecic worms feed mainly on litter collected at the soil surface that they drag into their burrows facilitating nutrient mineralization and humification of soil resulting from litter comminuting within the confines of the burrows. While anecic earthworm burrows in temperate regions have been extensively studied, little has been done for tropical burrows. Further the role of anecics in soil fertility and productivity has not been subject to study in the tropics.

Probably as in temperate regions, tropical anecic earthworms can significantly reduce surface litter and increase its decomposition and mineralization. Anecic worm burrows attract many other organisms as they form suitable environments for micro arthropods and are foci of intense microbial activity (Brown, 1995).

2.3.3 Endogeic earthworms

Endogeic worms are found within the upper 20cm of soil and are important soil engineers. They burrow extensively mainly horizontally, with some vertical furrows within the rhizosphere forming galleries and tunnels within the upper 20 cm of the soil. Endogeics are primarily geophagous (soil feeding) and their role in soil fertility within the tropics is much more studied.

They influence soil processes significantly by ingesting up to 30 times their body weight, of fine organo-mineral particles egesting them as casts (consolidated waste matter composed of undigested organic matter soil and mineral particles), that they deposit either on the surface or within the burrows in the soil (Barley, 1961; Daugbjerg *et al.,* 1988; Edwards, 1989; Kladivko and Timmenga, 1990; Lal, 1991; Lavelle, 1988; Lee and Foster, 1991; Linden *et al.,* 1994; Logsdon and Linden, 1992; Sarr *et al.,* 2001).

Endogeic earthworms have established mutual association with soil microflora within their gut enabling them obtain nutrients from low quality foods, through adding mucus and water to ingested soil. The ingested microflora are stimulated to increase in activity making possible digestion of organic substrates in the foregut that is then absorbed in the hind gut (Barios and Lavelle, 1986; Lavelle, 1998; Lavelle and Gilot, 1994).

2.4 Importance of below ground biological diversity

While soil biodiversity is critical, it is a neglected component of global biological diversity both in natural landscapes and agricultural ecosystems, below ground organisms drive an array of biological processes that contribute significant goods and essential services to ecosystems that include improvement of soil structure and water regimes, by maintaining good soil physical structure, they help regulate percolation, retention and flow of water and nutrients (Kang *et al.*, 1991).

Earthworm activity has a significant effect on functional processes in the soil. Biogenic structures (casts, sheeting's, nests, burrows and galleries) built by these organisms modify conditions for smaller and less mobile soil organism's (collembola, nematodes, protozoa, fungi and bacteria) and hence influence their abundance and diversity (Brown, 1995; Decanës *et al.,* 1999; Jones *et al.*, 1997).

In tropical regions farmers decisions on agro ecosystems have for long retained similarity with natural ecosystems whose diversity of components and interactions distinguish them from simple agroecosystems in temperate regions. Incidental BGBD conservation within agricultural systems through planned agro-biodiversity retains bio-ecological components and functioning similar to pristine natural forests, that might buffer farmers against short term risk and have the long term benefit of enhancing functional diversity, to carry out biological functions that increase resilience of agroecosystems. These farmer decisions such as type of crop, intercropping and crop rotations is planned diversity and are a deliberate choice on agrobiodiversity management impacting on associated below ground diversity (Swift and Ingram, 1996; Vandermeer *et al.*, 1998; van Noordwijk and Swift, 1999).

Ideally stability of soils in tropical humid forests rely on their species diversity and relatively closed nutrient cycles such that there is a dynamic equilibrium between natural inputs and outputs within the system (Fresco and Krooneberg, 1992; Leiros *et al.*, 1999). However, this equilibrium has been distorted with land use conversions resulting from huge demand for food production to meet the ever growing human populations, to an extent that restorative fallows (De rouw, 1994; Groombridge, 1992; Seubert *et al.*, 1977), that may help re-establish this equilibrium are no longer an option.

Therefore, the biodiversity of soil under natural vegetation should be taken as a baseline for monitoring changes in sustainable soil productivity under varying land-use types and intensities once conversions have occurred. However, though presumed that tropics may contain the highest levels of diversity, data for tropical regions on BGBD is scant, further despite the fact that biological diversity of below-ground organisms is probably higher than that above-ground, it has generally been overlooked in surveys of ecosystem biodiversity because of its obscurity.

CHAPTER THREE

MATERIALS AND METHODS FOR STUDYING IMPACTS OF LAND USE CHANGE; INTENSIFICATION AND SOIL QUALITY ON SOIL MACROFAUNA IN EMBU AND TAITA BENCH MARK STUDY SITES.

3.0 Location of benchmark study areas

The study was carried out in two geographical localities in Kenya (Figure 1). Embu district, situated in eastern province of Kenya, Mount Kenya region bordering Irangi forest 37° 18' and 37° 28' E, and 0° 20' S. and 0° 28'S. The second site Taita Hills, Wundanyi area is situated in Taita Taveta district bordering Ngangao forest, and is located in lower southeastern Kenya. The Taita hills rise from a level of 600-900 m a.s.l., to a maximum elevation of 2228 m a.s.l. at Vuria peak, and cover an area of 1000 km^2 these hills form the northernmost part of the Eastern Arc Mountains and are isolated from other mountainous areas by the vast plains of Tsavo National Park.

3.1 Site selection, characterization and sampling criteria

The benchmark sites were selected as they constitute areas of landscape with considerable land use intensification gradients ranging from natural protected forests with least anthropogenic intensification, through plantation forests to highly intensified horticulture cropping systems. Being part of a broader global project covering seven countries in the tropics (see introduction) guidelines for window selection were adopted at a global meeting using methods provided by FAO-UNESCO (1997), for characterizing and classifying soils.

Selection of the two study sites of Embu and Taita was that they exhibited characteristics of Diverse Land use/Land Cover types representative of the Kenya, with at least five land use/cover types. Unique agro-ecological zones that dominantly favour agricultural land use, and are areas of high population density promoting diverse environmental aspects including land use, conflicts and land degradation that have an important bearing on biodiversity its distribution and survival.

Major Land Use/Land Cover Types covered in the study sites included: Tea, Coffee, Tea/Coffee interphase Coffee/Bananas interphase, Maize, Other Crops (Potatoes, Vegetables, Passion fruits). Forest Classes of plantations forests, Un-disturbed indigenous forest and degraded indigenous forest.

Areas utilized for study were determined from aerial and topographic maps followed by ground truthing, these were surveyed and windows established. To cover desired land use types, three windows were selected for Embu and two for Taita. In Embu, two windows were half a kilometre apart, with a sampling area of 4 km^2 each. However, because of varied nature of land cover types, window three was larger with an area of 4.5 km^2 split into two blocks to for account tea farms in one block with plantations and the natural forest, represented in the other.

3.1.1 *Window Selection*

Guidelines for window selection were adopted at the below ground biological diversity (BGBD) Indonesia-Bogor Global Meeting from (Anderson and Ingram, 1993; Moreira *et al.*, 2008; Swift and Bignell, 2001), setting the minimum site sampling plot of 6 km^2 for each benchmark site. Sampling windows were designated as E_1, E_2 and E_3 for the Embu benchmark study site and T_1 and T_2 for the Taita benchmark study site.

The benchmark study sites were selected to comprise areas of landscape with considerable land use diversity and intensification gradients ranging from natural protected forests with least anthropogenic intensification, through plantation forests to highly intensified horticultural cropping systems. The selection was done by adopting methods provided by FAO-UNESCO (1997), for characterizing and classifying land. Since not all land use types are represented in one area, sampling blocks covering land use types and containing desired attributes were delineated in the study areas; these were termed as "*windows*".

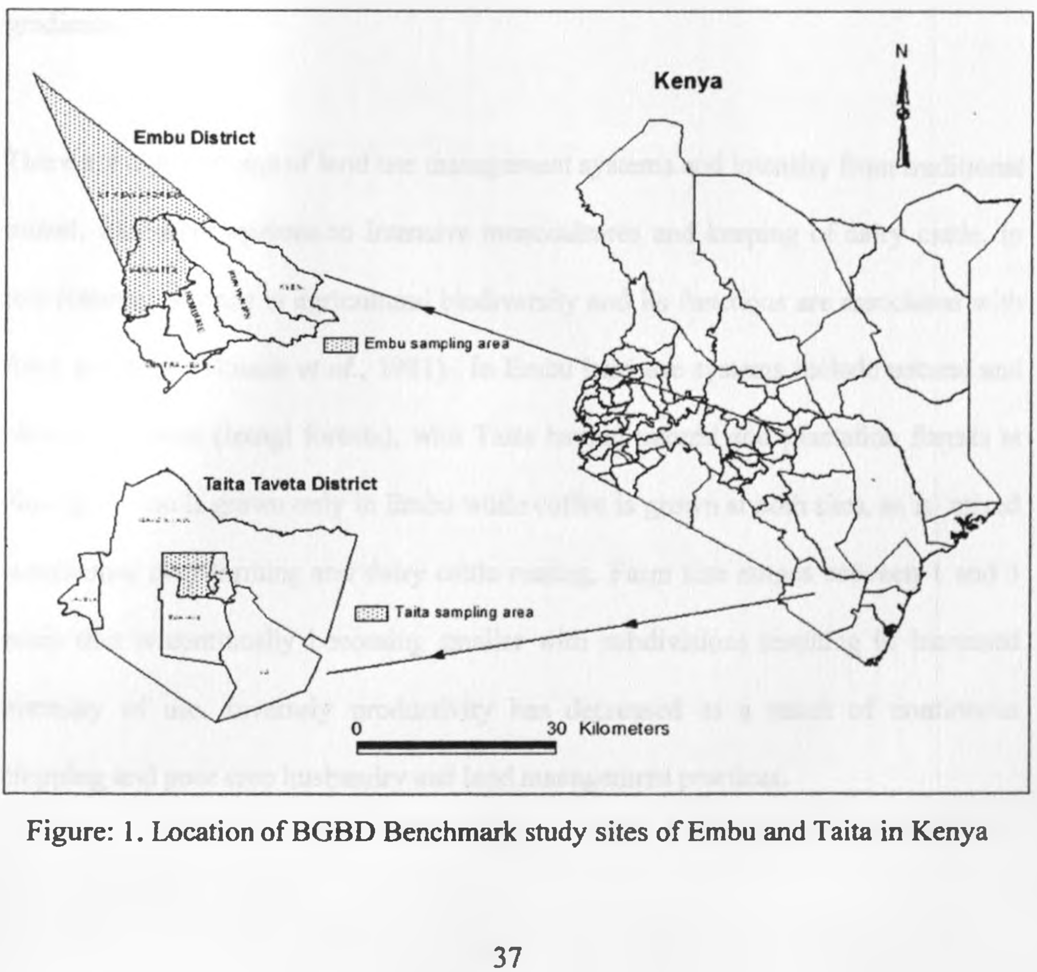


Figure: 1. Location of BGBD Benchmark study sites of Embu and Taita in Kenya

3.1.2 *Site description*

The Embu and Taita benchmark study sites are of high agricultural potential with residents being mainly smallholder subsistence farmers. Soil fertility within the humid forest zones is low due to the old age of the landscape that is geologically inactive with low pH (acidic) and leached soils.

However, the natural vegetation is lush hence the gross above ground and below ground eco-systems have a lot to offer in terms of nutrient stock reserves. The benchmark sites were selected because of their existing significant land use intensification gradients. The study sites exhibit a variation of fauna and flora with changes in altitude and concomitant changes in climatic characteristics, which influence overall biodiversity, ecosystem functions, land use patterns and intensity gradients.

There are a wide range of land use management systems and intensity from traditional mixed, low input systems to intensive monocultures and keeping of dairy cattle. In this respect, changes in agricultural biodiversity and its functions are associated with these gradients (Dounte *et al.*, 1981). In Embu land use systems include natural and plantation forest (Irangi forests), with Taita having natural and plantation forests at Ngangao, tea is grown only in Embu while coffee is grown at both sites, as is mixed subsistence crop farming and dairy cattle rearing. Farm size ranges between 1 and 3 acres that is continually becoming smaller with subdivisions resulting in increased intensity of use. Inversely productivity has decreased as a result of continuous cropping and poor crop husbandry and land management practices.

3.1.3 *Sampling points*

Sampling points were generated within the windows on a systematic grid (Fig. 2) utilizing geographical positioning systems (GPS). The grid system of plot allocation was used since it ensured the best coverage of most land use types reducing the chance of any stratum being under-sampled.

The sample points were established at fixed intervals within the sampling windows at a fixed distance apart, with the recommended distance between sample plots being 200 m to avoid auto-correlation (Groupe and Theriault, 1984). Data for sampling points collected was digitized and utilized for development of field sampling maps

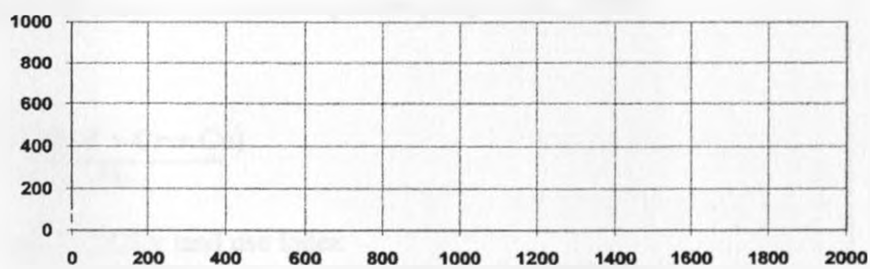


Figure: 2. Systematic sampling grid (200 x 200m)

3.1.4 *Sampling point attribute data*

Attribute data for each sampling point included: Plot owner, Major land cover type, Soil type, nearest reference point, coordinates of the point, elevation, inputs application and type, frequency of input application, cropping density and intensity, and cultivation intensity.

Of these data, input application and type; frequency of input application; cropping density and intensity of cultivation intensity were utilized for calculation of land use intensity indices. The maximum combined intensity of these attributes was assigned a value of 1 so that each of the four components contribute a value of 0.25 to the total score of 1 (Muya et al., 2009).

3.1.5 *Land Use Intensification (LUI) index*

The land use intensification (LUI) index of a given land use system is a summation of the indices of input application frequency of input application, cultivation intensity and cropping density and derived from the (LUI) (equation. 1)

Equation1. The Land Use Index equation (Muya *et al.*, 2009)

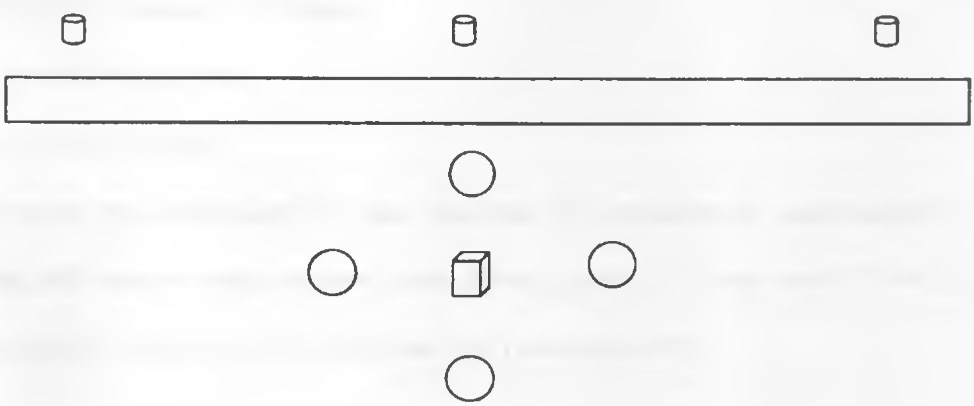
$$\mathbf{LUI} = \Sigma \left(\frac{Y + f + Cr + Cu}{Ni.} \right)$$

Where LUI = land use index
Y= Total of organic and inorganic inputs applied
Cr= number of crops per season
Cu= frequency of cultivation per year
Ni= number of input variables used

The LUI indices when plotted against each of the main land use systems portray the magnitude of difference in intensity between land use systems (Muya *et al.*, 2009).

3.2 Sampling

One hundred twenty (120) sampling points were set out, of 200 meters apart in the study sites with a representation of land use types of at each bench mark site. At each sampling point soil was augured to 12cm, for soil characterization of depth, colour, texture, consistence, surface sealing, crusting and compaction. Then classified according to soil map of the world, (FAO-UNESCO 1997). A kilo of composite soil sample was collected for laboratory analysis using standard procedures of the National Agricultural Research Laboratories (NARL) Kenya, as described by (Hinga *et al.*, 1980)



Key

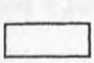
Symbol	Description
	Non baited pitfall trap (13 cm diam.) – 3 traps per sampling point
	Semi-quantitative transect of 2 x 20 m where 3 (5x2m) quadrats sampled
	Monolith (25 x 25 x 30 cm) – including litter - 1 per sampling point
	Soil sample 4 sub samples for chemical and physical analysis and soil classificati coring depths: 0-10; 10-20; 20-30 cm. Inside a 6 m radius circle

Figure: 3. Sketch of BGBD sampling protocol for soil and macrofauna

3.3 Soil physical characteristics sampling and determination

Bulk density soil core samples were taken in the upper 5cm of the soil surface for soil physical characterization of using a 5cm steel corer. This were driven vertically into the soil, carefully packed and moved to the NARL laboratories where they were oven dried for 24 hours to obtain the dry weight and determine bulk density. Soil porosity was determined from similar samples take for bulk density from equation **2** (Muya *et al.*, 2009).

Equation 2 *Soil porosity*

% porosity = $1\text{-}d_b/d_e \times 100$ where

d_b = dry bulk density and

d_e = soil particle density

Soil texture, was determined for clay, sand and silt granulometric percentages by sieving soil samples using different mesh sieves, graded as Coarse sand: (2.0-0.2), Fine sand (0.2-0.02), Silt (0.02-0.002) and clay (less than 0.002).

3.4 Analysis of soil chemical properties

Soil Chemical properties of Phosphorous (P), Potassium K, Sodium (Na) Calcium (Ca) and Magnesium (Mg) were determined using the Mehlich double acid method (Anderson and Ingram 1993), total organic carbon using the colorimetric method (Heanes, 1984; Nelson and Sommers, 1982), total nitrogen using micro Kjeldahl method, (Bremner and Tabatabai, 1972), pH was measured in a1:1 ((w/v) soil water suspension and micronutrients using the EDTA method (Okalebo *et al.*, 2002).

3.5 Sampling macrofauna

Sampling criteria for macrofauna at both benchmark study sites were based on protocol by (Anderson and Ingram, 1993; Moreira *et al.*, 2008; Swift and Bignell, 2001). Three different methods were employed for sampling macrofauna these being:

Monolith: This is a soil block excavated as per methods of (Anderson and Ingram, (1993), Moreira *et al.*, (2008).

Transect: A surface area of designated dimensions within which sampling is done.

Pitfall traps-Non-baited: These are cups placed in holes drilled into the soil where their mouths are flush with the ground level and contain glycol/water alcohol mixture to trap crawling organisms.

All three methods were utilized in general macrofauna sampling at selected GIS/GPS generated sampling points, all macrofauna encountered (arthropod and annelid) were collected. However for experimental plots, only the monolith method was utilized. Samples collected were taken to the Zoology department, Invertebrate section of the National Museums of Kenya (NMK), where sorting, preparation, identification counts and curation were done. All macrofauna specimens collected within the study period are held at the National Museums of Kenya Invertebrate section repository.

3.5.1 *Monolith sampling method*

For this method, a single soil monolith block of dimensions 25 x 25 x 30 cm was excavated as per methods of (Anderson and Ingram, (1993), Moreira *et al.*, (2008), Swift and Bignell, (2001) per sampling point of each land use systems under study. For ease of sorting out samples, the monoliths were sub divided into three 10 cm sections representing depths of 0-10cm, 10-20cm and 20-30cm that were individually hand sorted for invertebrate macro fauna greater than two millimeters (>2mm) picking out all macrofauna encountered during the visual search.

Sampling was stratified with, 60 monoliths excavated at the Embu benchmark study site cutting across different land use systems (natural forest-8, plantation forest-9, fallow-8, coffee-9, tea-10, napier-8, and maize-8 were excavated in the months of January/February 2005, and 42 monoliths at the Taita benchmark study site, similarly cutting across different land use systems (natural forest-6, plantation forest-3, fallow-12, coffee-5, Horticultural farms- 5, napier-4, maize-7) were excavated in April/May 2005.

3.5.2 *Transect sampling method*

At each sampling a transect of dimension 20 m long x 2 m wide was set out 8 meters from the monolith edge. Within each transect, three 1 x 1m^2 quadrats were sampled on a fixed time basis of 20 minutes per quadrat. Visual search was done at soil surface, beneath, litter, logs, branches and humic accumulations mainly for termites and using shovels dug up to 5 cm depth for shallow subterranean burrows where active nests were observed within the transect. All macrofauna encountered were collected.

3.5.3 *Pitfall trap sampling method*

Along the 20 m length edge of transect, three non baited pitfall traps were spaced, six meters apart by placing 500ml plastic cups of 13cm diameter buried with their mouths flush with the ground and filled with 50 ml of a 40% glycol/alcohol mixture. These were set up and any macrofauna trapped collected after 24 hours. Trapped invertebrate samples were collected and immediately preserved in vials containing 70% alcohol.

All earthworms collected were first narcotized and killed in 40% alcohol on being sampled and immediately fixed in 4% formalin for a minimum of 24 hours and then transferred to 70% alcohol pending sorting, counting, preparation and weighing.

3.6 Macrofauna sample specimen data

3.6.1 *Macrofauna identification*

Macrofauna identification was done first by isolating groups morphologically where there were obvious morphological differences separated the using identification Keys for taxonomic determination. As for earthworms adult specimens were selected and observed under a dissecting microscope for gross external anatomy and dissected for internal anatomy observations of taxonomic characters.

3.6.2 *Sample counts*

These were done after identification of taxonomic groups by counting all specimens of a given taxa collected and recording their total numbers per land use type.

3.6.3 *Earthworm biomass*

Earthworms collected first placed on whatman filter paper to soak off preservative, then on weighed on boats using a sartorius professional scientific digital balance with an accuracy of 0.0001 grams. Weights were for all worms collected in a given land use system.

3.7 Data capture and processing

Data were captured in excel spreadsheet and tabulated prior to an overall quantitative analysis and synthesis, and utilized for analysis of correlations. Macrofauna Sampling data included absolute numbers (abundance) and for earthworms' fresh weight, was also done to compute biomass. For sampling points their X and Y coordinates and altitude data were captured using a GPS and recorded. Additional attributes related to each sampling point was also collected and digitized accordingly in excel.

Earthworm abundance and biomass data for effect of soil amendments were log transformed (normalized by $\log_{10}(x+1)$ before being subjected to a one way ANOVA. Mean abundance per meter square (individuals' m^{-2}), were calculated from mean of total replicates of treatment, while conversion of biomass (gm^{-2}) was by multiplication of mean body mass of populations by density estimates for each treatment, weight and transformed by square root (Dangerfield, 1990).

3.7.1 *Statistical analysis*

Soil attributes and productivity indices were analyzed statistically using SPSS statistical software version 15.0. Land use types were characterized by their chemical properties whose means were compared utilizing ANOVA.

For macrofauna, matrices of total numerical density, and biomass data were tabulated and an overall quantitative synthesis of data done for abundance (individuals' m^{-2}), and computation of earthworm biomass (g $m^{-2)}$ for each agroecosystem, with tests of significance t-test at 95% confidence limits performed by post-hoc multiple comparison test.

Given the multiplicity of land use types, management, environmental factors and macrofauna data, multivariate analysis was carried using Biodiversity-R (Kindt and Coe, 2005). One important reason for studying and measuring diversity is to measure the *impact* of projects or interventions planned to achieve landscape domestication. To demonstrate such impacts, one needs to measure diversity before and after interventions hence use of Biodiversity R.

Level of significance among interactions was performed by Post Hoc Multiple comparisons test (Tukey's significant difference test) and t-tests at 95% confidence limits. To assess the strength and statistical significance of relationship between soil fauna density against soil chemical parameters, ordination constrained to environmental variables was performed.

3.7.2 *Rényi diversity profiles*

Diversity indices within this study were determined utilizing Biodiversity R programme to generate Rényi diversity profiles of species richness and evenness.

Equation 3 Rényi diversity profiles

$$H_\alpha = \frac{\ln\left(\sum_{i-1}^{s} pi^{\alpha}\right)}{1-x}$$

Whereby:

The Pi values are proportions of each species.

If the profile value for α =8 the proportions are raised to the power α (=8).

Assuming that at a sampling site the species proportion is $(1/3)^8$ = 0.000152 these proportions are summed up for all species (0.000152 +0.000152 + 0.000152) = 0.000457 then the natural log derived (1n (0.000457) = -7.6960) which is then divided by (1 - α = -7) which is (-7.690/-7)=1.0986

A profile is calculated by substituting value of α from 0 to infinity. In R the standard values of α range from 0.25, 0.5, 1, 2, 4, 8.... to infinity. R values can be calculated separately for each site or an entire dataset. Other values can be used to calculate these values since these values are related to Shannon and Berger-Parker indices.

3.7.3 *Redundancy analysis (RDA) ordination*

To asses relationship between macrofauna abundance and soil chemical properties redundancy analyses were carried out using Biodiversity R. This ordination technique depicts Euclidean distances of macrofauna within and between land use types on ordination graphs, with the ordination constrained by environmental parameters.

The Eigen values of the RDA indices are environmental (soil) parameters that explain the variance of macrofauna abundance within land use systems. RDA were fitted to constrained environmental variables and utilized to generate graphical presentations of macrofauna occurrences in relation to soil properties and depict factors that most influence macrofauna occurrence

3.7.4 *The Tukey's test*

The TUKEY's test is a single-step multiple comparison procedure and statistical test generally used in conjunction with an ANOVA find which means are significantly different from one another. It compares all possible pairs of means, and is based on a studentized distribution q (this distribution is similar to the distribution of t. The test compares the means of every treatment to the means of every other treatment; that is, it applies simultaneously to the set of all pair-wise comparisons,

$$\mu_i - \mu_j$$

and identifies where the difference between two means is greater than the standard error would be expected to allow. This comparative test is done to see if there were significant differences from the observable results obtained from analysis of variance.

The global project on Below Ground Biological Diversity BGBD was unique in that it delved in understanding soil dwelling organisms not in isolation, but undertook to study various soil functional groups concurrently rather than to study specific taxa separately. The localities of study (bench mark study sites) of Embu and Taita were selected for their perceived diversity of land use patterns that provided a land use intensification gradient, allowing investigation on effects of land use intensification on the soil functional groups. The overall thrust was to improve knowledge and understanding of below ground biodiversity and its importance to sustainable agricultural production.

Soil management practices are known to impact on soil quality which is core to soil productivity. Since soil degradation and decline in productivity are important constraints to food production and security in Africa (Bationo, 2008; Woomer and Swift, 1994). It is postulated that BGBD plays a vital role in maintaining soil quality, productivity and its resilience, and that land use intensification is the most possible reason for BGBD loss, that has resulted from a decline in soil quality and productivity.

A comprehensive knowledge of the soil habitat and how organisms living within it interact with it and how they impact on each other is therefore imperative in understanding soil organisms and their functions in the soil. It was therefore crucial to undertake study not only of the organisms but also the soil matrix that they reside in. The study was multi-disciplinary, so were the methods employed in studying the several of the soil biophysical and chemical aspects, soil organism's ecology and biology as well as socioeconomic characteristics of the study areas and findings interrelated.

CHAPTER FOUR

LAND USE AND BIOPHYSICAL CHARACTERISTICS OF EMBU AND TAITA BENCH MARK STUDY SITES.

4.0 Introduction

Examination of physicochemical characteristics of soil across land use intensification gradients and ecosystems provides an opportunity for correlating environmental variables of soil quality with soil macrofauna. Soil quality is the capacity of soil to function, within a given ecosystem boundary, support production of food and biological activity, and maintain the environment, by acting as filter and environmental buffer for air, water, nutrients and chemicals. (Doran and Parkin 1996).

Site characterization contributes to understanding use of soil organisms in conserving the environment, improving ecosystem health, and enhancing agricultural productivity. It provides a basis of answering questions if there are relationships between functional groups and soil structure attributes that determine soil quality and ecosystem functions, and whether higher biological implies greater ecosystem stability, resilience and resistance (Barrios *et al.*, 2005).

Management of soil macrofauna among other soil biota for sustainable ecosystem requires an understanding of the ecosystem structure including but not limited to: 1. composition of biological community (such as species, numbers, biomass, life history, and spatial distribution of populations) 2. The quantity distribution of abiotic materials such as nutrients and water, along with range and gradient of existing conditions of, altitude, slope, temperature and light.

It is important to understand ecosystem services of energy flow through ecosystems and biogeochemical cycling and biological or ecological regulation, of organisms by both environment and regulation of environment by organisms. The flow of materials along ecosystem gradients and their utilization can be optimized by understanding interactions between biological communities and biophysical variables that have been modified through cyclic intervention by man. These biophysical variables include physical and chemical properties, vegetation, slope, weather conditions, water table, and landscape position (Doumbia, 1999).

Objectives of site characterization were to: 1. Determine characteristics of benchmark sites of relief, geology, geomorphology and soils 2) Determine biophysical characteristics of soils in land use mosaics.

4.1 Materials and methods

Topographic maps aerial photographs GPS and GPS digitizers' datasheets were used. Desk top study of existing information on topographic and vegetation maps satellite imagery and aerial photos was done. This facilitated description of broad ecosystems of the study sites using standard profile description and classification, based on FAO-UNESCO guidelines (1997) and Kenya Soil Survey Staff (1987).

4.1.1 *Land use intensity indices*

Land use intensity (LUI) indices within in Embu and Taita were determined based on type and amounts of organic and inorganic inputs, frequency of inputs to improve productivity, cropping intensity (number of crops seasonally) and density and cultivation intensity (type and frequency of cultivation).

Components of land use intensity criteria and assigned values were adopted from Muya *et al.*, (2009). The highest combined level of a component input observed in any land use was given a value of 0.25 with other management aspects given a fraction of this proportionate to the highest value.

Soil health and quality attributes used to determine productivity index were soil organic matter content, pH, acidity, nitrogen, phosphorous and potassium. Understanding relationships between these attributes and crop yield is essential in developing productivity indices of different agro-ecosystems and recommendations for sustainable management of soils. Aune and Lal, (1997), give functional relationships between soil attributes and crop yields and develop critical limits for determining productivity index for a given soil under specified land use (Lal, 1988).

4.2 Results

4.2.1 *Eco-zones and land use systems in benchmark study sites*

Broad ecosystems described for the study sites are natural and planted forests at the steep mountain tops; Agroforestry on uplands; Annuals and perennials on uplands; and mixed cropping and horticulture on the bottomlands. Both study sites of Embu and Taita traverse areas of diverse land use ecosystems with varying levels of intensification which include natural undisturbed forest, disturbed regenerating "secondary" forests, planted forests, cultivated perennial (cash crops) and annual (food) cropping systems, grazing land, open shrub land and occasional fallow land, providing an opportunity for comparable BGBD studies along land use and intensification gradients.

Main ecosystems in the benchmark study sites are natural (mixed) and planted (pure stand) forests, fallow/grassland arable farmland with tea, coffee, maize/beans and horticulture, located on characteristic landscapes. These ecosystem variations and restrictions were useful in delineating BGBD sampling points.

Within the Taita study site, natural and plantation forests lie within mountain crests with poor herbaceous vegetation cover underneath, degradation is moderate in nature. Within the mid slopes there is inadequate vegetation cover with moss covered stone outcrops, the rate of degradation here is evidently very high, and the stony outcrops act as rain catchment from where the water seeps through the insufficient soil cover flowing downwards coming out as springs below.

Within higher level upland hills and foot slopes agroforestry is practiced and shrubs are left to contain the soil erosion, farmers in Taita do not invest significantly in establishment or maintenance of terraces due to the steep nature and low land productivity, and degradation is particularly high. In the lower level uplands are elaborate bench terraces, where annual arable crop agriculture is practiced, with coffee farms (perennial crop) are evidenced intercropped with maize and beans, soil degradation here is minimal.

Finally mixed crop agriculture is practiced within the bottom lands. Beside food crops of maize, beans, potatoes and cassava (annuals), extensive horticulture is carried out taking advantage of nutrient rich silt from uplands deposited here, and the all year round availability of water, hence a major income generating activity within the area.

Within Mount Kenya region lies the most extensive and compact natural forest block of the country. However, 31% of species are in danger of extinction (Newmark, 1988). The forest has therefore been recommended as one of the four forests for biodiversity conservation in Kenya. Within it and the surrounding region are about eighty one (81) endemic plant species, and several animal species that are rare or endangered (Milner *et al.,* 1993). Ecological zones are mainly as a result of relief.

Similar to Mount Kenya the ecological zone in Taita hills are as a result of the relief resulting in different climatic conditions. The indigenous forests of the Taita Hills, which are of great importance for conservation, have suffered substantial vegetation loss and degradation since the early 1960's. To date, less than 400 ha of original forest are retained in Chawia (50 ha), Ngangao (92 ha) and Mbololo (220 ha), and nine tiny remnants, embedded in a mosaic of human settlements, small-holder cultivation plots and exotic plantations. However, major forest loss and land degradation continues threatening ecosystem stability, a result of which has seen several plant species classified as endangered and vulnerable to extinction.

4.2.2 *Land use types*

Both benchmark sites have level upland areas, with different land uses. The eco-zones follow the topographic diversity with natural forests (plate 1), natural grassland (moorland) and planted forests (plate 2). Within the upper level uplands the land use occasions minimal land degradation.

Plate 1: Natural forest Embu (Source BGBD Kenya 2004)

Plate 2: Plantation forest (Pinus *spp*) Taita (Source BGBD Kenya 2004)

Tea and coffee are grown on the volcanic footridges with moderate land degradation experienced during establishment of the plantations (plate 3).

Plate 3: Coffee on bench terraces Taita (Source BGBD Kenya 2004)

In Embu within low level upland volcanic foot ridges and bottom lands the main activity is annual crop farming and horticulture, higher up along volcanic footridges are tea, coffee and agroforestry ecosystems (Plate 4).

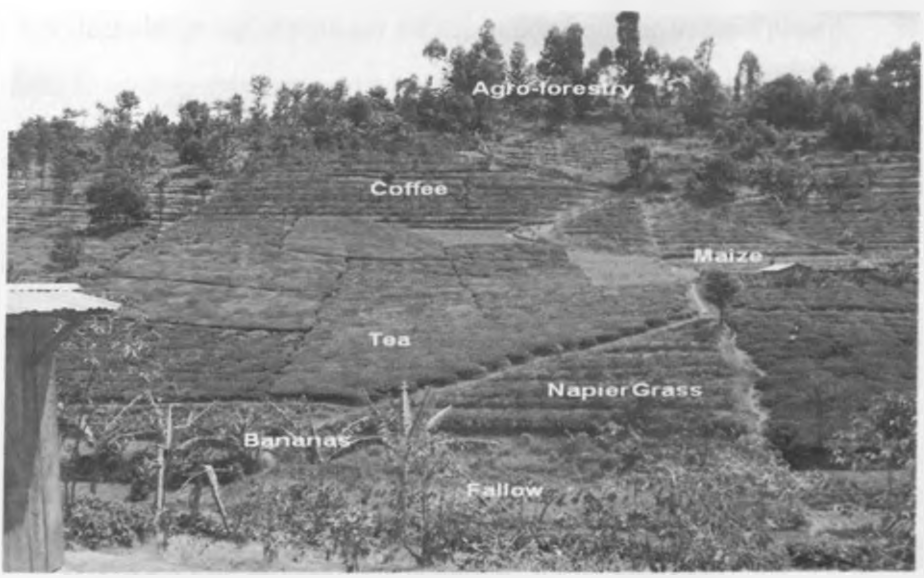


Plate 4: Land use mosaics in Embu (Source BGBD Kenya 2004)

While high level uplands are dominated by tea and forest ecosystems (plate 5).

Plate 5: Eucalyptus plantation forest in level uplands Embu Tea in foreground (Source BGBD Kenya 2004)

In Taita at the lower foot slopes arable farming is the main activity with a variety of crops including horticulture with high intensification. Maize based cropping systems and agroforestry are observed within the plateau area with low degradation evidenced, mixed cropping and irrigation horticulture practices at the bottom, lands where there is very low degradation but significant silt deposition from the uplands plate 6.

Plate 6: Maize in background with horticulture Taita (Source BGBD Kenya 2004)

4.2.3 *Geomorphology and Physiography of bench mark study sites*

The geology of Embu consists of tertiary basic igneous rocks and a physiography of uplands, plateau and bottomlands. In Embu, elevations of about 1600m above sea level form part of the lower volcanic foot ridges and slopes which are the dominant geomorphic features. Slope angles range between 5 to 15%, with some very steep side slopes of up to 80% and narrow valleys Plate 7.

Plate 7: Tea plantations in upper midlands with undulating hills and valleys Embu (Source BGBD Kenya 2004)

The physiography of Embu is characterized by typical tropical highlands, midlands, undulating hills and valleys, the highland altitudes range from 1,500 at the top to 4,500m. The midlands with volcanic foot ridges and slopes as dominant geomorphic features range from 1,200 to 1,500m above the sea level (Muya & Kiome, 1999), which is the locality of the study sites with the main land use being tea coffee and subsistence maize based farming. As for the Taita Hills geology, uplands are underlain by undifferentiated Precambrian rocks, while mountains, foot slopes and hills are underlain by quartz-feldspar gneiss and felsic granulites (plates 8 and 9).

Plate 8: Rocky outcrops within mid slopes Taita (Source BGBD Kenya 2004)

Plate 9: Steep undulating hills with rocky outcrops in the fore ground characteristic of Taita hills benchmark study site (Source BGBD Kenya 2004)

The Taita hills cover an area of 1000 km^2 and form the northernmost part of the Eastern Arc sub-montane forests in Kenya. The Eastern Arc Mountains are recognized by Conservation International as globally important "hot spots" for forest biodiversity as they are rich in endemic-species and under considerable threat.

The hills are isolated from other mountainous areas by vast plains of Tsavo plains of the National Park. From the level ground at the bottom of the hills at 600-900m a.s.l., the Taita Hills rise to an elevation of 2228m a.s.l. at Vuria peak. The Taita Hills study site is of high biodiversity interest, containing a large number of endemic plant and animal species and is designated among the twenty-five globally recognized biodiversity "hotspots" (Bytebier *et al.*, 2001; Mittermeier *et al.*, 2005).

4.2.4 *Topography of benchmark study sites*

The Embu site was classified into four zones as:

i. Upper level uplands with slope angles ranging between 15-80%; ii. The volcanic foot ridges with slope angles ranging between 10-65%; iii. The plateau with slope angles ranging between 0-5% and iv. The bottom lands with slope angles ranging between 0-1%.

While in Taita, the topography was classified into five zones being:

i. Mountain crests with slope angles ranging from 20-50%; ii. Mountain mid slopes with rock outcrops whose slope angles range from 50-70%; iii. High level upland hills and foot slopes, with slope angles of between 20-60%; iv. Bench terraced lower level uplands slopes with slope angles of between 5-16%; v. The bottom lands.

In the study, occurrence and abundance of macrofauna taxa in different land-use systems was determined in relation to changes in land use and intensification that were characterized into broad agro-ecosystems, with their abiotic factors, biophysical conditions, current practices, and intensity of land use assessed and linked to below ground biological diversity, so as to obtain an understanding of how these influence macro-fauna dynamics.

4.2.5 *Soil characteristics of study sites*

Soil characteristics at the study sites are very variable, the main soil types in Embu benchmark site are mainly Humic Nitisols within window in window 1 and 2, and in the upper level highland with forest cover Andosols in window 3 (FAO, 1989), derived from basic volcanic rocks (Jaetzold and Schmidt, 1982). The Embu soils range from loam, through clay-loam, to clay in places. They are extremely deep, well drained, friable clay texture, with a smeary consistency and humic acid top soils and of moderate to high inherent fertility.

While on the other hand Taita Taveta soils on the other hand are firm and compact, sandy clay and loam, with moderate fertility, high infiltration rates and are excessively drained. The soils here have low water holding capacities hence prolifically leached and acidic. They are classified as Acrisols, Cambisols, Luvisols and Regosols, and have characteristic high aluminum toxicity, low calcium and potassium, resulting in low Cation Exchange Capacity (CEC) (TSBF-CIAT BGBD GEF-UNEP 2002).

Land productivity and low water use efficiency are diminishing within the benchmark study sites, as a result of declining soil quality and health. This is due to increasing land degradation as a consequence of anthropogenic activity of, increasing land conversion and continuous cropping without appropriate land and environmental management and conservation strategies, coupled with associated topography of the landscape. It was noted that different ecosystems have a corresponding assortment of management practices, topographical characteristics, vegetative cover types and density hence soil degradation is also taking place within them at different rates.

Within the mountain ecosystems are a range of soils with different characteristics, in Taita these soils are shallow and stony but relatively stable due to canopy cover and undergrowth with limited anthropogenic interference, whilst increased water infiltration into the soil reduces surface run-off.

On the other hand areas with poorly covered steep Mountain slopes with rocky bases and outcrops are a rain catchment area with excess water moving down slope coming out as springs through poorly covered steep mountain slopes. The Embu study site has an appreciable extent of gentle slopes with soils that are very deep, friable, and highly permeable, consequently have a relatively low surface run off and high water holding capacity realized within the flat tops.

On cultivated slopes, apart from topography, the degree of land degradation caused by overland flow depends on efficacy of management practices within ecosystems on lower slopes, including agroforestry that is found mainly in mid uplands, hills and foot slopes. Effectiveness of land cover, crop performance and effectiveness of bench terraces and agroforestry in controlling erosion varies from one farmer to another.

While most of the shrub land ecosystem is fallow, consisting of grass and shrub providing good cover and protection against land degradation by impact of rain. Excess floods do result in severe gully erosion and land degradation, where no effort has been made to check the flow. Consequently due to increasing demand for food with the prevailing limited suitable arable land available, areas with marginal fertility are rapidly being converted for agriculture to meet the shortfall in food production.

These conversions and use of agricultural inputs to boost production are leading to loss in soil and water quality. In addition to land conversion and intensification, degradation is being promoted by overgrazing, that reduces land cover with inadequate conservation practices, hence negating the issue of sustainable land management that promotes an ecosystem balance and resilience, which depend on the soil quality and within soil biodiversity.

At the mid level uplands, bench-terraces have been constructed on very steep slopes with the cropping systems comprising of both perennial and annual crops. These bench terraces have varying degrees of effectiveness in controlling land degradation depending on their maintenance and stability, often resulting in degradation (plate 10).

Plate 10: Terraced slopes with varying effectiveness due to differences in management Taita (Source BGBD Kenya 2004)

The arable cropping on middle level uplands is maize based, but due to increasing costs farmers' manipulate soil fertility using organic and inorganic inputs and adopting cultural practices such as appropriate plant population resulting in better yields.

At the bottomlands mixed cropping is extensive with mainly horticultural crops for commercial purposes with high input of fertilizers and pesticides to control pests/diseases to meet market demand, this in turn is contaminating the water

4.2.6 *Climate of benchmark sites*

The Embu benchmark study site receives an annual rainfall of between 1200 and 1500 mm in two seasons, whose distribution is controlled by the north-south movement of Inter Tropical Convergence Zone (ITCZ). The dry season in January and February is followed by the rainy season from mid-March to the end May (long rains) followed by a spell of dry season from June to mid-October then the short rains season from mid-October to the end of December.

The minimum mean monthly temperature range between 14° C to 19.5° C. and maximum mean monthly temperatures ranging from 24 to 36° C. (Muya, *et al.*, 2005; Muya & Kiome, 1999).

The Taita Hills benchmark study site lies at an altitude of 2228m above sea level, the climate within this area is also influenced by the Inter-Tropical Convergence Zone (ITCZ), receiving an average annual rainfall of 1500 mm in the highlands and 250mm in the lowlands. There are two rainy seasons in the area: March-June and October-December, however variation of precipitation from year to year is high, especially at lower altitudes. The highest mean monthly rainfall is about 2000 mm, occurring in April and the lowest of about 50 mm received in July. The mean maximum and minimum temperature is 22.6°C and 18.5°C respectively. Soils are mainly sandy loam with high infiltration rates, low pH, water holding capacity, and nutrient contents owing to excessive leaching. Generally climatic variation between the two sites is narrow (Muya, *et al.*, 2005; Muya & Kiome, 1999).

4.2.7 *Soil productivity*

Soil productivity is generally low within agroecosystems as is evidenced by the fact that despite a high computed intensification index of between 10-30%, within maize based systems, the corresponding productivity index is low compared to forests, moorland and grasslands that have an intensification index of 2% and estimated productivity indices of between 50 and 70%.

4.3 Discussion

It emerges that the two study sites Embu and Taita, have variations in their physiography, geomorphology, altitude, soil types, eco-zones and diverse vegetation that are influenced by altitude land use type and anthropogenic activity. The determined land use intensity indices portray a magnitude of the difference in the intensity between different land use systems that provide land use intensification gradients of the benchmark study sites.

The research sites, exhibit two contrasting soil structural conditions, with the Embu site, having well-formed stable aggregates of red clay soil that have over time been pulverized into dust through intensive and continuous cropping. Consequently leaching and loss of nutrient bases, reduced soil pH and increased acidification has resulted. While In Taita the soils have been formed into extremely compact structures, from sandy clay loam to sandy clay soils, consequently the soils have low water uptake and a high volume of run-off.

The state of soil conditions and the physiography of steep slopes angled between15 and 80%, that dictate the rate of water movement into and through the soil or surface due to slope influence, and soil type determining how much soil materials will be removed depending on the erodibility factor of the soil, whose characterization is essential to understanding ecosystem function and stability within the study sites.

The level of compaction or pulverization affects nearly all physical, chemical and biological properties as well as functions of the soil as it results into alterations of pore size distribution, decreased porosity and changes in movement of air, water and nutrients in the soil. The state of degradation and soil structural conditions observed are as a result of anthropogenic activities, which influence the course of soil biological processes required to sustain aggregate stability. Soil ecosystems contain a diverse assemblage of soil biota that live within and interact with the soil and with other groups of organisms in a complex web of biological activity and influence soil quality and productivity through accelerating decomposition of organic detritus matter, mineralizing nutrients from organic matter, buffering soil functions and resilience from extreme events, and regulating soil borne pests and diseases (Brussaard *et al.*, 1997).

High land use intensification estimated at between 30 to 40% within agroecosystems, particularly maize based and horticultural crops is not surprising since maize is the staple food in both study areas and therefore the inclination to take care of it religiously, while horticulture provides the much needed income from sales. therefore land is continually tilled, and inter-planted through the year with only seasonal variations in crop type.

The most remarkable contrasting characteristic of the two study sites being that while soils in the Embu site are highly pulverized, soils are extremely compacted within the Taita study site hence calls for site specific intervention to correct the anomalies. It should be appreciated that while density and diversity of soil biota is influenced by properties and characteristics of natural soil environment as well as anthropogenic management factors, individual plants can have considerable marked differences on soil.

Land use patterns and level of intensification has a considerable impact on soil, in Embu carbon content of soils is highly variable within different land uses and individual farms with high values of up to 6.4% being evidenced in plantation forest, that are protected hence substantial detritus accumulation that is not removed by those bordering forest.

Intensification of agriculture in the tropics has resulted from a shortage of farmland and insufficient food production to satisfy the needs of an expanding population. Many tropical farmers are challenged by the prospect of intensifying their production while sustaining or improving the fertility and productivity of soils with only locally available natural resources.

Waste products of plant and animal production represent some of the most abundant natural resources available for use by tropical farmers to achieve these goals. However, the efficient use and management of these resources depend on understanding the role that decomposer biota play in regulating the structure and function of agricultural ecosystems.

4.4 Conclusion

Since soil physicochemical characters are pointers to soil quality and are closely linked to land use type, intensification and productivity. Therefore corrective interventions should be site specific aimed at resolving pulverization of soils in Embu and compaction in Taita. There is need to identify farming systems and management practices that balance between macro- and micro-aggregates turnover in order to get some equilibrium between safeguarding and decomposition of soil organic matter (Harris et al., 1963; Six et al., 2001).

CHAPTER FIVE

OCCURRENCE ABUNDANCE AND DIVERSITY OF SOIL MACROFAUNA ALONG AN INTENSIFICATION GRADIENT AT EMBU AND TAITA, KENYA

5.0 Introduction

Soil macrofauna comprise a variety of visible soil organisms larger than 2mm in diameter and spend all or part of their life within the soil (Dangerfield, 1993). The macrofauna guild (a group of organisms that exploit the same class of environmental resources in a similar way) include ants, termites and earthworm that are most conspicuous Brussaard, (1998).

Though most remain undescribed, they are acknowledged for their functions that contribute to maintain life on earth (Altieri, 1999; CBD, 2001; Lavelle, 1996), and their role in soil structure formation organic matter translocations, decomposition and mineralization (Lavelle 1996, 1999). This limited knowledge on macrofauna community structures and functional roles in ecosystem processes constitutes a major challenge for soil science and biology (Birang, 2004).

While soil macrofauna are beneficial to soil and its productivity, they have been largely neglected even in agriculture apart from focusing on their detrimental aspects as pests in crop production systems, that has led to wide spread use of pesticides (ICIPE, 1997).

Land use type and intensification to overcome challenges of reduced food production under circumstances of an ever increasing human population is known to impact on soil macrofauna. Intensification of land use accelerates soil degradation processes that cause loss of soil carbon and deplete nutrients, a process that is difficult to reverse (Sanchez, 2002).

Soil macrofauna occurrence, composition, densities their activity and impacts on soil processes are known to vary depending on residue inputs and soil management practices (Choo and Baker; Lavelle *et al.*, 1994a; Mackay and Kladivko, 1985; 1988; Pulleman *et al.*, 2004). It can therefore be hypothesized that different land management practices impact on macrofauna differentially.

However little is known about these impacts in land use mosaics of agroecosystems within the tropics. Soil fertility results from and relies on complex factors and processes where macrofauna play a vital role and it is pre-supposed that great diversity of soil macrofauna is more likely to maintain all ecosystem functions than a system low in diversity (Birang, 2004).

Therefore land use changes that result in systems reducing soil macrofauna diversity and densities are likely to lead to degradation than those systems that maintain high soil macrofauna diversity and density. For example immediate impacts of deforestation result in compaction, removal of top soil, mixing of soil layers and burning impact on faunal habitats. A change in micro-environmental (temperature and water) conditions after removal of forest cover and subsequent use of the land for cultivation of crops aggravates the situation further. Kooyman and Onck (1987), observed that species richness and densities decreased with intensities of cultivation, those that living within the upper layers of soil being more susceptible to tillage operations.

Increase in human populations has led to intensification that does not allow for prolonged fallows for recovery of soil as cropping periods have been extended. This has led to substitution of biological and organic inputs with inorganic fertilization, transiting from internal to external regulated systems and from sustainable to degraded systems gradually or abruptly (Giller *et al.*, 1997; Izac *et al.*, 1996; Ruthenberg, 1980; Van Noordwijk 2002).

In the humid tropics of Cameroon, where slash and burn is still practiced, over 85% of deforestation is attributed to small holder agricultural practice, hence the rural population density plays a significant role in determining the extent of canopy cover (Kotto-Same *et al.*, 2000). With such alarming rates of land conversion, it is essential to quantify the level of macrofauna diversity and density under ideal (natural) conditions to provide options for introduction of management techniques to farmers that maintain macrofauna diversity for ecosystem functioning within agroecosystems on conversion.

Since land use mosaics within the benchmark study sites range from natural and plantation forests with low intensification indices to horticultural farms that are continually tilled, with abundant external inorganic inputs to maintain soil productivity a similar understanding is imperative.

It is assumed that land use intensification results in biodiversity loss, and that loss in soil biodiversity may impair soil functioning in terms of soil structure, hydraulic conductivity, decomposition of organic matter and nutrient cycling. The challenge of maintaining, sustaining and enhancing productivity among resource poor farmers in the tropics is reliance on biological processes, as they have limited resources to access inorganic inputs. Therefore maintenance and enhancement of soil biodiversity for sustained productivity may be relevant to such farmers (Giller *et al.*, 1997). Hence documentation of existing diversity is vital.

The objective of the study was to determine the impacts of land use intensification on macrofauna occurrence abundance and diversity along a gradient.

5.1 Materials and methods.

5.1.1 *Study sites*

The study was conducted at Embu and Taita benchmark sites, (Fig 1. Chapter3), Kenya.

5.1.2 *Sampling sites and points*

At the benchmark study sites, macrofauna sampling was stratified cutting across different land use systems. The prevailing weather conditions during the sampling period were also similar (beginning of short rains). Sampling was done at GIS/GPS generated sampling points.

At the Embu benchmark site, sixty (60) monoliths were excavated in January/February 2005, comprising 8 in natural forest, 9 in plantation forest, 8 in fallow, 9 in coffee: 10 in tea, 8 in napier: and 8 in maize. While at the Taita benchmark area a total of forty two (42) monoliths were excavated in April/ May 2005, comprising similar land use types except for tea that is not grown in Taita, this was substituted by horticulture.

5.2 Data capture

Data generated from the analysis were captured on a excel data sheet and late utilized for analysis of correlations

5.2.1 *Statistical analyses*

Given multiplicity of land use types, management, 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).

5.2.2 Rényi diversity profiles

Diversity indices within this study were determined utilizing Biodiversity R programme to generate Rényi diversity profiles of species richness and evenness.

Rényi diversity profile formula

$$H_{\alpha} = \frac{\ln \left(\sum_{i=1}^{s} pi^{\alpha}\right)}{1-x}$$

5.2.3 *The Tukey's test*

TUKEY's test was done to find if means are significantly different from one another.

5.3 Results

5.3.1 *Macrofauna, rank and abundance across land use mosaics in Embu and Taita*

Main macro fauna invertebrate groups recorded in the Embu and Taita benchmark study sites comprised of *Hymenoptera, Isoptera, Coleoptera*, earthworms (*Oligochaeta*) and *Orthoptera* and *Araneae* (Tables. 1) whereby *Hymenoptera* were most abundant of macrofauna groups constituting 45% of the invertebrate macrofauna collected; followed by Isoptera at 39%. *Coleoptera* accounted for (6%) taking up the third and *Oligochaeta* at 5% the fourth position respectively. These four genera accounted for over 90% of the total macrofauna sampled in Embu. Other macrofauna groups encountered including *Hemiptera, Diptera, Phasmidae Blattelidae* each constituted <1% of macrofauna in Embu.

Table: 1. Macrofauna Composition Rank and Abundance Embu, Kenya.

Macrofauna grp	Rank	Abundance
Hymenoptera	1	26576
Isoptera	2	23104
Coleoptera	3	3600
Oligochaeta	4	3168
Orthoptera	5	1712
Arenae	6	912
Hemiptera	7	464
Diptera	8	64
Blattodea	9	64
Phasmidae	10	16

At Taita benchmark study site main macro fauna invertebrate groups recorded (Table 2) comprised of *Hymenoptera, Isoptera, Coleoptera, Oligochaeta* and *Orthoptera* and *Araneae* (Table. 2). *Hymenoptera* were again most abundant constituting 36% of the total invertebrate macrofauna collected followed by Isoptera at 22%, earthworms (*Oligochaeta*) accounting for 16% and *Coleoptera* 10% in taking up third and fourth positions respectively. The same four genera accounted for 84% of total macrofauna sampled in Taita. Other macrofauna groups encountered including *Hemiptera, Diptera, Phasmidae Blattelidae* each constituted <1% of total macrofauna in both cases.

Table: 2. Macrofauna composition rank and Abundance in Taita, Kenya.

Macrofauna group	Rank	Abundance
Hymenoptera	1	59440
Isoptera	2	36416
Oligochaeta	3	26160
Coleoptera	4	16080
Arenae	5	8208
Diplopoda	6	4384
Diptera	7	3840
Orthoptera	8	3408
Blattelidae	9	2208
Isopoda	10	1792
Chilopoda-G	11	1712
Hemiptera	12	1040
Opiliones	13	656
Chilopoda-S	14	528
Lepidoptera	15	336
Dermaptera	16	112
Phasmidae	17	32
Mantodea	18	16

The mean macrofauna abundances across land use systems are in Embu and Taita are depicted in (Table. 3) Embu and (Table 4) Taita

Table: 3. Mean Macrofauna abundance (number m^{-2}) across land use systems Embu, Kenya.

	Land use systems								
	Number m^{-2}								
Macrofauna group	NF	PF	C	F	M	N	T	**Mean**	**P value**
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
Total	**1110**	**309**	**1170**	**1356**	**820**	**1566**	**55**		**0.21ns**

Key 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: 4. Mean Macrofauna abundance (number m^{-2}) across land use systems of Taita, Kenya

Macrofauna group	Land use systems — Number m^{-2}							Mean	P value
	C	F	H	M	NF	PF	N		
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
Chilopoda G	6c	13c	3c	25cb	83b	171a	36b	48	<0.001***
Chilopoda S	0b	4b	3b	7b	35a	59a	0b	15	<0.001***
Isopoda	6b	13b	3b	5b	99a	304a	8b	63	<0.001***
Total	**3315**	**4929**	**2950**	**3257**	**2019**	**1131**	**3088**		

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.

5.3.2 *Macrofauna taxa diversity across land use mosaics in Embu and Taita.*

Soil macrofauna taxa occurring in the various land uses sampled in Embu and Taita are presented. Following collection sorting and taxonomic identification, thirty four (34) genera/ species were recorded for Embu (Table. 5) and (78) taxa genera/ species for Taita (Table. 6)

Table: 5. Macrofauna taxa diversity across land use systems in Embu, Kenya.

Macrofauna Diversity			
Class	Order	Family	Genus/sp
Insecta	Blattellidae	*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]

Land use systems						
T	C	N	F	M	IF	PF
+	-	-	+	+	-	-
+	-	+	-	+	-	-
+	-	+	+	+	-	+
+	-	+	+	+	-	-
-	+	+	-	-	-	-
-	+	+	-	+	-	-
+	+	+	+	+	+	+
+	+	+	+	+	+	+
+	-	+	+	-	+	-
-	+	+	-	+	-	-
-	+	+	+	+	+	+
-	+	+	+	+	+	+
-	-	+	-	+	-	+
-	-	+	-	-	-	-
-	-	-	-	-	+	-
+	+	-	+	-	+	-
+	+	+	-	+	+	+
+	-	+	-	+	+	+
-	-	+	+	-	+	+
-	+	+	-	-	+	+

		Hemiptera
	Arachnida	Araneae
	Oligochaeta	

Scarabaeidae	*Acanthocerodes sp*[6]	-	-	+	-	+	-	-
Scarabaeidae?	*Sp7*	-	-	+	+	-	+	+
Carabidae	*Cyphloba sp*[8]	+	-	+	-	-	-	-
	Menigius sp[9]	-	-	-	-	-	+	-
Ellateridae	*Conodenus sp*[10]	-	-	+	+	-	-	-
Coreidae	*Sp1*	-	-	+	+	+	-	+
Coreidae	*Anoplocnemis sp*[2]	-	+	-	-	-	-	-
Aphraphoridae	*Sp3*	+	+	+	-	-	-	-
Cydnidae	*Sp4*	-	-	+	+	+	-	-
Lygaeidae	*Sp5*	-	-	+	-	+	-	+
Pentatomidae	*Sp6*	-	-	-	-	+	-	-
Aphididae	*Sp7*	-	-	-	-	-	+	-
	Sp1	+	-	+	+	+	+	+
	Sp1	+	+	+	+	+	+	+

Table 6. Macrofauna taxa diversity across land use systems in Taita, Kenya.

Macrofauna Diversity

Class	Order	Family	Genus/sp
Insecta	Blattellidae	*Pseudoderopeltis*	*Sp*^{1}
		Blattoidea/Blattidae	*Blattella sp*^{2}
		Gryllidae	*Gryllus sp*^{1}
	Orthoptera		*Phaeophilacris 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}
			Sp^{9}
		Asilidae	
		Chloropidae	*Sp*^{10}
	Isoptera	*Termitidae*	*Odontermes sp*^{1}
		Termitidae	*Sp*^{2}
		Rhinotermitidae	*Sp*^{3}
		Alates	*Sp*^{4}

Land use systems

M	C	Ht	F	N	NF	PF
+	-	+	+	-	+	+
-	-	+	+	+	+	+
+	-	+	+	+	+	+
-	-	-	+	+	-	-
+	+	+	+	+	+	-
-	+	-	-	+	+	-
+	+	+	+	+	-	-
+	+	+	+	+	+	-
+	-	+	+	+	-	-
+	+	+	+	+	+	-
-	+	-	+	+	+	-
-	+	-	+	+	+	-
+	-	-	+	+	+	-
+	-	+	+	+	+	-
-	-	-	+	-	-	-
-	+	-	+	-	-	-
-	+	-	-	+	-	-
+	-	+	+	+	-	-
+	-	+	+	+	+	+
+	+	-	-	+	-	-
+	-	+	+	+	+	+

Macrofauna Diversity

Class	Order	Family	Genus/sp
	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		*Sp*[1]
		Gratididae	
	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]

Land use systems

M	C	Ht	F	N	NF	PF
+	-	+	+	+	+	+
+	-	+	+	+	-	+
+	-	+	+	-	-	-
+	-	+	+	+	-	-
+	-	-	+	+	-	-
-	+	-	+	-	-	-
-	+	+	+	+	-	-
+	-	-	-	+	-	-
+	-	+	-	+	-	+
+	-	+	-	-	-	-
-	-	-	-	-	-	+
+	-	+	+	+	+	+
-	+	-	+	+	-	-
+	-	-	+	-	-	-
-	+	+	+	+	-	-
-	+	-	-	+	+	-
-	+	-	+	+	-	-
+	+	+	+	+	+	-
+	+	+	+	+	+	-
+	+	-	-	+	-	-
-	+	-	+	+	-	-
+	+	-	-	+	-	-
+	+	-	-	+	-	-
-	+	-	-	+	+	-
-	+	-	+	+	+	+

Macrofauna Diversity

Class	Order	Family	Genus/sp
			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]
			Sp[25]
		Carabidae?	
		Lagrididae	*Aeritolagria sp*[26]
		Bostrychidae	*Bosstrycharis sp*[27]
		Paussidae	*Paussus sp*[28]
		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]

Land use systems

M	C	Ht	F	N	NF	PF
-	+	-	-	+	+	-
+	+	+	+	+	+	+
+	-	-	+	-	+	-
+	-	+	+	-	-	-
+	+	+	+	+	+	-
-	+	-	-	+	+	-
-	+	-	-	+	+	-
+	+	-	+	+	+	-
+	+	-	-	+	-	-
+	+	-	+	+	-	-
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+	+	+	+	+	-	-
+	+	+	+	+	+	-
+	-	+	-	-	+	-
-	-	-	+	-	-	-
+	+	+	+	+	-	-
+	+	+	+	+	+	-
-	-	-	-	-	+	-

Macrofauna Diversity

Class	Order	Family	Genus/sp
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}

Land use systems

M	C	Ht	F	N	NF	PF
+	+	+	+	+	+	+
-	+	-	-	+	+	-
+	+	+	+	+	+	+
+	+	+	+	+	+	+
+	+	+	+	+	+	+
+	+	+	+	+	+	+
+	+	+	-	+	+	+
-	-	-	+	+	+	-
+	+	+	+	+	+	+

5.3.3 Rényi Diversity Indices

Within the Embu benchmark study site, the Rényi diversity profile indicated in regard to species richness (**α at** ∞), plantation forest was richest in species among land use mosaics, ahead of coffee and tea, that was greater than napier which in turn was greater than natural forest with fallow/pasture being the least diverse. Tea and coffee were not significantly different from each other in their species richness at (**α** at ∞) (Fig 4).

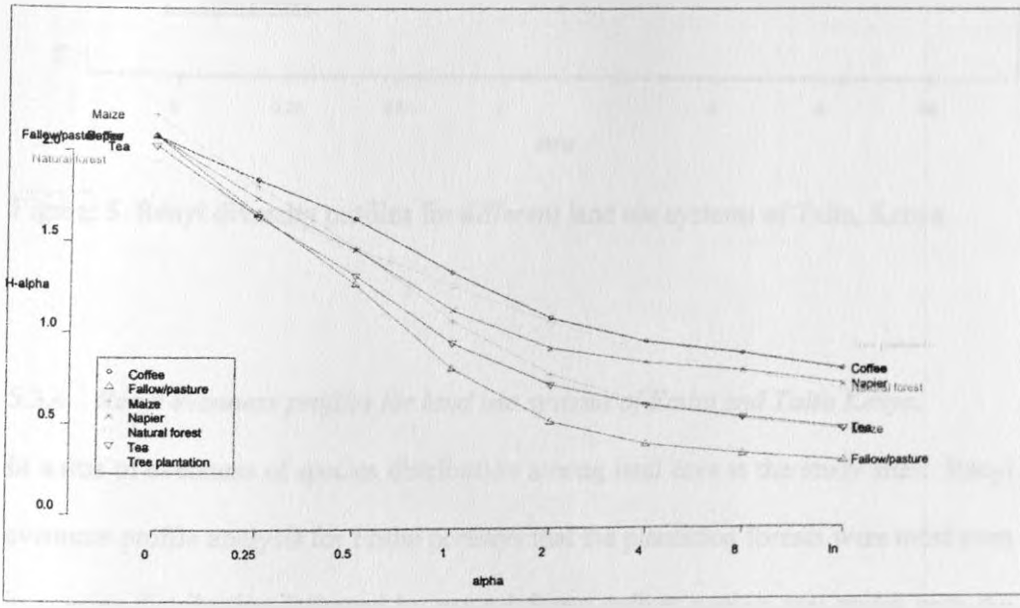

Figure: 4. Rényi diversity profiles for different land use systems of Embu, Kenya.

For Taita, an appraisal of the Rényi diversity analysis the indication is that there were no observable significant differences in species richness, as is characterized by very close diversity profiles at **α = 0** (Figure. 5).

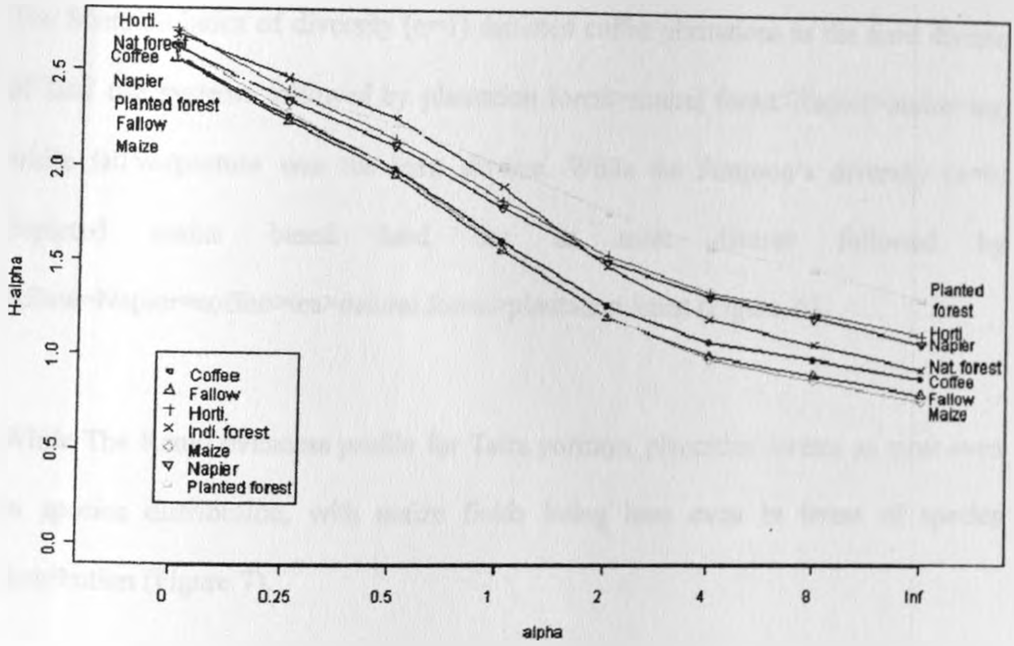

Figure: 5. Rényi diversity profiles for different land use systems of Taita, Kenya.

5.3.4 *Rényi evenness profiles for land use systems of Embu and Taita Kenya.*

In terms of evenness of species distribution among land uses at the study sites. Rényi evenness profile analysis for Embu portrays that the plantation forests were most even in species distribution followed by natural forest coffee; napier; tea; maize with the least even being within the fallow/pasture agroecosystem. However since profiles for all land use systems decline as from left to right slanting rather than being horizontal indicates that the species are not evenly distributed. Since the profiles of land use systems cross each other, it was not possible to clearly order or rank the land use systems in terms of diversity because of predisposition of the two indices, with many crossings observed of the diversity curves.

The Shannon index of diversity (α=1) depicted coffee plantations as the most diverse of land use systems followed by plantation forest>natural forest>Napier>maize>tea, while fallow/pasture was the least diverse. While the Simpson's diversity (α=0) depicted maize based land use as most diverse followed by fallow=Napier=coffee>tea>natural forest>plantation forest (Figure. 6).

While The Rényi evenness profile for Taita portrays, plantation forests as most even in species distribution, with maize fields being least even in terms of species distribution (Figure 7).

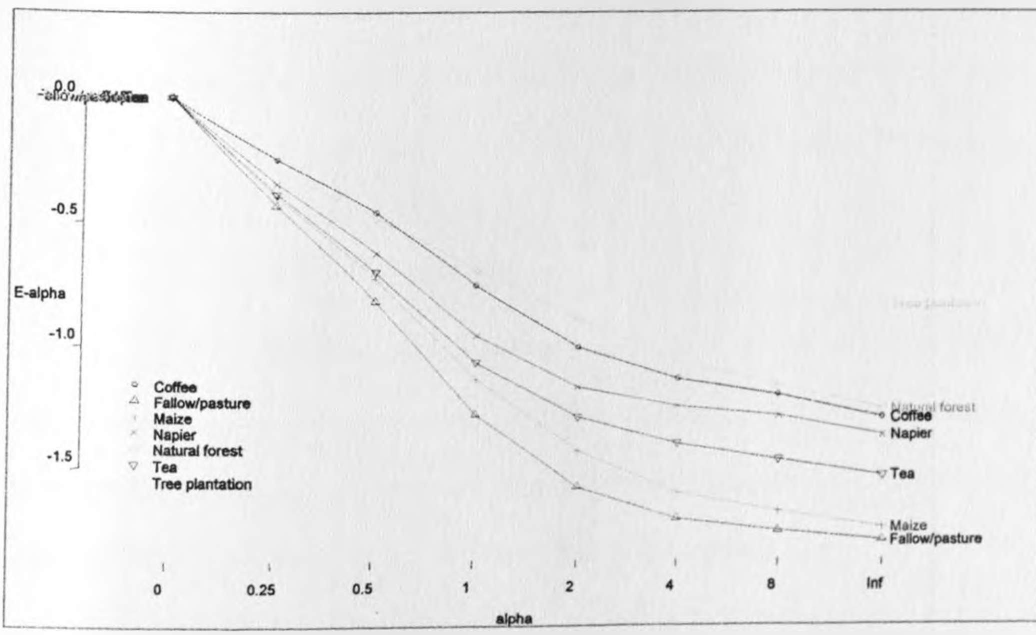

Figure: 6. Rényi evenness profile across different land use systems of Embu, Kenya.

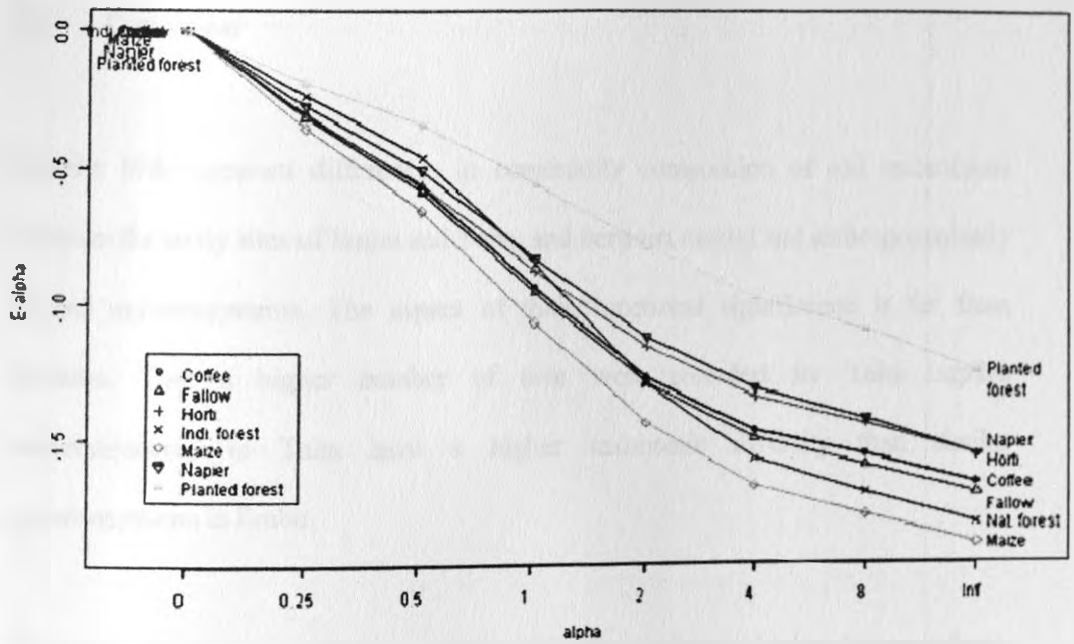

Figure: 7. Rényi evenness profile across different land use systems of Taita, Kenya

5.4 Discussion

Despite little apparent differences in community composition of soil macrofauna between the study sites of Embu and Taita; and between natural and anthropogenically altered agroecosystems. The aspect of their functional significance is far from obvious. That a higher number of taxa were recorded for Taita implies agroecosystems in Taita have a higher taxonomic diversity than similar agroecosystems in Embu.

Plantation forests at the Embu benchmark study site have a higher in macrofauna species diversity and abundance, and generally forests and in particularly natural forest ecosystems have higher species evenness than agroecosystem mosaics. Forest disturbance, clearance and cultivation alter and create a hostile environment unsuitable to soil organisms.

It is known that fauna with cryptic behaviour, or capable of vertical migration within soils or nest building such as termites may overcome temporary adverse conditions, by burrowing deeper and retreating into nests. Findings from this study indicate that plantation forests within Taita are similarly rich in macrofauna species as those of Embu and also depict higher species distribution or evenness than the agroecosystems.

Though most macrofauna groups do not differ significantly across the land use systems as per results obtained, the forests harbour higher *Chilopoda* and *Isopoda* density than the agroecosystem mosaics. Results of this study also indicate that most of macrofauna groups such as *Hymenoptera, Oligochaeta, Coleoptera, Diplopoda,* *Diptera, Arenae, Blattelidae,* and *Hemiptera* are more abundant in arable systems than in the forest ecosystems.

However insignificant variations for some groups across the different land use systems implies management practices do not significantly influence macrofauna density. Hence other factors such as food availability and habitat preference may explain differences in abundance and species composition of soil organisms.

Observation of low *Chilopoda* and *Isopoda* densities in arable agroecosystems in Taita could be as a result of management practices that destroy suitable habitats, altering soil microclimate and removal of detritus substrate, consequently resulting in low diversity and availability of food sources for associated macrofauna groups.

Management practices of land clearing, litter burning, continuous tillage, monoculture, crop rotation, organic residue inputs, retention or removal and use of agrochemicals inputs; to bolster production have been demonstrated to cause alteration of soil fauna population structure, disappearance or reduction of key species and in some cases extremely low abundances and biomass (Brown *et al.*, 1996; Dangerfield, 1993; Roper and Gupta, 1995; Warren *et al.*, 1987).

While understanding complexities of soil biodiversity is of high priority in global biodiversity conservation efforts (Hawksworth and Ritchie, 1993; Linden *et al.*, 1994), further information and knowledge on macrofauna is important in identifying keystone species of biological and economic importance to soil quality and productivity is important.

With reduced species richness and evenness, dominance of Coleoptera and Araneae within cultivated areas is an indication of change in proportional representation of different groups following land use conversion and management practices. Converting natural ecosystems leads to considerable loss of soil organic matter, soil faunal biomass and is detrimental to microfloral and macrofauna communities (Beare *et al.*, 1995; Lavelle and Pashanasi, 1989; Watanabe and Ruaysoongnern, 1984).

Tian *et al.* (1993a), demonstrated that microclimatic effects occasioned by surface mulches strongly affect densities and diversity of soil fauna and that temperature consistency or variations have a significant impact on distribution of soil biota within the soil is acknowledged by (Critchley *et al.*, 1979), who observed that diurnal temperatures in cultivated soils in the upper 0-10cm ranged between 26°C -32°C compared to a constant 25°C in bush soils which also had higher moisture content than cultivated land year round, as a result occurrence and activity of soil dwelling fauna is higher in area under bush.

5.5 Conclusions

Results obtained from this study demonstrate that quantitative changes in diversity and density of soil fauna communities occur when land is subjected to different uses and levels of intensification. The resultant changes are associated with management practices that consequently result in destruction of habitats, modification of soil microclimate in these habitats and removal of organic substrate hence reduced availability of food sources for associated macrofauna groups.

CHAPTER SIX

IMPACTS OF SOIL PHYSICOCHEMICAL CHARACTERISTICS ON MACROFAUNA IN EMBU AND TAITA

6.0 Introduction

Soil chemical characteristics may directly or indirectly play a role in influencing the density, distribution and structure of macrofauna communities. Chemical factors are important for productive soil, of which soil pH, Carbon, Nitrogen, Phosphorous and Potassium are key in sustainable agroecosystems.

Soil pH is a measure of the acidity or basicity in soils, also defined as the negative log of molar concentration of dissolved hydrogen ions (H^+). pH values range from 0-14 with 0 being most acidic and 14 highly basic and 7 being neutral. Soil pH is a principal variable in soils as it influences many chemical processes that take place in the soil matrix. It specifically affects plant nutrient availability by controlling chemical forms of nutrients. The optimum pH for most plants lies between 6 and 7.5 though many plants have adapted themselves to survive at pH values outside this range.

Carbon is a crucial element in soil, it has been established that fertility of soils decreases rapidly following slash-and-burn Lal, (1987, 1996). Up to eighty percent of the total carbon and nitrogen content of the soil are sequestered within macro aggregates, partly protected from microbial action and burning. When forests are converted to cultivated cropland, the organic layer is depleted and soil carbon contents and Cation Exchange Capacities (CEC) decrease. Globally soils hold more organic carbon more than the amount in vegetation and the atmosphere; hence soils are sinks for atmospheric carbon and may assist in mitigating global warming as carbon accumulates almost entirely in soil macro aggregates. The potentially rapid destruction of macro aggregates following tillage, however, raises concerns about the long-term persistence of these carbon pools. Within this study, it is noted that soil organic carbon amounts exhibited considerable variability depending on land use within and between soil profiles with forests and perennial cropping systems being superior for sinking carbon.

Land use intensity and soil depth exert a significant effect on bulk density of soil with lower bulk density (bulk density is a measure of a soils mass per unit volume of soil) being observed in forest ecosystems and of negative correlation to soil organic matter (SOM) hence conversion from forest to cultivated land leads to loss of soil organic matter, as a result of reduced input of organic matter into the soil.

Most plant derived residues are removed from cultivated lands essentially mining the carbon and increased oxidation of organic matter due to tillage of land since there is a substantial transfer of carbon from slow pools with long residence times of years to active pools with mean residence times of weeks. Therefore restoring soil carbon pools by reducing land use intensity as a potential strategy for partially offsetting carbon dioxide release into the atmosphere is imperative.

Nitrogen (N) in the soil is the single most important element for plant development (primary production). It is required in large amounts and where deficits occur, it must be added to the soil to avoid a deficiency. It is responsible for luxuriant, vigorous plant growth and development. However, when applied in excess, it results in a diminished root system. Though nitrogen is the most abundant element in our atmosphere, plants cannot use it unless it is naturally processed in the soil, or added to soil as an inorganic fertilizer.

Organic or naturally occurring nitrogen is a by-product of microorganisms breaking down organic matter, a process that is slow and with an extended release period. Since nitrogen is a large component of plant and animal material, substantial amounts of N are lost from the soil system through crop removal which accounts for a majority of the N that leaves the soil system.

Phosphorus (P) is an essential macronutrient required in large amounts by plants. And is required for the growth and development of the plant roots and leaves, it is one of the three nutrients generally added to soils in commercial inorganic fertilizers. The most notable role of phosphorous P in living organisms is in transfer and storage of energy in form of adenosine tri-phosphate (ATP). Organic compounds containing P are used to transfer energy from one reaction to drive other reactions within cells.

Adequate availability of P for plants stimulates early stages plant growth and hastens maturity. In soils, phosphate ions are adsorbed to soil particles and also combine with elements such as calcium (Ca), magnesium (Mg), aluminum (Al), and iron (Fe), to form solid compounds in the soil. The adsorbed phosphate and the newly formed solids are relatively available to meet crop needs.

Phosphate ions generally react by adsorbing to soil particles or by combining with elements in the soil such as calcium (Ca), magnesium (Mg), aluminum (Al), and iron (Fe) forming solid compounds making it unavailable to plants. These reactions that reduce P availability occur in all ranges of soil pH but are pronounced in alkaline soils (pH > 7.3) and acidic soils (pH < 5.5), in which the phosphate forms insoluble compounds that cause the phosphate to become fixed and unavailable over time resulting in a decrease in its availability in the soil.

In alkaline soils with soil pH greater than seven (7), Calcium (Ca) is the dominant cation (positive ion) that reacts with phosphate forming various compounds, the formation of each compound results in a decrease in solubility and availability of phosphate to plants. While in acidic soils particularly with soil pH less than 5.5, Aluminum (Al) is the dominant ion that reacts with phosphate. In these soils the products formed are amorphous Aluminum (Al) and Iron (Fe) phosphates that gradually change into compounds that are very insoluble and generally not available to plants as it is tied up. Soil pH of between 6 and 7 is the optimum range that ensures availability of phosphate to plants, hence maintaining soil pH of between 6 and 7 generally results in the greatest availability of phosphorous for plants.

Potassium is an emerging, limiting plant nutrient in humid and sub-humid regions of Kenya (ICRAF, 1997; Kanyanjua and Buresh, 1999). Though the total Potassium (K) content of soils frequently exceeds 20,000 (ppm Parts per Million) (Muya and Kiome 1999), and exists as a structural component of soil, and therefore not readily available for plant growth.

Water soluble potassium held in exchange sites on clay is what is available for plant growth, a drop in soluble (K) due uptake by plants, results in more being released from the clay particles. High soil moisture increases availability of K, as does soil aeration that increases root respiration therefore more K is available in soils not fully saturated. Warm soil temperatures also encourage (K) uptake, it is of importance to note that soil temperature is fundamental to plant functions as root activity and physiological processes all increase as soil temperature increases. This increase in physiological activity with temperature, leads to increased K uptake, with the optimum soil temperature for K uptake being between 15.5-26°C, and is reduced at low soil temperatures.

In farming systems where minimum tillage and ridge-till planting systems are practiced, retarded soil availability of K has been demonstrated. The exact cause of this reduction is not entirely clear; however it may be due to restrictions in root growth combined with a restricted distribution of roots in the soil.

Sufficient air (oxygen) is necessary and required for root respiration, K uptake, root activity and the subsequent K uptake may decrease in soils not turned over in no-till and ridge till systems as they have limited influx of air. Though higher soil moisture usually results in greater availability of K, as increasing soil moisture increases movement of K to plant roots and enhances its availability, when soil moisture content increases to saturation, levels of oxygen are reduced hence K becomes limiting.

6.1 Materials and methods

Soil, characterization and analysis of samples in the study sites of Embu and Taita was undertaken in collaboration with participants in the BGBD project Mr. E. Muya, of Kenya Agricultural Research Institute/Kenya Soil Survey (KARI/KSS), and H. Roimen of the Department of Remote Sensing and Resource Surveys (DRSRS). Results obtained were evaluated for relations and correlations with macrofauna abundance in the study sites.

6.1.1 *Study sites*

Study sites for this were Embu and Taita Kenya (Fig. 1). Where increase in land degradation and decline in soil quality resulting in decreased productivity due to low water and nutrient use efficiency are evident.

6.1.2 *Soil sampling*

At each point for macrofauna, soils were collected utilizing a soil auger, at each of the sampling points up to a depth of 12cm. at both study sites and used for soil characterization including, colour, depth, texture, consistency, surface sealing, crusting and compaction. Making use of FAO-UNESCO 1997 world soil map, soil profiles were developed based on the above parameters.

For soil physicochemical analysis samples from isolated monoliths in agroecosystems at sampling points were collected randomly, pooled and well mixed before a Kilogram (1kg.) in volume of sub sample of soil was taken, sealed in Zip lock bags, then appropriately stored to be analyzed later.

For soil bulk density five soil core samples 5cm deep were taken at surface of soil using a steel corer, driven vertically into the soil.

6.2 *Soil analysis*

Analysis of soil properties were performed using standard methods of the National Agricultural Research Laboratories NARL (Kenya).

6.2.1 *Soil chemical analysis*

Soil chemical analysis was carried out as described by Hinga *et al.,* (1993), with available soil nutrients of Magnesium(Mg), Sodium (Na), Phosphorous (P) and Potassium (K), assayed according to methods outlined by (Anderson and Ingram, 1993), Carbon by colorimetric assay (Nelson and Ingram, 1982).

The analyses of soil samples included, pH measured for pooled soil samples at each agroecosystem in a soil/water solution of ratio 1:2.5 (Asawalam *et al.,* 1997). Total sequestered carbon stocks (C); determined by the Heanes' colorimetric improved chromic digestion and spectrophotometric procedure (Heanes, 1984). Total nitrogen (N), by micro-Kjeldahl digestion and distillation, (Bremner and Tabatabai, 1972). Phosphorus (P) measured colorimetrically by a spectrophotometer using the same digestion solution used for N extraction. 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 measured using atomic absorption spectrophotometry (Okalebo *et al.,* 1993). Soil moisture was measured gravimetrically during each study period from composite soil samples.

6.3 Data collection

Data generated from the analysis were captured on a excel data sheet and late utilized for analysis of correlations

6.4 Statistical analysis

Multivariate statistical analysis was carried using Biodiversity-R (Kindt and Coe, 2005). Analysis 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 selected macrofauna groups' density and some soil chemical parameters and linear ordination (Redundancy analysis (RDA) constrained to the environmental variables was performed.

6.5 Results

Soil chemical properties for land use types in benchmark study sites of Embu and Taita are presented in Table: 7 Embu and Table 8 Taita below

Table: 7. Soil chemical properties for various land use systems in Embu study site

	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

Table: 8. Soil properties for various land use systems in Taita study site.

Soil parameters	Land use systems 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	6.07	7.58	7.61	7.85	8.40	6.75	8.90
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

6.5.1 *Soil pH*

Within the Embu study site soil mean pH levels were found to range between pH 3.54 in natural forest and pH 4.19 in fallows at the Taita study site, soils are also acidic with pH levels ranging between pH 3.06 in plantation forest and 4.93 in napier fields.

6.5.2 *Acidity*

Acidity levels recorded in Embu study site were of 2.75 in natural forest highest and 1.05 in maize bean land use the lowest. Mean acidity levels in Taita study site were highest of 2.38 in natural forest and 0.31 in maize bean land use being the lowest.

6.5.3 *Soil Nitrogen (N)*

Similarly Nitrogen (N) levels recorded in Embu were highest in plantation forest at 0.88% and lowest in coffee plantations 0.32% while in Taita nitrogen (N) levels in ranged between 0.42%, within natural forest and 0.2% within agroecosystems of maize, coffee and horticulture fields.

6.5.4 *Soil sequestered carbon (C)*

Plantation forests were found to have the highest percentage of soil sequestered organic carbon 6.55%, with the lowest value of 3.43% being observed in coffee plantations. Elevated levels of soil sequestered C were also observed in the Taita forests, with plantation forest mean levels recorded being 2.88% and lowest in horticulture 1.57%

6.5.5 *Soil Phosphorous (P)*

In Embu study site, recorded Phosphorous levels were 21.13_{ppm} in natural forest and 10.83_{ppm} in coffee plantations. While in Taita high levels of phosphorous observed 58.25_{ppm} in napier fields and 53.4_{ppm} in horticultural plots, and very low 5.33_{ppm} in planted forest.

6.6 Correlations between soil properties and macrofauna abundance

6.6.1 Redundancy Analysis Embu

When Redundancy Analysis (RDA) plots of macrofauna abundance in Embu were fitted to constrained environmental variables (Table. 9), and plotted (Fig. 6). A redundancy of 5.6 from total of 34.8 or 16.1% of variance explained, while Redundancy Analysis (RDA) plots of macrofauna abundance in Taita fitted to constrained environmental variables (Table. 10), and plotted (Fig.7). The variables explain a redundancy of 5.6 from total 58.72 or 29.89% of the variance of macrofauna abundance.

Table: 9. Hybrid RDA constrained to environmental parameters (Soil characteristics) Embu

Total: 34.83
Constrained: 5.61 (16.12%)
Unconstrained: 29.22 (83.88%)

Axes	RD1	RD2	RD3	RD4	RD5
Lambda	2.77	1.75	0.63	0.33	0.11
Accounted (%)	7.90	13.0	14.8	15.8	16.1

Table: 10. Hybrid RDA constrained to the environmental parameters (Soil characteristics) Taita.

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
Lambda	10.844 7	2.867 1	1.963 8	1.132 5	0.4989
Accounted (%)	0.1847	0.233 5	0.267 0	0.286 3	0.2948

Correlation between soil macrofauna abundance in Embu and all soil parameters as constraining variables, with soil characteristics represented by arrows, (Figure 8).

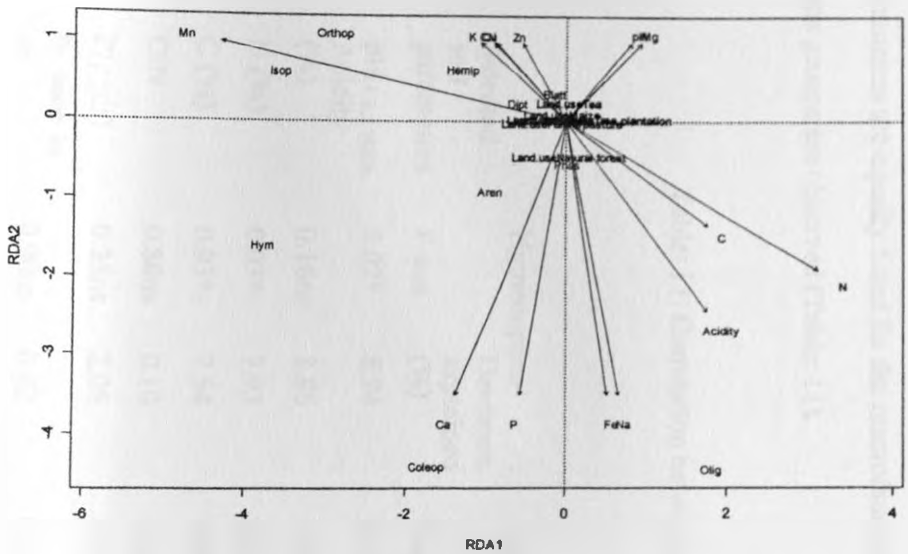

Figure: 8. Redundancy Analysis bi-plot Embu (RDA)

Correlation between soil macrofauna abundance in Taita and all soil parameters as constraining variables, with soil characteristics represented by arrows (Fig. 9)

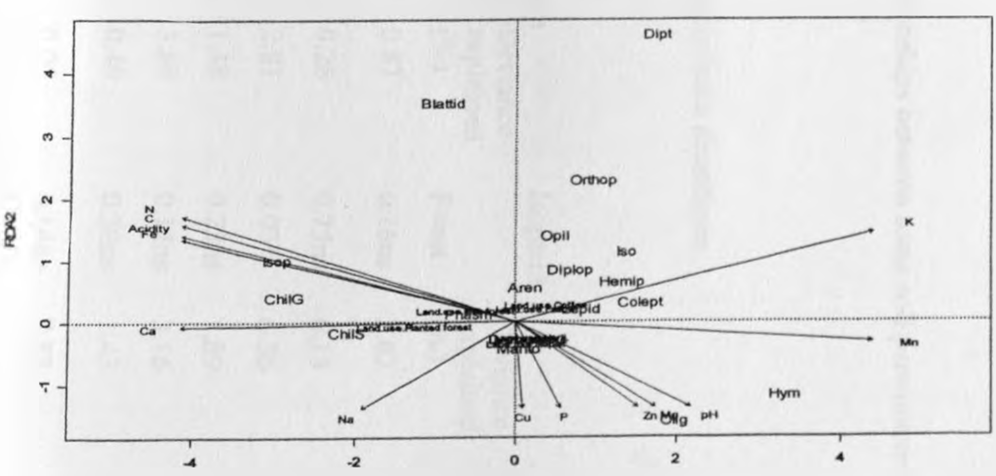

Figure: 9. Redundancy Analysis bi-plot Taita (RDA)

6.6.2 Correlation between selected soil properties and macrofauna abundance

When soil parameters are equally fitted for the macrofauna groups, significant strong relationships between some soil parameters with some soil macrofauna groups are observed (Table: 11).

Table: 11. 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

On plotting Hymenoptera abundances in relation to soil chemical parameters, Hymenoptera were found to be negatively correlated to soil chemical parameters of pH, percentage C and N (Figure 8. a-c). While the *Isoptera* group is negatively correlated with soil N (Figure 9A), and the earthworms (*Oligochaeta*) are positively correlated to soil N (Figure 9B).

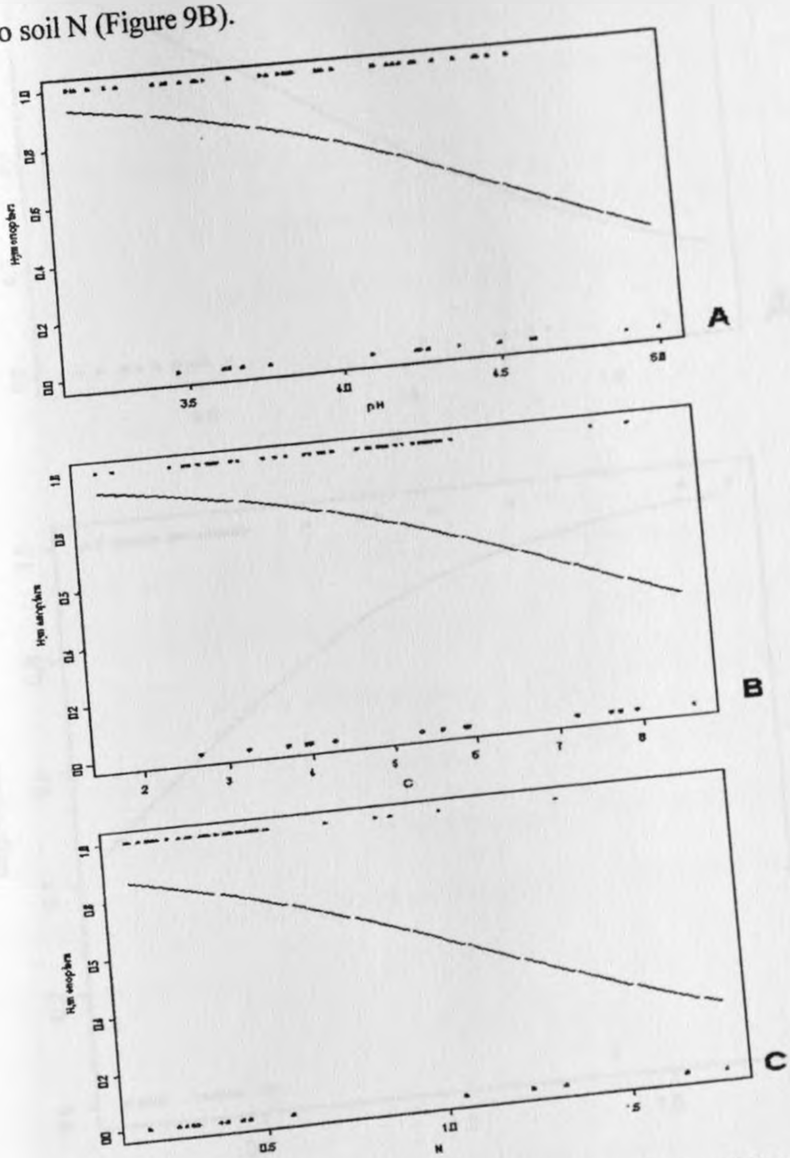

Figure: 10. (A-C) Correlation of Hymenoptera with pH, Carbon (C) and Nitrogen (N)

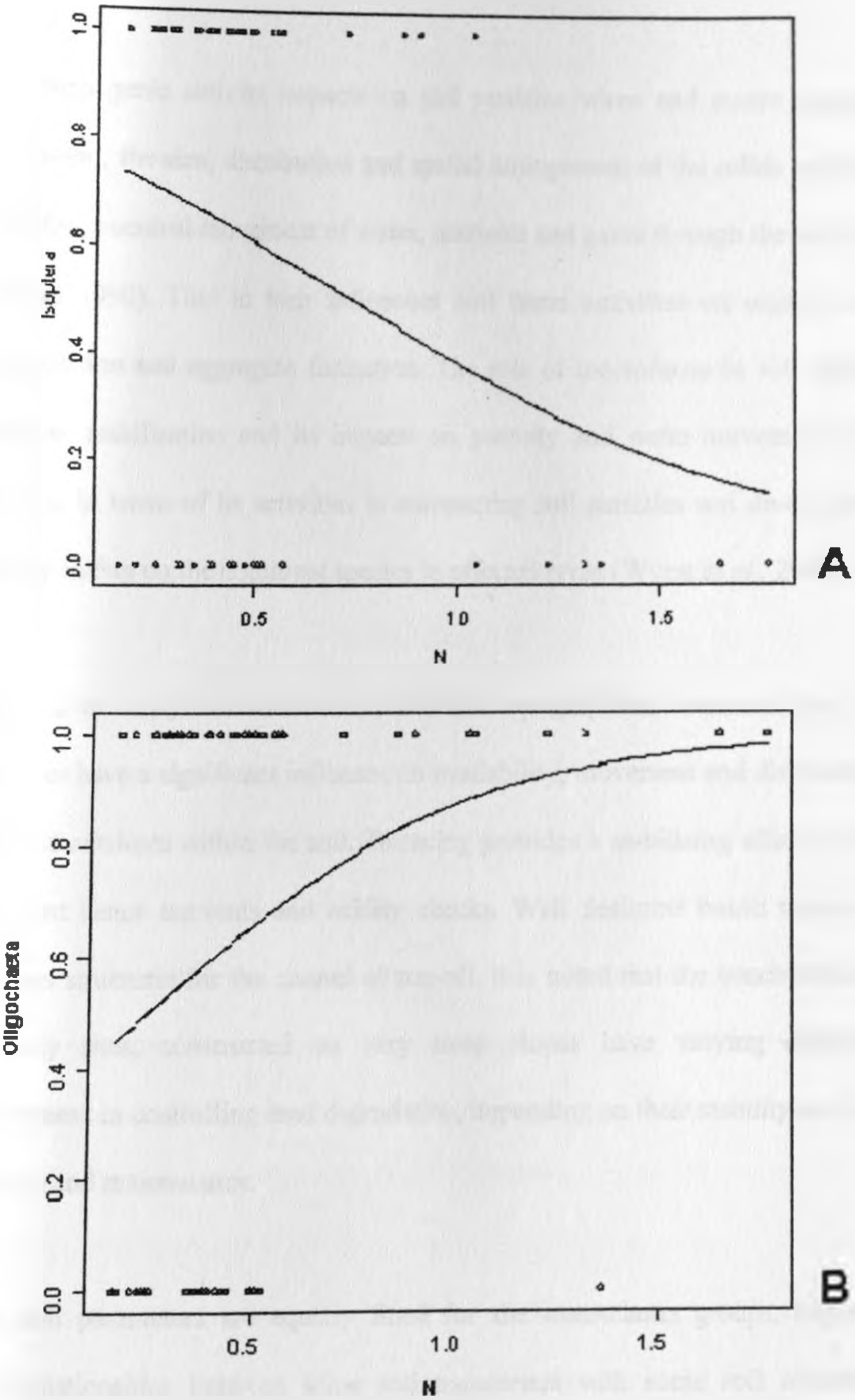

Figure: 11 (A - B). Correlations between soil % Nitrogen and Hymenoptera group

6.7 Discussion

As anthropogenic activity impacts on soil particles micro and macro aggregates arrangement, the size, distribution and spatial arrangement of the solids and spaces around them control movement of water, nutrients and gases through the soil matrix (Metting, 1990). This in turn influences soil fauna activities on organic matter decomposition and aggregate formation. The role of macrofauna in soil structural formation, stabilization and its impacts on porosity and water movement can be expressed in terms of its activities in compacting soil particles and de-compacting them depending on the dominant species in affected areas (Wuest *et al.*, 2001).

Variations in ecosystem structures, relief and topographical characteristics in the study sites have a significant influence on availability, movement and distribution of water and nutrients within the soil. Terracing provides a stabilizing effect on water movement hence nutrients and acidity checks. Well designed bench terraces are important structures for the control of run-off, it is noted that the bench-terraces in the study sites, constructed on very steep slopes have varying degrees of effectiveness in controlling land degradation, depending on their stability as a result of design and maintenance.

When soil parameters are equally fitted for the macrofauna groups, significant strong relationships between some soil parameters with some soil macrofauna groups are observed. On correlation analysis between selected soil properties and densities of macrofauna groups (Table 11) the *Hymenoptera* is negatively correlated to soil pH, percentage C and N (Figure 10.A-C). Similarly *Isoptera* group was negatively correlated with soil N (Figure 11A). On the other hand, Oligochaeta were positively correlated to soil N (Figure 11B).

Strong correlations were observed between pH, percentage soil C, N and the group *Hymenoptera*, explaining between 8.73, 7.93 and 7.54 % deviance for pH, Carbon and Nitrogen (Table. 11). However there were no significant correlations between *Hymenoptera* and other soil parameters of acidity, phosphorous (P) and potassium (K).

Whereas a strong significant negative correlation was observed between soil Nitrogen (N) and the *Isoptera* group, no correlation was observed between this macrofauna group and the other soil parameters of pH, acidity, soil C, P and K., conversely, whereas a significant positive correlation was observed between percentage Nitrogen (N) and earthworms (*Oligochaeta*) group explaining 7.5% of deviance, earthworms (*Oligochaeta*) were similarly not significantly correlated other soil parameters (Table 11). Coleoptera on the other and was not significantly correlated with any of the soil parameters (Table 11).

On assessing observed correlations between selected soil properties and macrofauna abundance, it was noted that the likelihood of sampling Hymenoptera in soils with high soil pH, C and N shrank with an increase of these soil variables. This may explain their being most abundant in natural forest and least in plantation forest. Isoptera abundances were higher in maize based systems and lower in plantation forest with the likelihood of sampling Isoptera in soils with high soil N decreasing with an increase in soil nitrogen (N), while the chances of encountering earthworms (Oligochaeta) in soils increased with an increase in soil nitrogen (N).

Consequently the highest numbers of Oligochaeta (earthworms) were sampled in natural forest that had high N amounts. While significant correlations between some soil macrofauna groups and select soil chemical properties demonstrate that, soil chemical characteristics may directly or indirectly play a role in influencing the density, distribution and structure of macrofauna communities, need exist to demonstrate how macrofauna occurrence, changes in their abundance and diversity associated with land use changes impact on ecosystem functions and how macrofauna functions are beneficial at plot, farm and landscape level in sustaining soil productivity.

Significant correlations between some soil fauna groups with soil chemical properties imply that, apart from direct influence of ecosystem disturbance, cultivation and soil fertility management practices, soil physiochemical characteristics play an important role in influencing density, distribution and structure of macrofauna communities, hence the prospect that these faunal groups are suitable candidates as bio-indicators of soil conditions and related productivity.

From results obtained following analysis within studies in Embu and Taita, it is apparent that variation in macrofauna diversity and densities observed are linked to soil properties, land use type and agricultural intensification For example high copper (Cu) content in soils is attributed to pesticide application in coffee plantations and high Carbon (C) and (nitrogen (N) attributed to undisturbed land in forests and grasslands. Where soils are less disturbed as in plantation, natural forest and napier, high acidity is exhibited. Similarly Iron (Fe) Carbon (C) and Nitrogen (N) are strongly correlated with specific land use types.

In Embu, it was established that macrofauna responded to apparent influence of soil chemical properties, with strong and significant at $p<0.01$ correlation with soil variables of C, Mn and N. While it was observed, that macrofauna correlation to other soil variables was weak.

Abundances of macrofauna groups of (*Coleoptera*, *Hymenoptera*, *Oligochaeta* and *Orthoptera*) varied significantly across land use systems, when these were traced and an assessment made on how they correlated with soil variables. Earthworms (*Oligochaeta*) were positively correlated to both C and N, but negatively to Mn. While *Orthoptera* and *Hymenoptera* are positively correlated to Mn, they are negatively correlated to C and N. On the other hand, *Coleoptera* were weakly correlated with these soil variables.

Likewise in Taita, it was observed that macrofauna responded to influence of soil chemical properties, with some macrofauna responding strongly and significantly correlated at ($p<0.05$) with soil parameters of acidity, C, N, Fe, (pH of ($p= 0.001$), (Mg, ($p=0.02$) while weakly correlated and insignificantly to other parameters such as Ca, Cu, K, Mn, Na, P and Zn. at ($p<0.05$).

On analysis of Eigenvalues of the redundancy analysis (RDA) constrained to environmental (soil) parameters axes generated indicate a redundancy of 5.61 from the total of 34.83 or 16.12% of observed variance of macrofauna abundance, with remaining Principal Components contributing to the remaining variance (83.88) of macrofauna abundance in Embu (Table. 9) and (Figure 8). While in Taita the Eigenvalues of redundancy analysis (RDA) constrained to environmental (soil) parameters indicate a redundancy of 17.55 from a total of 58.72 or 29.89%, about a third of the observed variance on macrofauna abundance, with the remaining Principal Components contributing to the remaining variance (70.11%) of macrofauna abundance (Table 10) and (Figure 9).

In regard to Eigenvalues of the RDA axes data from Taita study site, *Oligochaeta* were positively correlated to N and were abundant in the forest ecosystems, while *Hymenoptera* and *Isoptera* are negatively correlated soil pH, C and N.

In this study, macrofauna groups such of *Chilopoda* and *Isopoda* are abundant in forests and positively correlated to high C, N, and Fe but negatively to high acidity (low pH). The two taxa were preferentially sampled in the forest environment as evidenced by higher numbers sampled in forest ecosystems than in agroecosystem mosaics.

Forests contain thick continuous litter layers resulting in high soil carbon and organic matter, which are the main energy source for soil organisms and soil acidity a condition that does not to favour *Hymenoptera* that in most cases feed on other macrofauna groups such as the *Isoptera*, consequently low numbers of these groups were recorded from forest ecosystems than in the agroecosystems mosaics.

The forest ecosystem has a characteristic low pH and high acidity; high C and N and Fe whereas arable mosaics (agroecosystems) have relatively higher pH levels but low C, N and Fe. Further, plantation forests, particularly *Pinus patula* in Taita have a thick continuous litter layer (about 10 cm) highly infused with fungal mycelia that guarantees high acidity, soil carbon and organic matter, conditions that appear favourable to two macrofauna groups (*Chilopoda and Isopoda*).

Soil health and quality attributes used to determine the productivity index of the land use types are soil organic matter content, soil pH, acidity, nitrogen, phosphorous and potassium utilizing select test crop.

Understanding the cause-effect relationships between these attributes and crop yield is essential not only in developing productivity index of different agro-ecosystems, but also for recommending sustainable management of soils (Aune and Lal, 1997), and having critical limits derived for a given soil under specified land use With the limit defined as the numeric value of soil properties (Lal, 1988).

Soil pH is a measurable soil attribute influencing several other factors responsible for sustaining soil productivity. Soil pH is determined by inherent soil properties, climate and anthropogenic activities. Within the benchmark study sites, pH is mostly low hence requires to be raised to mitigate against negative impacts of soil acidity on plant growth. The trend observed in at the Taita benchmark site was that soil pH increases from steep uplands with natural and planted forest, through lower level hills and foot slopes to bottomlands, while exchangeable acidity decreases.

Soil acidity significantly affects nutrient release hence availability to plants with influence on growth. Low acidity was observed for within napier grass that is almost exclusively maintained by an input of organic nature (manure and compost), but very high within tea plantations that are frequently dosed with inorganic fertilizers. Acidity levels observed match availability and accumulation of chemical bases in the soil with calcium (Ca) levels being high in soils under napier compared to other land uses.

The low capacity of soil to supply nutrients in the study sites is mainly associated with high acidity. Crop performance under acid conditions is limited by deficiencies of such nutrients as N, P, K, Mg, and Mo. This problem is exacerbated by poor nutrient uptake by the roots due to aluminum toxicity, which decreases efficiency with which plant nutrients and water are used, by interfering with growth and physiological functions of the roots (Ryan *et al.*, 1993).

The processes involved in development of acid conditions in the soil have been reviewed by Wong *et al.*, (2004); these processes should be understood in order to identify appropriate intervention and management techniques.

Over ninety (90) % of soil nitrogen is in organic form that is not available to plants unless mineralized to its inorganic form, a function that is performed by soil biota interactions between micro and macrofauna. High nitrogen levels are observed in all land use types in at both study benchmark study sites Embu of Embu and Taita, while soil nitrogen (N) content is high in the indigenous forest, it is low within land planted with maize.

From observations of the Taita study site, soils sampled from most agroecosystems have moderately high nitrogen levels of more than 0.2% soil N over and above the threshold value of 0.02% (Gachimbi and Maitima, 2004). Hence the soils have adequate soil N (Carr, 1971). Therefore despite having sufficient nitrogen levels in soils of all land use types within the study sites, high acidity (low pH) hinders mineralization of nitrogen hence its release and availability to plants.

Within study sites of Embu and Taita, soil carbon (C) content is higher within natural and plantation forests than within agroecosystems, however Embu has much higher soil carbon than Taita particularly within agroecosystems such that in maize fields Embu has twice as about much carbon recorded than in Taita these variation reflect management practices of placing organic manure in farmlands in Embu.
Soil organic matter acts as store for essential elements, and the release of major nutrient elements N, P, and K among others from organic matter, through mineralization processes, is influenced by soil pH through its impact on macrofauna and microbial activities.

While recorded phosphorous amounts within agroecosystems are fairly high resulting from frequent application of inorganic inputs, its availability to plants is curtailed by fixation to Aluminum (Al) and Iron (Fe), further aggravating soil acidity and rendering availability of phosphorous unavailable to plants. The inherent low native Phosphorous (P) status of soils in the upper steep slopes, within the benchmark study sites makes availability of (P) limiting with values as low as 5.33 ppm in planted forest as compared to 53.4 ppm recorded within horticultural fields of Taita in lowlands where it accumulates following leaching in the uplands.

However phosphorous (P) and potassium (K) levels within soils of the Taita site are higher than those recorded within the Embu study site. Other areas with low (P) levels are shrublands and where agrforestry is practiced within the steep mountains, hills, uplands and footslopes. Within the mid level uplands, trends in pH, acidity and (P) change sharply with a very high increase in soil pH. The observation with phosphorous increasing from the uplands to lower lands and can be explained by increase in pH and decrease in acidity.

Since soil phosphorus it is most available for plant uptake at pH values of 6 to 7. When pH is less than 6, plant available phosphorus becomes increasingly tied up as aluminum phosphates, and as soils become more acidic (pH below 5) phosphorus is fixed as iron phosphates, on the other hand when pH values exceed 7.3, phosphorus is increasingly made unavailable by fixation as calcium phosphates.

When Phosphates convert into insoluble compounds they are not readily available to plants under low pH and high acidic conditions, this high P-fixing capacity. High pH can be attributed to increased accumulation of nutrient bases leached from the upper slopes, a trend that can possibly be explained by varying degrees of land degradation including changes in soil macrofauna structures in different ecosystems, hence variations in soil quality, fertility and productivity along the ecosystem intensification gradients.

Influence of soil pH is also apparent in phosphorous availability to plants. Inorganic phosphorus (P) is negatively charged in most soils. Because of its particular chemistry, phosphorus reacts readily with positively charged iron (Fe), aluminum

(Al), and calcium (Ca) ions to form relatively insoluble substances. When this occurs, the phosphorus is considered fixed or tied up. In this regard, phosphorus does not behave like nitrate (NO3-), which also has a negative charge but does not form insoluble complexes. The solubility of the various inorganic phosphorus compounds directly affects the availability of phosphorus for plant growth and is influenced by the soil pH.

Soil toxicity due to increased availability of Fe, Al, Mn and H reduces availability of essential nutrients such as Magnesium (Mg), Calcium (Ca), Phosphorous (P) and Molybdenum (Mo), a severity that increases as pH decreases. In strongly acid soils with pH less than 5.0, aluminum (Al) adsorbed in the colloidal surfaces becomes soluble and toxic interfering with growth, physiological functions and biological processes of roots, with plants affected by low pH having few, short, thickened and dull roots, whose lateral growth is severely affected with dead tips.

The core issue of sustainable land management is soil ecosystem balance and resilience, which in turn depends on the soil structure, i.e. the arrangement of solid parts of the soil and of pore spaces located between them (Marshall and Holmes, 1979) and soil quality. A wide range of soil health quality indicators (e.g. soil activity, presence of beneficial and detrimental organisms) and methods of their determinations are available that can facilitate analysis of soil quality, productivity and sustainability of a given ecosystem (Gafur *et al.* 1999, 2000). However, agroecosystem soil quality is continually being degraded by anthropogenic activity disturbing the environment, through continual tillage and cropping, cultivation on steep slopes without adequate soil physical conservation structures and application of organic and inorganic agricultural inputs, herbicides and pesticides.

With an ever growing human population, food sufficiency is dependent on intensification of agriculture, an intensification which impacts on biological regulation of soil processes that are altered and have to be substituted by chemical inorganic inputs to sustain or increase production. However under the prevailing economic meltdown, most farmers in tropical regions have limited access and ability to purchase inputs despite being forced by prevailing conditions to intensify production. Under such circumstances, maintenance and enhancement of soil biodiversity is particularly critical for increase and maintenance of production with increased intensification.

Land use type and agricultural intensification levels have a significant influence of soil health and quality. Clusters of land use types and level of intensification should therefore be recognized, based on a productivity index, calculated on the basis of quality attributes. The soil characteristics under different land use types are associated with changes in soil quality in response to land use intensification gradients.

It has been established that fertility of soils decrease rapidly following slash-and-burn (Lal, 1987). Burning reduces the amount of organic carbon associated with macro aggregates, and when forests are converted to cultivated cropland, the organic layer is depleted and soil carbon content and cation exchange capacities decrease.

Adverse consequence on soil of continuous tillage without adding any amendments (organic or inorganic) and nutrient mining through continuous cropping are not envisioned as a threat or root cause of poor soils and water quality by small scale peasant farmers, through continuous cultivation and conventional tillage results in the reduction of soil health. It was observed in Australia that crop yield decline was associated with poor soil health, caused by monoculture and excessive tillage.

6.8 Conclusion

The benchmark study sites having been intensively cultivated areas have undergone loss of nutrient bases through leaching and mining, as well as removal through erosion, exceeding the soil's pH buffering capacity resulting from mineral weathering. Hence management strategies to be considered should be to minimize these losses and balance nett gains of alkalinity.

Use of macrofauna as soil quality indicators of extent to which soils are degraded physically, chemically and biologically should be demonstrated to farmers at plot level, within the study sites. Soil organisms with significant functional influence on soil productivity sensitive to changes in soil pH, can be efficient as sensitive indicators to environmental quality and soil biodiversity loss. They can be useful for assessment of within soil interactions and provide necessary information for planning and decision making in biodiversity conservation and sustainable land resource utilization.

Therefore assessment of soil health must be made on carefully selected functional farms, then up scaled. Such soil health assessment exercise will aid researchers and farmers in evaluating impacts of farm practices on cultivated soils and in identifying pertinent characteristics influenced by macrofauna that determine soil health as related to soil productivity and environmental quality.

CHAPTER SEVEN

CONSEQUENCES OF SOIL FERTILITY AMENDMENTS ON EARTHWORM ABUNDANCE AND BIOMASS IN MAIZE BASED AGROECOSYSTEMS TAITA, KENYA.

7.0 Introduction

Earthworms are of universal occurrence with their distribution, density and diversity determined and influenced by soil type, organic matter availability and level of anthropogenic manipulations (Barley, 1961; Boag *et al.*, 1997; Didden, 2001; Edwards and Bohlen, 1996; Edward and Lofty, 1979; Evans and Guild, 1947; Fragoso and Lavelle, 1992; Fragoso *et al.*, 1993; 1997; Hairiah *et al.*, 2001; Lee, 1985; Tischler, 1955; Swift and Van Noordwijk 2001). Earthworms are sensitive to soil physicochemical changes (Blanchart, 1992; Blanchart *et al.*, 1999; Brussaard *et al.*, 1993; Doube and Schmidt, 1997; Hauser, 1994). They are therefore potential candidates of soil quality indication (Oades and Walters, 1994; Scamberger, 1988).

Importance of earthworms in soil processes and their potential use in agriculture are of great interest. Various studies show that they contribute to maintenance of soil structure and regulation of soil organic matter dynamics (Lavelle, 1997; Brussaard 1998). Earthworms' role in enhancing plant growth and production requires that they remain in the same place (synlocation) and that their activities be synchronized with the phase of active root growth and nutrient demand by plants.

To assess the potential of role of earthworms in plant production it is imperative that information on earthworm life history, field population variations, ecological strategies and impact on soil properties along with plant and environmental attributes of climate, soil type, cropping systems and management of the agroecosystems are taken into account (Fragoso *et al.*, 1997). Several studies have been undertaken to evaluate soil quality utilizing earthworms as indicators and impact of anthropogenic activity on earthworms (Daugbjerg, *et al.*, 1988; Hendrix, 1995; Koehler, 1992; Stork and Eggleton, 1992).

Earthworms are sensitive to anthropogenic disturbance, thus natural and anthropogenic factors acting at various scales will affect earthworm diversity. For example, conversion of tropical rain forests to pasture in Mexico, Peru and India, that not only resulted in a great reduction of plant and animal species, but also of surviving earthworm species (Fragoso *et al.*, 1997; Sanchez, *et al.*, 1983; Whitmore and Sayer). This resulted in soil compaction due to massive surface casting by anecic earthworms impacting on soil productivity.

Being detritus feeders, earthworms effect decomposition of organic matter through fragmentation and inoculation with microbial spores (Dangerfield, 1990) the egested fecal matter of macrofauna contains inocula of micro-organisms as has been shown for millipedes (Anderson & Bignell, 1980; Hanlon, 1981) and earthworms (Satchell, 1967). Earthworm biodiversity is modified when forests and natural savannas are converted to agroecosystems, these changes can be studied from a taxonomic or functional point of view (Fragoso *et al.*, 1997).

Some key biological services provided by earthworms impacted upon by anthropogenic activities include lowered residue comminuting and decomposition, carbon sequestrations, organic matter distribution, nutrient cycling, mineralization or immobilization, bioturbation and soil aggregation. The anthropogenic practices affecting these being reduction in crop diversity, residue removal or burning, tillage, pesticide application, irrigation, pesticide application and fertilizer application.

Soil tillage renders earthworm populations susceptible to predation by birds and rodents, by exposing them and negatively impacting on soil faunal communities and biological processes they provide of, placement and distribution of crop residues (Beare *et al.,* 1993; Bowen and Harper 1988; Doran, 1980; Hendrix *et al.*, 1986) and. This in turn affects rate of residue decomposition, (Beare *et al.*, 1992; Broder and Wagner, 1988), carbon sequestration (Holland and Coleman, 1987), nutrient mineralization and immobilization (Beare, *et al.*, 1992).

Intensity of cultivation directly impacts on soil structure, pore size and particulate distribution that indirectly impacts on physical processes in soil of bioturbation and aggregation, through changes in diversity and composition of biological communities (Beare, 1995; Berry and Karlen, 1993; Hendrix *et al.,* 1992).

Pesticide application impacts on target and non targeted groups, affecting composition and diversity of soil biological communities. However effects on non target organisms such as earthworms are not well known, though such pesticide induced changes impact on abundance, composition and structure of soil communities that have important implications on residue decomposition (Hendrix and Parmelee, 1985 Tian *et al.*, 1995), soil bioturbation and nutrient cycling (Sharpley *et al.,* 1979).

Fertilizer application quantities, placement and timing, are known to influence nutrients that may be derived from biological fixation and cycling of nutrients. In case of phosphorous (P), its application to soil stimulates the rate of nitrogen (N) fixation by leguminous plants by enhancing plant root system in contrast to nitrogenous (N) fertilization that slows down nitrogen fixation rates (Giller and Cadisch, 1995, (Giller *et al.*, 1997; Kahindi *et al.*, 1997).

There is a growing concern over adverse effects of agricultural intensification on soil dwelling organisms in agricultural areas worldwide. Agricultural intensification practices in New Zealand are accelerating processes that are a potential threat to the environment, soil biodiversity and sustainability of agricultural production (Rowarth, 2008).

Soil biodiversity is influenced by these changes at various spatial scales ranging from local to regional. At field scale greatly simplified agro-ecosystems have had an impact on below ground fauna (Swift, 1987; Swift *et al.*, 1994; 1996). On the other hand landscape heterogeneity in land use mosaics resulting from varying local management practices influences macrofauna species richness and abundance (Decaëns and Jaménez, 2002; Fragoso *et al*, 1997; 1999).

This study was undertaken to determine likely impacts of adding soil fertility amendments namely *Trichoderma* (a soil dwelling fungi with biocide properties), Manure (cow dung) and inorganic fertilizers of Triple Super Phosphate (TSP), Mavuno (Nitrogen phosphate compound), and Calcium Ammonium Nitrate (CAN) on soil dwelling earthworms within experimental plots at the Taita BGBD bench mark site.

Trichoderma are most prevalent of soil fungi whose species are frequently isolated from forest and agricultural soils at all latitudes, with their dominance attributed to their diverse metabolic ability (Eland, 2000; Haran *et al.*, 1996a; 1996b). While Trichoderma can suppress pathogenic fungi, such as *Rhizoctonia* and *Pythium* that cause, seed, root, stem and fruit rot, *Trichoderma* is completely natural and non-toxic to plants, humans and animals. Seed treated with *Trichoderma* species resist pre-germination rot, have a reduced germination period and improved germination rate, as demonstrated by (Altomore *et al.*, 1999; Chet, 1987, 1993; Eland and Kapat, 1999; Grabeva *et al.*, 2004; Hjeljord and Tronsmo, 1998; Howell *et al.*, 2000).

Fast germination, vigorous plant growth accompanied by improved disease resistance in crops is an important factor in productivity.

Following a general macrofauna survey within the Taita benchmark site, experiments were set up on farmer fields and at the Farmers Training Center (FTC), to assess impact of soil fertility practices on earthworm abundance and biomass. The objective of this study was to evaluate impact of soil fertility amendments on abundance/ densities and biomass of earthworms in maize based agroecosystems.

7.1 Materials and methods

Treatments were utilized in experimental assessment of soil amendments included, local isolates of *Trichoderma*, Manure (cow dung), Triple super phosphate fertilizer (TSP) of 40% phosphate, Calcium Ammonium Nitrate (CAN) of 46% nitrate, Mavuno, (Nitrogen Phosphate inorganic fertilizer with soil liming qualities), Nitrogen Phosphate potassium composite (NPK of ratio 23:23:0). These were used singly or in combination to make up six experimental treatment types and a control (Table 12) and rates of application (Table 13).

Table: 12. Soil amendments used in on farm experiments

	Farmer Test Strip	Farmers Training Center
AMENDMENTS	CON	CON
	MAN/TRI	MAN/ TRI
	MAV/TRI	MAV/TRI
	MAV	MAV
	TSP /CAN	TSP/CAN
	TRI	TRI
	MAN	MAN

Key- CON-Control, CAN-Calcium Ammonium Nitrate; MAN-Manure; MAV-Mavuno; TRI-Trichoderma; TSP- Triple Super Phosphate.

Table: 13. Amendment application rates

Amendments	Application rate /m^2	Rate per acre Kgs
CAN	78 gms	315 Kgs.
MAN	500 gms	2024 Kgs.
MAV	78 gms	315 Kgs.
TRI*	seed coating	2gms/ kg of seed
TSP	90 gms	364 Kgs.
CONTROL	Nil	Nil

*note *Trichoderma* formulation was $3.0x10^8$ of colony forming unit

Key: CAN- Calcium Ammonium Nitrate; MAN-Manure; MAV-Mavuno; TRI-Trichoderma; TSP- Triple Super Phosphate; Control Nil application. (TSP/CAN amounts are the KARI recommended farmer practice)

7.1.1 *Experimental design*

Split plot experimental design was adopted and for each experimental plot on Farmer Fields was replicated five and those at the Farmers Training Center replicated twelve times, making a total of 119 plots. In case of amendment mixtures such as Triple Super phosphate (TSP)/Calcium Ammonium Nitrate (CAN) the amendments were applied in succession. Mavuno, dry cattle manure, *Trichoderma* was applied as a dry seed dressing.

7.1.2 *Sampling for earthworms*

Earthworms were sampled following methods as described by (Anderson and Ingram, 1989; 1993; Swift and Bignell, 2001; Moreira *et al.*, 2008). A monolith was extracted from all experimental plots and hand sorted, with all earthworms encountered collected and narcotized in 40% acohol, then immediately fixed in 4% formalin, before storage in 70% alcohol. These are curated at The National Museums of Kenya, Invertebrates Section.

7.2.3 *Data collection and processing*

Earthworm sampling data of absolute numbers (for abundance) and fresh weight (for biomass) were captured in excel prior to normalization and overall analysis. Mean abundances (individuals' m^{-2}), were computed from total replicates of each treatment, while conversion of biomass (g $m^{-2)}$ was by multiplication of mean body mass of treatment type data computed density for each treatment weight and transformed by square root (Dangerfield, 1990).

7.2.4 *Statistical analysis*

A log (n+1) transformation, of the data normalized the frequency distribution and subsequent Quantitative one way ANOVA analysis and synthesis with post-hoc multiple comparison test of significance t-test at 95% confidence limits were done for abundance (individual's' m^{-2}) and biomass (g $m^{-2)}$ for each agroecosystem.

7.3 Results

7.3.1 Earthworm Densities

Earthworm densities were computed to eleven ($11m^{-2}$) individuals per square meter

Table: 14. Farmer Fields Earthworm density analysis

SUMMARY

Treatments	*n*	*Sum*	*mean*	*Variance*	*SD*	*SE*
Trichoderma	5	65.605	13.121	6.3265	2.5152	1.1248
MANURE	5	54.901	10.980	3.9008	1.9750	0.8832
CAN/TSP	5	76.844	15.368	25.7464	5.0740	2.2692
TRIC/MANU	5	60.758	12.151	5.43019	2.3302	1.0421
CONTROL	5	76.505	15.301	16.4266	4.0529	1.81254
MAVUNO	5	80.320	16.064	28.1989	5.3102	2.37482
MAV/TRIC	5	74.167	14.833	19.01873	4.3610	1.95031

P-value

0.33387

Table: 15. Farmers training Center (FTC) Earthworm density analysis

SUMMARY

Treatment	*n*	*Sum*	*mean*	*Variance*	*SD*	*SE*
TRICODERMA	12	119.961	9.9968	33.48716602	5.7868	1.6705
MANURE	12	105.151	. 8.7626	30.39728386	5.5133	1.5915
CAN/TSP	12	101.250	8.4375	46.01321728	6.7833	1.9581
TRIC/MANU	12	120.281	10.0234	37.51460327	6.1249	1.7681
CONTROL	12	98.985	8.24876	46.28991815	6.8036	1.9640
MAVUNO	12	107.959	8.99665	32.92027769	5.7376	1.6563
MAV/TRIC	12	103.700	8.64173	57.34151838	7.5724	2.1859

P-value

0.91877

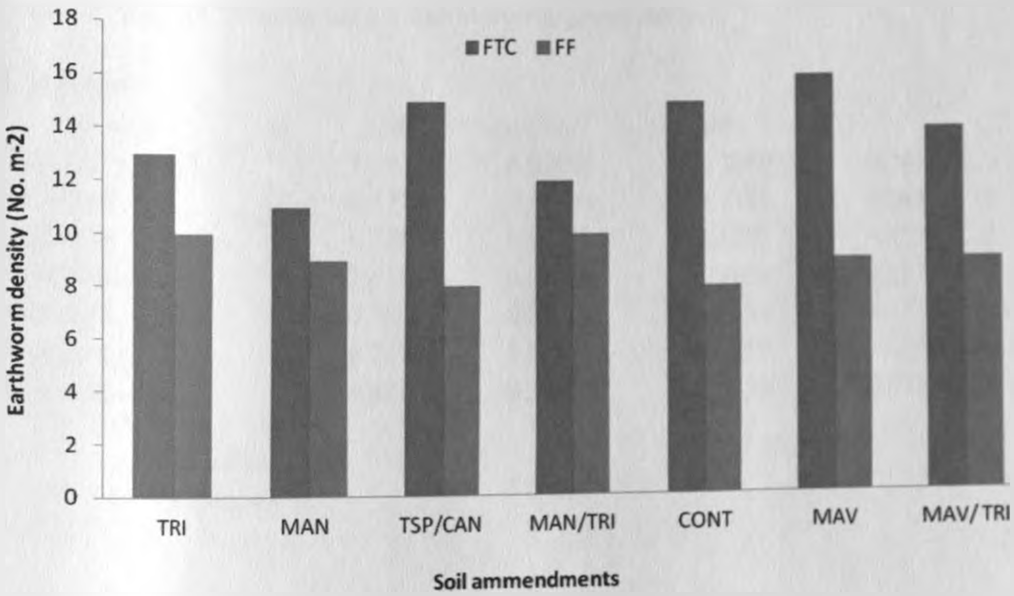

Figure: 12. Earthworm densities on farmer demonstration experimental plots

7.3.2 Earthworm Biomass

The mean biomass of earthworms in experimental plots is 9.5g gm^{-2}.

Table: 16. Farmers Fields Earthworm biomass analysis

SUMMARY

Groups	*n*	*Sum*	*Average*	*Variance*	*SD*	*SE*
Trichoderma	5	17.469	3.4938	5.9103	2.43111	1.08722
Manure	5	279.507	55.9014	1513.044	38.89787	17.3956
CAN/TSP	5	15.7853	3.1570	4.860752	2.20471	0.98597
Manure/Trichoderma	5	16.1457	3.2291	2.91124	1.7062	0.76305
Control	5	21.523	4.3046	9.01670	3.00278	1.34288
Mavuno	5	27.145	5.4290	10.75245	3.27909	1.4664
Mavuno/Trichoderma	5	434.321	86.8642	2752.62	52.4655	23.4632

P-value
0.45645

Table: 17. Farmer Training Center Earthworm biomass analysis

SUMMARY

Groups	*n*	*Sum*	*Average*	*Variance*	*SD*	*SE*
TRACODERMA	12	7.49761	0.62480	0.13080	0.36167	0.104
MANURE	12	6.57199	0.54766	0.1187	0.34458	0.099
CAN/TSP	12	6.32815	0.52734	0.1797	0.42395	0.122
TRAC/MANU	12	7.51756	0.62646	0.14654	0.38280	0.110
CONTROL	12	6.18657	0.51554	0.18081	0.42522	0.122
MAVUNO	12	6.74749	0.56229	0.12859	0.3586	0.103
MAV/TRAC	12	6.48129	0.54010	0.22399	0.47327	0.136

P-value
0. 79347

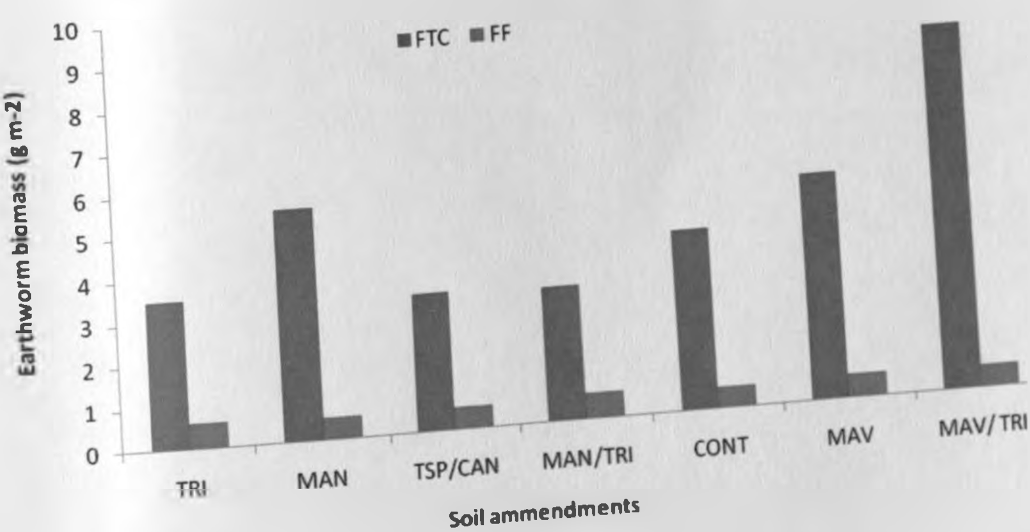

Figure: 13. Mean Earthworm biomass gm^{-2} in experimental plots

7.4 Discussion

An analysis of variance (ANOVA) showed no significant between differences in earthworm abundance in Farmer Fields at p >0.05) and Farmers Training Center, (p >0.05) Similar tends are observed for biomass.

There was no significant difference of earthwom densities between treatments at the Farmers training Center (FTC) taking into account the significance (P) values. There is visible clustering with the lowet densities being 10 individulas with manure treated plots and highest observed with mavuno treatment standing at 16 individuals (Fig. 12).

Similarly within farmer fields, there are no significant differences in earthworm densities between and with treatment plots taking into account the significance (P) values and not visible so (Fig. 13). It is noted that *Trichoderma* and *Trichoderma*/Manure combination, have the highest densities with all other treatments having near similar densities.

A similar pattern to that of densities, high biomass values was recorded for *Trichoderma* and Mavuno treatment at $87gm^{-2}$ and manure treatment at $56gm^{-2}$ respectively, with low biomass recorded in all other treatments, the lowest being the control plots within farmer fields at $0.51gm^{-2}$.

As with densities there were no significant differences of earthworm biomass within and between treatments plots. On a comparative basis there was no significant difference between the farmer Fields and Farmers Training Center experimental plots.

Soil fauna are an essential component of soil ecosystems as they drive soil biological processes (nutrient cycling, organic matter transformation, microbial oxidation, respiration, biological nitrogen fixation, and mineralization, humification, decomposition and nutrient retention that contribute to soil fertility enhancement and functioning by increasing amount and efficiency of nutrient acquisition and recycling,

Macrofauna are known contribute greatly to biodiversity in agroecosystems and are important as effective components of natural soil ecosystems (Dangerfield, 1993). It is noted in this study that inoculation of soils with known with micro fauna (in this case *Trichoderma*) that was done with view of determining its efficacy as a bio-fertilizer or bio-pesticide was found to have a significant positive influence on productivity on the maize bean crop production system utilized (Mwangi *et al.*, 2009; Okoth *et al.*, 2009).

Addition of biological amendment *(Trichoderma)*, did not affect abundance (densities) nor biomass of earthworms significantly as shown by results obtained. It seems earthworm may have evolved alongside beneficial soil micro fauna such as *Trichoderma* and are able to tolerate them at concentrations higher than those in nature, since the treatments. Therefore earthworms can be utilized as a vehicle for dissemination and dispersion of beneficial micro fauna within the rhizosphere of arable cropping systems. High earthworm biomass values were realized for *Trichoderma* and manure treatments at $87gm^{-2}$ and $56gm^{-2}$ respectively and low in all other treatments with the lowest being the KARI recommended farmer practice of TSP/CAN with $3.15gm^{-2}$.

Organic mulches enhance earthworm habitat by moderating microclimate and supplying a food source. In Pennsylvania, earthworms were observed to be most abundant in corn plots, not plowed and where corn residues had been chopped and left as a mulch, regardless of whether the plots were organically or conventionally managed (Werner and Dindal, 1990). In Denmark, addition of manure increased earthworm abundance and biomass of certain species (Andersen, 1980), as was also observed at the Rothamsted experiment station long term experimental plots in England that have received manure for over 118 years while application of inorganic fertilizers caused decrease in earthworm populations (Edwards and Lofty, 1974; Edwards, 1983).

It is noted that quality, quantity and placement of organic matter is the main determinant of earthworm abundance and activity in agricultural soils (Edwards, 1983; Lofs-Holmin 1983), as are disturbances of the soil by tillage, cultivation, and the use of pesticides (Doran and Werner, 1990).

Studies on earthworms within the tropics have been fragmentary and incidental to other research albeit being important belowground macrofauna influencing soil properties, quality and function (Blanchart *et al.*, 1992; 1999; Brussaard, *et al.*, 1993; Hauser, 1994), with limited information on their importance within the humid tropics (Bhadauria and Ramakrishna, 1989; Henrot and Brussaard, 1997). Within agroecosystems far apart studies have been carried out (Cook *et al.*, 1980; Lavelle and Pashanasi, 1989). Hence need exists to undertake more research to elucidate relationships between earthworm species diversity and their functional aspects within the soil ecosystem.

Though Management practices including land clearing, litter burning, continuous tillage, monoculture, crop rotation, organic residue inputs, retention or removal and use of agrochemicals inputs to bolster production have been demonstrated to cause alteration of soil fauna population structure, disappearance or reduction of key species and in some cases extremely low abundances and or biomass (Brown *et al.*, 1996; Dangerfield, 1993; Roper and Gupta, 1995; Warren *et al.*, 1987;). Therefore other factors such as food availability and habitat preference may explain differences observed (Castellarini *et al.*, 2002; Uhia and Briones, 2002).

Earthworm populations are significantly depressed in cropped fields relative to pasture or undisturbed lands, in a South African soil, Lumbricid earthworms decreased following cultivation to about one-third of original levels, with species that are able to burrow deeper being less affected, as they are able to escape the zone of disturbance (Reinecke and Visser, 1980). (Mackay and Kladivko (1985), noted that earthworm abundance increased in plots that received disk cultivation and actually doubled in or no-till plots compared with ploughed plots.

Preferential feeding activity of earthworms impacts on fungal populations (Spiers *et al.*, 1986), where these may be controlled or dispersed hence infect a larger root area for benefit of plants as is the case with *Trichoderma* and Vesicular *arbuscular mycorrhizae* (VAM) (Reddell and Spain, 1991). It is noteworthy that intact viable spores have been isolated in earthworm casts from 13 earthworm species in Australia and a vast increase of VAM reported in presence of *Pontoscolex corethrurus* in potted experiments in Peru (Ydrogo, 1994).

While limited research has been done in the tropics on relations between earthworms and microbes (VAM and *rhizobia*) that have significant impacts on plant growth, it is possible that this can be adopted within the tropics. Findings from recent field studies, demonstrate that it is apparent that soil type, land use type and land use management systems influence distribution and abundance of *Trichoderma*, with soil type influencing species occurrence (Okoth *et al.*, 2010).

Soil fauna and earthworms in particular are an essential component of soil ecosystems as they drive soil biological processes (nutrient cycling, organic matter transformation, microbial oxidation, respiration, biological nitrogen fixation, and mineralization, humification, decomposition and nutrient retention) that contribute to soil fertility enhancement and functioning by increasing amount and efficiency of nutrient acquisition and recycling.

7.5 Conclusion

As per results obtained, it is inferred that addition of soil amendments of (Trichoderma, manure, triple super phosphate calcium ammonium nitrate and Mavuno) ostensibly to improve soil fertility and hence productivity, did not have a negative impact on earthworm densities nor biomass. While it is generally accepted that soil macrofauna and earthworms in particular, are an integral part of soil decomposition processes and nutrient cycling their roles are unquantified in agroecosystems.

Therefore earthworms may have evolved alongside beneficial soil microfauna and are able to tolerate them at concentrations higher than those in nature, since the treatments did not negatively impact on them. The tendency for earthworms to show aggregated distribution may have contributed to the high variance in population density estimates observed in this study.

The role of soil organisms in high input agroecosystems has for long received little attention because natural and biologically mediated processes like those regulating soil structure, nutrient supply, pests and disease control have been largely replaced by human inputs (Barios, 2007). This situation should be addressed as it is no longer tenable with the ever increasing costs of production that is unaffordable to rural masses of small holder farmers within the tropics.

CHAPTER EIGHT

8.0 Discussion of findings

Intensive farming practices to feed ever increasing populations have left soils in the tropics severely eroded and degraded, reducing the productive potential of agricultural ecosystems with very little below ground life. This deterioration in soil quality and biodiversity greatly challenges the capacity to maintain subsistence from the land.

Historically studies of soil agroecosystems have focused on biophysical and chemical aspects of crop production, with ecological dimensions of soil systems considered less important. Need therfore exists to develop greater knowledge of soil ecosystems, their biological diversity and ecological functions, in order to build a basis for sustainable land use, as soil fauna are known to provide ecological goods and services that maintain or improve soil productivity.

Adverse consequence on soil of continuous tillage without adding any amendments (organic or inorganic) and nutrient mining through continuous cropping are not envisioned as a threat or root cause of poor soils and water quality by small scale peasant farmers. This is evident with soils in Embu being highly pulverized while compacted in Taita as anthropogenic activities impact on soil particle micro and macro aggregates arrangement. With size, distribution and spatial arrangement of solids and voids, controlling movement of water, nutrients and gases through the soil matrix, that in turn influences' soil fauna activities on organic matter decomposition and aggregate formation.

Within the benchmark study sites of Embu and Taita, diversity and variations in ecosystem structures, relief and topographical characteristics have a significant influence on availability, movement and distribution of water and nutrients in the soil. Terracing on slopes provides a stabilizing effect on water movement hence that of nutrients and acidity checks. Therefore well designed bench terraces are important structures for control of run-off. It is however noted that bench-terraces in the study sites, constructed on very steep slopes have varying degrees of effectiveness in controlling land degradation, depending on their stability as a result of design and maintenance. Apart from interventions that reduce runoff and stabilize soils, there is need to encourage establishment and optimal functioning of soil macrofauna to ensure long term soil quality sustainability and productivity.

Due to all year round availability of water a treasured ecosystem service in Taita mid highlands, where water flowing down the slopes is intercepted and at bottom lands, irrigation has been taken up to produce high value horticultural crops. This has resulted in continuous tillage and use of considerable amounts of inorganic inputs of fertilizers and agrochemicals for control of pests and diseases, to improve on crop quantity and quality to meet market demands which in turn impact negatively on soil macrofauna.

Macrofauna diversity is able to modify soil structure and hydraulic its characteristics that benefit and improve on ecosystem services of water percolation, retention and organic matter translocations. However water use efficiency and appropriate irrigation scheduling, based on optimum cropping patterns, crop water requirements, water uptake and retention capacity of soil are yet to be embraced.

At the benchmark study sites, soil nitrogen levels are generally above the 0.2% threshold values (Gachimbi and Maitima, 2004), hence soils have adequate soil N (Carr, 1971). However, over ninety (90) % of soil nitrogen is in organic form that is not available to plants unless mineralized to its inorganic form a function performed by soil biota interactions between micro and macrofauna. This situation is acerbated by Low pH, (high acidity) and high aluminum toxicity within the study sites impairing nitrification of organic form nitrogen into nitrates that can be taken up by plants (Oka and Wada, 1991).

Soil pH and acidity are determined by inherent soil properties, climate and anthropogenic activities. pH at both study sites is generally below 5, ranging between 3.54 to 4.19 in Embu and 3.06 and 4.93 in Taita. pH is an important determinant in plant acquisition of nutrients, this therefore sheds light on possible underlying limitations to agricultural productivity within the benchmark study sites.

For this, among other reasons, development of integrated soil acidity management is imperative taking into account economic ability of small scale subsistence farmer to be able to correct this shortcoming (Wong, *et al.*, 2004). Since the low capacity of soil to supply nutrients in the study sites is mainly associated with high acidity. Crop performance under acid conditions is limited by deficiencies of such nutrients as N, P, K, Mg, and Mo.

Soil toxicity resulting from decrease in pH leads to increased availability of Fe, Al, Mn and H, which in turn reduces availability of essential nutrients such as Magnesium (Mg), Calcium (Ca), Phosphorous (P) and Molybdenum (Mo), a severity that increases as pH decreases. In strongly acid soils with pH less than 5.0, aluminum (Al) is adsorbed in on colloidal surfaces and becomes insoluble causing toxicity that interferes with plant growth, physiological functions and biological processes of plant roots hence productivity.

Observed nitrogen (N) and carbon (C) levels are much lower in agroecosystems than in natural or plantation forest while the opposite is observed for phosphorous (P), with Phosphorous (P) levels being much higher in agroecosystems than natural and plantation forests. While Phosphorous (P) level variations within the benchmark study sites are very narrow, there are higher phosphorous levels at Taita benchmark study site than the Embu site for similar land use systems.

Solubility of various inorganic phosphorus compounds directly affects its availability for plant growth and this is influenced by the soil pH. Soil phosphorus is most available for plant use at pH of 6 to 7 Soil phosphorous content is observed to increase from uplands to lower lands, and this can be explained by increase in pH (decrease in acidity) increasing (P) solubility. When pH is less than 6, plant available phosphorus is increasingly tied up as aluminum phosphates and as soils become more acidic (pH below 5) phosphorus is fixed as iron phosphates. On the other hand when pH values exceed 7.3, phosphorus is increasingly made unavailable by fixation as calcium phosphates.

So as agricultural production further intensifies it is imperative that research is focused not on coarse (functional groups) but on finer (species) taxonomic levels to be able to unravel more subtle changes that occur gradually at species level.

8.1 Conclusion

Management of soil erosion degradation process of continual tillage is an important aspect to be embraced taking into account steep slopes that dominate the relief of Embu and Taita study areas. Along with soil conservation, emphasis should be placed on identifying and demonstrating practices that increase water uptake and retention capacity of soils that will enhance ecosystem service should be within the benchmark study sites.

Findings on soil chemical characteristics within this study are imperative in elucidation of changes in soil biological communities and ecosystem goods and services that soil macrofauna avails in various land use types, natural and agroecosystems. These may shed light on possible underlying limitations to agricultural productivity within the benchmark study sites and used as a precursor to possible interventions that can be instituted to remedy the situations.

Since soil organisms with significant functional influence on soil productivity are sensitive to changes in soil pH, they can be utilized as efficient and sensitive indicators to soil and environmental quality. They can be very useful for assessment of within soil interactions, providing necessary information for planning and decision making in biodiversity conservation and sustainable land resource management.

As sustainable land-use practices that integrate extractive resource use with biodiversity conservation are key to mitigating impacts of agricultural intensification in modified landscapes. Need exists to establish long term field trials at the benchmark study sites to evaluate significance of agricultural intensification on macrofauna and ecosystem functions they contribute to at temporal and spatial scales. This is crucial in understanding how biological populations respond to ecosystem characteristics and management practices, as influenced by land use conversion, and intensification.

Such a soil health assessment exercise can assist researchers and farmers in evaluating impacts of existing and new farm practices on cultivated soils and in identifying which pertinent characteristics influenced by macrofauna to determine soil health as related to soil productivity and environmental quality.

8.2 Challenges in studying Below Ground Biological Diversity

During the study period, the weather was unpredictable with delay in rains and being sub normal hence influencing the sampling regime. That different soil functional groups were being worked on simultaneously resulted in logistic challenges just as the sampling methods.

The volume of soils to be sifted through was enormous and tedious needing constant close supervision of field assistants. Several shortcomings called for improvisation and innovation that slowed down the working pace significantly. Despite the challenges a working team on below ground soil biodiversity in Kenya emerged.

Terrestrial ecosystems consist of producer and decomposer subsystems that are interdependent, as both involve consumer organisms and as a result ecosystems include both a herbivore-focused food web located largely aboveground and a detritus-based food web below ground. Primary producers (above ground) are the principal source of organic carbon for the combined system, with decomposers in the soil being responsible for breakdown of organic matter, release and cycling of nutrients.

An understanding of ecosystem functioning therefore requires an explicit consideration of both subsystems, as interactions occurring within as well as between these food webs, plays a major role in determining how they function. Most ecological work on aboveground organisms has traditionally been conducted without consideration of belowground organisms, similarly most soil biology has been undertaken without much acknowledgment of interactions and mechanisms occurring aboveground, with plants seen by soil scientists merely as sources of carbon addition to the soil (Wardle 2002).

The soil being a "black box" whose contents and activities can at most be imagined or inferred in a generalized likelihood within terrestrial ecosystems, as soils contain by far the greatest diversity of organisms present, with majority of organisms being invertebrate macrofauna, spending at least a portion of their life cycle belowground. Despite a vast assemblage of organisms below ground, the majority are yet to be described despite their functions contributing immensely to life on earth (Lavelle, 1996; Altieri. 1999; CBD, 2001).

Notwithstanding functional role of belowground organisms in ecosystem processes, most of the current body of ecological theory on soil dwelling organisms is based on synthesizing data and information generated by above-ground ecologists, Currently publications on above ground and below ground are done exclusively in different journals with authors rarely reading those of the other discipline, hence not surprising to find that what may be hailed as a break through by one discipline has for long been common knowledge for the other sub discipline.

Therefore soil macrofauna among other BGBD research is central to meeting challenges of conservation and sustainable management of natural resources for sustainable development. Since interactions between soil organisms, landscape characteristics and land use and management practices, integrated with farmers' perceptions of Below Ground Biology Biodiversity (BGBD) can form an integral part of decision support tools for identification of appropriate strategies for sustainable management of land resource base including BGBD itself.

Future research must therefore focus on describing native species, their role and interaction with or replacement by exotic species belonging to the same or to a different ecological group in soil function and agroecosystem productivity

Information on species diversity and preferred habitat will be useful when considering policies on introducing soil biodiversity for agricultural management, integrated soil fertility, pest management, soil improvement and degraded site reclamation.

NINE

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