

**INFLUENCE OF INDIGENOUS TREES ON SOIL  
MACROFAUNA AND SOIL ORGANIC MATTER  
DYNAMICS IN TROPICAL MIOMBO WOOLANDS**

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**A THESIS SUBMITTED IN FULLFILMENT OF THE REQUIREMENTS FOR  
THE AWARD OF THE DEGREE OF DOCTOR OF PHYLOSOPHY IN SOIL  
SCIENCE**

**DEPARTMENT OF LAND RESOURCE MANAGEMENT AND  
AGRICULTURAL TECHNOLOGY**

**FACULTY OF AGRICULTURE**

**COLLEGE OF AGRICULTURE AND VETERINARY SCIENCES**

**UNIVERSITY OF NAIROBI**

**NOVEMBER, 2015**

## DECLARATION

This study is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with my/our approval as University supervisors.

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## **DEDICATION**

To my parents Mr. and Mrs. Joshua Chumo, who deprived themselves of the comfort to make sure I went to school.

To my wife Juliana, you have been my support and encouragement.

To my daughters, Ruth, Phoebe, Deborah, Hope and Esther, you provided a peaceful studying environment.

## **ACKNOWLEDGEMENT**

The study was supported by World Agroforestry Centre in collaboration with the University of Nairobi and I thank the two institutions for the support. I also take this opportunity to express my thanks to my supervisors Prof. Nancy Karanja and Dr. Fredrick Ayuke (University of Nairobi) and Dr. Edmundo Barrios and Dr. Keith Shepherd (World Agroforestry Centre Nairobi) for their tireless efforts to peruse through this thesis and for their constant expert guidance, advice and support throughout all the stages of the research work. Special thanks go to Ric Coe, and Andrew Sila for their contribution in the statistical analysis. Many thanks go to ICRAF SD1 and SD4 staff for their support during the entire research period. I am indebted to Mercy Nyambura, John Nyaga, Solomon Kamau, Elvis Weulow and Lukelysia Nyawira for their support and assistance during laboratory analysis. My gratitude also goes to ICRAF library staff for allowing me to use the library facilities and always being there for me throughout the entire research period. I would wish to express my special appreciations to AfSIS for allowing me to use their Kiberashi Sentinel Site for my study and CIAT staff Arusha office for their assistance in obtaining the Tanzania soil permits. I also thank Kilindi District Agricultural, Irrigation and Cooperatives Officer and the local Government officers for granting me the opportunity and freedom to carry out the study in Kibirashi and Kisangasa Wards, Kilindi District. To my family, a lot of thanks for their encouragement and support during the entire research work. Above all, I thank the Almighty God for granting me sufficient strength and grace to accomplish this study.

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## **ABBREVIATIONS AND ACRONYMS**

AE	Agro-ecological
AfSIS	African Soil Information Service
AIC	Akaike Information Criterion
AMF	Arbuscular Mycorrhizal Fungi
At	Ant
Bt	Beetle
C	Carbon
CIAT	International Center for Tropical Agriculture
Cp	Centipede
Ew	Earthworm
FAO	Food and Agricultural Organization
ICP	Inductively-couple plasma spectroscopy
ICRAF	International Centre for Research in Agroforestry
iPOM	Intra-aggregate Particulate Organic Matter
Kg	Kilogram
LM	Large Macroaggregate
LSDF	land Degradation Surveillance Framework
m	microaggregates
mM	microaggregates within Macroaggregates
MIR	Mid infrared diffuse Reflectance
mm	Millimeter
Mp	Millipede
MWD	Mean Weight Diameter
N	Nitrogen

NIR	Near Infrared
PCA	Principal Component Analysis
S+C	Silt and Clay
SM	Small Macroaggregate
SOM	Soil Organic Matter
TC	Total carbon
Tm	Termites
TM	macroaggregate
μ	Micron

## GENERAL ABSTRACT

Studying the interactions between the trees and the soil macrofauna would provide an insight into the activities and functions that take place below and above ground under the tree canopies.

Objective of this study was to evaluate the effects of indigenous trees on soil macrofauna and soil organic matter dynamics in miombo woodland. Soil macrofauna study was conducted at the Kiberashi Sentinel Site, Tanzania, following the Land Degradation Surveillance Framework nested sampling design across a total area of 100 square kilometers. A total of six-hundred and forty monoliths were excavated and collected, soil macrofauna separated by hand sorting, and soil samples prepared for spectroscopic analyses. Organisms were identified into main taxa.

Focus group discussion and key informants interviews were conducted, where information on influence indigenous trees on the spatial and temporal distribution of soil macrofauna were collected. Furthermore, farmers identified trees that were beneficial to crop production, improve soil fertility and those that influenced soil macrofauna distribution. Five dominant indigenous tree species, *Acacia seyal* Delile, *Albizia amara* Boivin, *Combretum molle* R. Br. ex G. Don, *Dombeya rotundifolia* Planch and *Vangueria infausta* Burch were selected and abundance of soil macrofauna, soil aggregates fractions and carbon contents under these trees determined. The area around each tree was subdivided into four concentric zones: 0-2m from the trunk (the first monolith) (zone A), from 2 m to half diameter of the crown (zone B), from half diameter to the edge of the crown (zone C), and from the edge of the crown plus half diameter of the crown (zone D). Two trees were selected from these five tree species based on the quality of their residues for a microcosm study. *V. infausta* (high quality) and *D. rotundifolia* (low quality) residues were used in the microcosm study with the following treatments: *Pontoscolex corethrurus* were introduced into microcosms, each with two kilograms of luvisols soils mixed with the residues as follows and in the treatment and each replicated thrice: 100% *V. infausta*, 75% *V. infausta*+25% *D. rotundifolia*, 50% *V. infausta*+50% *D. rotundifolia*, 25% *V. infausta*+75% *D. rotundifolia*, 100% *D. rotundifolia* and control with no residues applied. Earthworm cast aggregate stability was assessed by wet-sieving and separated into three aggregates groups i.e. Total macroaggregates (>250  $\mu\text{m}$ ), microaggregates (53 – 250  $\mu\text{m}$ ) and silt+clay, and then further fractionated into

microaggregate within macroaggregate and silt+clay within macroaggregate size fractions to assess aggregate composition and carbon distribution.

The study revealed that, key agroecological variables (land use and soil moisture) and soil properties (total C, clay content, pH, available P and exchangeable bases) influenced significantly the abundances of soil macrofauna., *A. seyal* increased significantly the abundance and biomass of millipedes and termites and influenced significant increase in quantities of total macroaggregates and mean weight diameter of the soil aggregates, while *C. molle* and zone increased significantly microaggregates and microaggregates within macroaggregates quantities. On the other hand, *A. seyal* increased significantly the contents of carbon in whole soil and total macroaggregate, with total carbon contents decreasing with increase in distance from the tree trunk. Correlation analysis showed that there was significant correlation between millipedes and termites with total macroaggregates, mean weight diameter and total carbon contents in total macroaggregates, microaggregates and microaggregates within macroaggregates. *V. infausta* residues fed to the *P. corethrurus* led to high quantities of cast and cocoon produced, while *D. rotundifolia* residues fed to the earthworms influenced quantities of microaggregates and microaggregates within macroaggregates as well as increased the contents of total carbon in microaggregates within macroaggregate.

Therefore use of *A. seyal* and *D. rotundifolia* as agroforestry trees in farmers' fields will play great roles in influencing millipedes and termites' abundances, improve soil structure and carbon sequestration.

## CHAPTER ONE

### 1.0 INTRODUCTION

#### 1.1 Background information

Agriculture represents the most common form of human-environment interaction as it consumes more natural resources than any other human activity (FAO 2007). Agricultural landscapes contain a number of land uses and management practices that generate a considerable variation in soil characteristics, including tree cover that influences soil organic matter (SOM) flows and dynamics, ultimately impacting on soil biodiversity and function, thus affecting soil fertility. Soil fertility is a measure of the ability of soil to sustain satisfactory crops' growth in the long-term and is the result of physical, chemical and biological processes intrinsically linked to soil organic matter content as key indicator of soil quality (Bot and Benites, 2005). Soil organic matter influences soil physical, chemical and biological properties, and the amount of SOM is affected by agricultural management strategies such as agroforestry (Barrios *et al.*, 1996a, 1997), crop rotation, tillage, and stubble management (Bunemann *et al.*, 2006). Soil fertility in small holder farming systems is being depleted because of continued nutrient mining without adequate replenishment (Hartemink, 2003), and this problem is further exacerbated by soil erosion on steep slopes under agriculture. In addition, the disappearance of long fallow periods in predominant shifting cultivation systems has also contributed to soil fertility decline (FAO and African Centre for Fertilizer Development, 1999).

Soil function is controlled by a suite of hierarchically organized determinants which include climatic factors (moisture and temperature); edaphic parameters (nature and abundance of clay minerals and overall nutrient richness in the soil) and quality of

organic matter produced, the relative importance of which depends on the scale at which they operate (Lavelle and Spain, 2001). Agroforestry practices affect soil functions while acting on these determinants and in turn affect soil macrofauna. Trees, within their zones of influence, foster hotspots of biological activity through carbon inputs, recycling of nutrients from soil depth and buffering microclimatic conditions (Barrios *et al.*, 2011) (Figure 1). The particular trophic and microclimatic conditions (shade, deep and perennial root systems, and the quantity and quality of litter) (Tian *et al.*, 1995; Vohland and Schrot, 1999) in the proximity of trees may significantly influence the soil macrofauna community and lead to single-tree effects on their distribution (Blair *et al.*, 1990). The challenge in such a system is to develop ways of maintaining soil macrofauna which in turn contribute to processes such as maintenance of soil structure, incorporation of organic materials into soil matrix and release of nutrients and therefore restore degraded soils (Brussaard *et al.*, 2007).

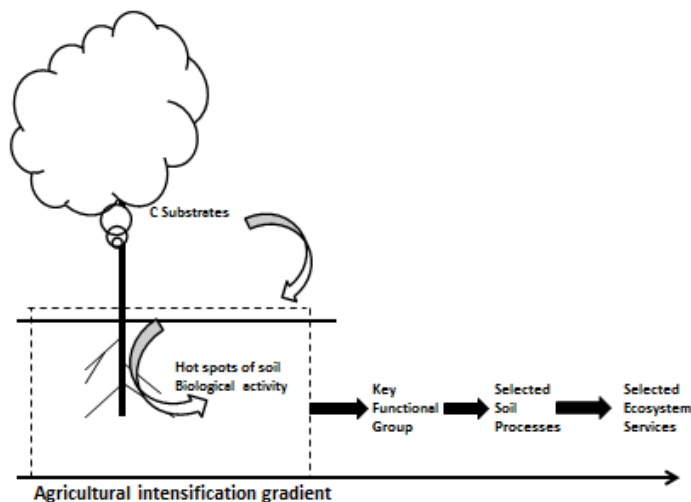


Figure 1: Conceptual model of trees as hotspots of biological activity and their influence on soil processes and soil based ecosystems services in agricultural systems and landscapes

In cereal-legume rotations where stubble is retained, SOM levels are maintained or increased, whereas tillage and stubble burning practices lead to SOM losses particularly under continuous cereal cropping. Organic residue incorporation into the soil allows SOM to accumulate in soil aggregates, thus increasing soil organic carbon and nitrogen contents (Tisdall and Oades 1982, Six *et al.* 1998). Organic matter protection in many soils results from the architectural packing system during formation of microaggregates, which encloses colloidal-sized particles of organic matter with minerals creating pores that are filled with organic matter. These minerals serve as physical protective barriers of organic matter from degradation (McCarthy *et al.* 2008). The microaggregate structure is such that SOM is protected from decomposition by microorganisms (Beare *et al.* 1994), and any disruptions by operations such as tillage will breakdown macroaggregates into microaggregates thereby releasing coarse intra-aggregate particulate organic matter thus resulting in a faster decomposition rate and subsequent loss of these particles (Six *et al.* 1998; 2004). Various options have been put in place to mitigate the declining trend in soil fertility. These include: increased nutrient inputs through the use of inorganic fertilizers (Smaling, 1993), use of organic resources and the combined use of organic resources and inorganic fertilizers (Vanlauwe, 2004; Ayuke *et al.* 2011b). Further, the use and management of beneficial soil organisms like nitrogen-fixing bacteria (Giller, 2001); soil macrofauna (e.g. earthworms, termites, ants) (Fonte *et al.* 2009) and arbuscular mycorrhizal fungi (Rillig *et al.* 2001) have also contributed to improve soil fertility particularly as part of agroforestry systems. Agroforestry systems, understood as the interaction of trees and agriculture, have increasingly received attention as land management systems to reverse the soil fertility decline by promoting soil biological activity, increased nutrient recycling and greater resource use efficiency (Barrios *et al.*

2005). The challenge in such a system is to develop ways of sustaining soil macrofauna which in turn contribute to processes such as maintenance of soil structure, incorporation of organic materials into soil matrix and release of nutrients and therefore restore degraded soils (Brussaard *et al.* 2007). Restoration of degraded soil would then lead to improved agricultural productivity through beneficial soil ecosystem services. The ability to study this variation in space as well as time will greatly enhance capacity to understand the linkages between land use intensity, biodiversity, and soil health.

## **1.2 Statement of the problem statement**

As agricultural intensification occurs, the regulation of functions through soil biodiversity is progressively replaced by regulation through chemical and mechanical inputs (Barrios, 2007). Both chemical fertilizer usage and tillage have significant negative impact on soil macrofauna (Lavelle and Pashanasi, 1989; Fernandes *et al.* 1997).

In slash and burn agriculture, very few trees are left standing and the mulch/litter layer is essentially eliminated, soil is subjected to high temperatures thus resulting to decline or death of soil macrofauna (Fonte *et al.* 2010). The bare soil is subjected to high sun's radiation exacerbating soil biota further decline leading to soil fertility decline.

The effect of various agronomic practices (organic and inorganic fertilizer use, mulching and crop rotation) on soils under conventional agriculture has been shown to promote changes in soil macrofauna communities (Ayuke *et al.* 2011a). Such studies target soil macrofauna at the plot scale, while little is understood about soil macrofauna density, diversity and activity in agroforestry systems especially when moving beyond the plot scale to the farm and landscape scales. Furthermore, there is

limited information about the effect of trees on the spatial distribution of soil macrofauna activity as part of agricultural systems and landscapes.

This study was undertaken to understand how indigenous tree species affect soil macrofauna distribution, soil organic matter and nutrient dynamics and hence useful for sustenance of soil macrofauna.

### **1.3 Objectives**

#### **1.3.1 Broad objective**

To evaluate the effects of indigenous trees on soil macrofauna and soil organic matter dynamics in miombo woodland.

#### **1.3.2 Specific objectives**

- 1) To assess the effect of trees on soil properties and soil macrofauna abundance and their spatial distribution in miombo woodland
- 2) To evaluate farmers' local knowledge on indigenous trees, soil macrofauna and their interaction in miombo woodland.
- 3) To evaluate the effect of indigenous tree species on soil macrofauna and soil organic matter and nutrient dynamics in miombo woodland
- 4) To assess the effect of residue quality on the physical stability and carbon storage of earthworm casts

### **1.4 Research questions**

1. i) What is the effect of tree species on soil properties and how these affect soil macrofauna abundance, diversity and spatial distribution?

2. i). What are farmer perceptions about the effect of indigenous tree species on the spatial and temporal distribution of soil macrofauna abundance?
- ii) According to the farmers, what are the key factors that affect distribution of soil macrofauna?
- 3(i) What are the effects of indigenous tree species on soil litter cover, soil carbon storage and soil macrofauna abundance and diversity?
- ii) Which attributes characterize those indigenous tree species that promote or those that negatively affect soil macrofauna activity and soil carbon storage?
4. What are the effects of indigenous tree residue quality consumed by earthworms on the physical and chemical characteristics of the casts they produce?

### **Outline of the thesis**

This thesis is composed of eight chapters. Chapter 1 covers the general introduction, problem statement and the objectives of the study. Chapter 2 covers the general materials and methods, while chapter 3 covers literature review. In chapters 4-7, the results of the research were presented as individual papers that will be submitted to different journals. These chapters provide a chronological overview of the current research with focus on increasing details from the landscape scale to the microcosm level.

Chapter 4 examines how agroecological factors (trees, landuse and soil moisture) and soil properties (soil texture, total C, available P, soil pH, exchangeable Al and exchangeable bases) affects spatial distribution as well as associations of soil macrofauna in landscape scale. Chapter 5 describes farmers' local knowledge on soil macrofauna in their farms, the trees and management systems that affect the

distribution of soil macrofauna. Five of the trees species identified in this chapter, growing as single trees in farmers' farms were used in chapter 6.

Chapter 6 examined how individual tree species (*A. seyal*, *A. amara*, *C. molle*, *D. rotundifolia* and *V. infausta*) and distance from tree trunk (zone) influenced the distribution of soil macrofauna as well as the individual tree species interaction with soil macrofauna influencing aggregates stability, carbon storage and soil properties around the trees species.

Chapter 7 describes a microcosm study where *P. corethrurus* were fed with varying proportions of residues from two selected tree species (*D. rotundifolia* and *V. infausta*) and how these affected cast quantities produced, cast stability and carbon storage of the cast produced.

Chapter 8 provides general discussions of the study described in chapters 4-7 against the background of existing theories and concepts.

## CHAPTER TWO

### 2.0 GENERAL MATERIALS AND METHODS

#### 2.1 Study site

The study was conducted at the Kiberashi Sentinel Site located in Tanzania, between Latitude 5°18'S and 5°23'S and longitude 37°26'E and 37°30'E and at an altitude of 1000 m above sea level (Amani Forest Inventory and Management Plan Project, 1988; National Bureau of Statistics and Tanga Regional Commissioner's Office , 2008). The area is underlain by crystalline rocks with the prevailing rock being gneiss and mixed biotite and hornblende. Soils are well drained, moderately deep to deep, dark reddish brown, yellow red or red sandy loams and sandy clays (rhodic luvisol) (FAO/UNESCO, 1988) with weak or moderate structure and low natural fertility. In the valley bottom they are deep, while on the ridges they are shallow with extensive rock outcrops (Pauw, 1984; Mlingano Agricultural Research Institute, 2006). Rainfall is bimodal with long rains usually occurring from March to May and short rains from October to December with a mean annual rainfall of 1000 mm. The mean maximum temperature is 24 °C, while mean minimum temperature is 19 °C (National Bureau of Statistics and Tanga Regional Commissioner's Office, 2008).

The Kiberashi sentinel site falls within the Miombo woodlands which represent (93.2%) of the total forest cover in Tanzania. Miombo woodlands are dominated by indigenous trees and shrubs which are also found scattered in areas converted to farming. Some of the dominant indigenous trees found in the site include: *Acacia tortilis*, *A. nilotica*, *A. seyal*, *Albizia amara*, *Albizia anthelintica*, *Albizia harveyi*, *Brachystegia mycrophylla*, *Combretum molle*, *Commiphora africana*, *Dalbergia melanoxylon*, *Dombeya rotundifolia*, *Erythrina burtii*, *Euclea divinorum*, *Ficus*

*exasperator*, *Ficus thonningii*; *Grewia bicolor*, *Juliberardia globiflora*, *Kigelia africana*, *Markhamia obtusifolia*, *Lannea shweinfurthii* and *Vangueria infausta* (Mbuya *et al.* 1994).

## **2.2 Reasons for choosing the study site**

The African Soil Information Services (AfSIS) was developing a map for characterizing the soil condition across the continent. The service was to identify the risk of soil degradation, how to prevent it and how land could be restored where soil fertility was already depleted. AfSIS took the advantage of recent advances in digital soil mapping, remote sensing, statistics and soil fertility management to analyze the various alternatives to protect and rehabilitate soil. Their project has also been testing a variety of farming techniques in an effort to discover the most effective methods to suit a wide range of conditions and situations. The data collected was to be used for addressing issues of food security, environmental degradation, and climate change in Sub-Saharan Africa (Vagen *et al.* 2010). The AfSIS project addressed various aspects of soil microbiology and little of soil macrofauna.

The study area was chosen because: i) No study on interaction of soil macrofauna with trees has been done in the site; ii) AfSIS had chosen the Kiberashi sentinel site as a pilot site to generate a large soil and habitat characterization database and this was available for use while doing this study; iii) AfSIS had set their study sites based on the degree of degradation and Kiberashi site is one of the sites with medium level of degradation ( Vagen *et al.*, 2010); iv) AfSIS established the site framework and therefore this study took advantage of the already developed framework, thus saving on the cost of setting up one.

### **2.3 Research activities**

Soils research has largely been conducted at plot scale using conventional strategies for soil sampling and analysis developed for plot-scale research. Nevertheless, new technologies involving spectroscopic methods are opening opportunities for landscape scale studies. Spectroscopic methods allow the handling of large numbers of samples collected from agricultural landscapes, that can be processed and analyzed within a short time span and generate high quality data sets. The importance of infrared (IR) spectroscopy is that it relates high density geo-referenced measurements of soil condition to remote sensing. IR spectroscopy has been used as a soil monitoring tool in Kenya, Mali and Mozambique to assess the impact of soil management interventions over large areas within a land degradation assessment framework (Shepherd and Walsh, 2007).

## CHAPTER THREE

### 3.0 LITERATURE REVIEW

Trees play important roles in natural and managed ecosystems by fostering more favorable microclimatic conditions, and producing mulch from litter fall and tree prunings, both of which have been shown to influence soil organism distribution and activity around the trees (Pauli *et al.* 2010; Barrios *et al.* 2011).

Land use and management has been shown to significantly affect diversity, density, and the biomass of the soil macrofauna through changes in vegetation structure, organic inputs and level of physical disturbance (Barrios *et al.* 2004; Pauli *et al.* 2011). Soil is one of the most diverse habitats on earth and contains one of the most diverse assemblages of living organisms which contribute to the maintenance and productivity of agro-ecosystems (Giller *et al.* 1997). Soil macrofauna influence soil processes by their ingestion of soil and the formation of biogenic structures. These structures are very important since they determine soil physical properties and organic matter dynamics. The activity and functional diversity of the soil macrofauna (termites, earthworms, ants, millipedes and coleoptera) determines soil aggregation, bulk density, soil porosity, hydraulic properties of the soil (Blanchart *et al.* 1999), mineralization and physical protection of soil organic matter in the biogenic structures (Pulleman, and Marinissen, 2004).

Soil organic matter (SOM) is a key factor in soil processes because it influences nutrient supply, water availability, soil structure maintenance, nutrient buffering and carbon sequestration (Vanlauwe, 2004). Biologically mediated soil nutrient availability is largely dependent on SOM mineralization processes (Barrios *et al.* 1996a). For example, long-term application of manure in combination with

inorganic fertilizers enhanced carbon and nitrogen stabilization thus improving soil physical, chemical and biological properties (Ayuke *et al.* 2011a). The location of SOM within the soil matrix influences its access by soil organisms thus leading to SOM pools that differ in stability and dynamics (Golchin *et al.* 1994). Aggregate protected pools of carbon are less labile than unprotected pools. Intra-aggregate organic matter is incorporated and physically stabilized within macroaggregates, while free organic matter is found between aggregates (Cambardella and Elliot, 1992, 1993). Christensen (1986) described the importance of differentiating the free and intra-aggregate SOM in conceptual models of physically based SOM pools. The three SOM pools are recognized: active, slow and passive pools with decreasing turnover time respectively (Elliot, 1986; Paul *et al.* 2001). These three SOM pools have been associated with three different physical soil fractions of different sizes, i.e. >250  $\mu\text{m}$  macroaggregates, 53-250  $\mu\text{m}$  microaggregates and <53  $\mu\text{m}$  silt and clay respectively. Several studies have shown the importance of microaggregates (Six *et al.* 1998, Puget *et al.* 2000), especially microaggregates-within-macroaggregates (Six *et al.* 2000; Denef *et al.* 2004) in the carbon sequestration as an ecosystem service. Among the three pools, active pool is the smallest and youngest of organic matter and has a turnover time of days to weeks. It is also the most labile organic matter pool (Cambardella and Elliot, 1993) which is involved in microbial mediated processes such as nitrogen mineralization (Barrios *et al.* 1996b). The free particulate organic matter (fPOM), an indirect measure of the active pool, is not associated with mineral particles and consists mostly of semi-decomposed organic residues (Barrios *et al.* 1996a; Six *et al.* 2002). In some soils, SOM decreases the wettability and rate of water entry into the aggregate (Chenu *et al.* 2000). The composition of organic matter and the type of organic binding agent will influence the stabilization and water

repellency properties of the aggregates. The main binding agents are classified as transient (e.g. polysaccharides), temporary (e.g., roots and fungal hyphae), and persistent (e.g., polymers) (Tisdall and Oades, 1982). Partly decomposed organic materials, fungal hyphae, and soil organic matter-derived products such as polysaccharides, humic and aliphatic substances and waxes (Chenu *et al.* 2000; Ellerbrock *et al.* 2005) induce hydrophobic properties to soils with a magnitude depending on the quantity and quality of soil organic matter. Excessive water repellency can increase surface runoff loss due to reduction in water infiltration (De Bano, 2000). Moderate repellency can be beneficial to many soil processes for example; it can increase soil aggregate stability and strength (Blanco-Canqui *et al.* 2007) and promote long-term soil organic carbon sequestration particularly in no-till soils. Rapid water entry into the aggregates causes air compression and slaking. Stabilization of aggregates not only would improve soil structural properties and reduce soil erodability, but also can protect intra-aggregate-occluded organic materials from rapid decomposition and promotes long-term carbon (C) storage and reduction in C turnover (Blanco-Canqui *et al.* 2007). On the other hand, mean weight diameter (MWD) is an index that characterizes the structure of the whole soil by integrating size class distribution into one number (Six *et al.* 2000b) and must be stable to the wetting and sieving processes (Amezkeka, 1999). It has often been used to indicate the effect of different management practices on soil structure (Six *et al.* 2000b) and also the stability of soil structure.

Soil macrofauna contribute to different soil functions and may be used as indicators of soil quality (de Bruyn, 1999; Murage *et al.* 2000; Barrios *et al.* 2006). Agricultural practices that reduce or eliminate soil macrofauna are unlikely to support sustainable crop production (Lee and Pankhurst, 1992). Soil macrofauna mostly

influence soil physical and chemical processes through: i) communitation; physical break up of plant matter into smaller pieces which increases their surface area thus facilitating exposure of substrates to the microflora and subsequent decomposition; ii) mixing of soil and creation of soil aggregates (e.g. faecal pellets or casts); iii) tunneling; creation of pores of different diameters in the soil that increase gas exchange, water infiltration, nutrient movement, root penetration and dispersal of other soil biota; iv) spatial concentration of nutrients (e.g. localized effects of termites and ants); v) mineralization of elemental nutrients; and vi) harbouring of symbiotic gut microflora (especially in earthworms and termites) for nitrogen, phosphorus and sulphur fixation and reduction (Woodman *et al.* 2008). Soil macrofauna are often used as indicators of soil biological quality and therefore constitute important components of soil biota, indicative of overall soil biodiversity and effects of land use change and management practices (Bignell *et al.* 2008; Ayuke *et al.* 2011a). Studies by Klironomos *et al.* (1999), Jimenez *et al.* (2001), Rossi, (2003) and Decaens *et al.* (2009) show that soil organisms are usually not randomly distributed, but exhibit spatially predictable, aggregated patterns over scales ranging from square millimeters to hectares, with scale-dependent controls.

Soil macrofauna comprises those soil organisms that are > 1 cm long or have a width or diameter of >2 mm (Lavelle and Spain 2001). This include a diverse array of organisms occupying various trophic levels such as major consumers of surface organic debris (e.g. millipedes, insect larvae), consumers of buried and more decomposed organic matter (e.g. earthworms), and predators (e.g. burrowing or ground-dwelling spiders, beetles) (Lavelle and Spain, 2001; Woodman *et al.* 2008). Earthworms and termites are the most important soil macrofauna in natural and managed ecosystem (Blanchart *et al.* 1997; Jouquet *et al.* 2006; Moreira *et al.* 2008).

Their ability to modify the soil environment and avail resources to other organisms by such varied mechanisms has earned them recognition as ecosystem engineers (Jones *et al.* 1994). They influence the physical and chemical properties of the soil they inhabit, by creating macropores and through the transformation and distribution of organic matter (Ayuke *et al.* 2011b). Ants and other macrofauna which represent predators, herbivores and bioturbators, also influence important changes in the physical and chemical properties of soils, as well as dispersing plant propagules. Soil macrofauna mostly influence soil physical and chemical processes through: i) communitation; physical break up of plant matter into smaller pieces which increases their surface area thus facilitating exposure of substrates to the microflora and subsequent decomposition; ii) mixing of soil and creation of soil aggregates (e.g. faecal pellets or casts); iii) tunneling; creation of pores of different diameters in the soil that increase gas exchange, water infiltration, nutrient movement, root penetration and dispersal of other soil biota; iv) spatial concentration of nutrients (e.g. localized effects of termites and ants); v) mineralization of elemental nutrients; and vi) harbouring of symbiotic gut microflora (especially in earthworms and termites) for nitrogen, phosphorus and sulphur fixation and reduction (Woodman *et al.* 2008). Verhoef and Brussaard (1990) showed that soil fauna contribute to nitrogen mobilization in natural and agro-ecosystems. Soil macrofauna are often used as indicators of soil biological quality and therefore constitute important components of soil biota, indicative of overall soil biodiversity and effects of land use change and management practices (Bignell *et al.* 2008; Ayuke *et al.* 2011a).

## CHAPTER FOUR

### EFFECTS OF INDIGENOUS TREES AND SOIL PROPERTIES ON SOIL MACROFAUNA ABUNDANCE AND SPATIAL DISTRIBUTION IN MIOMBO WOODLANDS

#### **Abstract**

Soil macrofauna study was conducted at the Kiberashi Sentinel Site, Tanzania following the Land Degradation Surveillance Framework nested sampling design across a total area of 100 square kilometers. A total of six-hundred and forty monoliths measuring 25 x 25 x 10 cm were excavated, soil macrofauna hand-sorted, and soil samples prepared for spectroscopic analyses. Soil organisms were not identified to species level, but only the main taxa were considered. In the laboratory, organisms were separated into six broad groups (earthworms, termites, ants, beetles, millipedes and centipedes). Density and biomass of each of these groups were determined in each of the soil monoliths. Mid-Infrared (MIR) Spectroscopic analyses and soil textural analysis were used to characterize monolith soils inhabited by soil macrofauna.

This study revealed that soil moisture and land use influenced occurrence of earthworms and beetles respectively. Whereas, total carbon influenced significantly ants, beetles, millipedes and termites occurrence. On the other hand earthworms and beetles occurrence were significantly influenced by soil pH. While, available phosphorus influenced significantly the occurrence of centipedes, millipedes and termites, whereas, clay influenced significantly the occurrence of ants and termites. On the other hand, exchangeable bases influenced significantly the occurrence of beetles and centipedes. Whereas, associations between beetles and millipedes was positive

and influenced by land use while that between ants and millipedes being negative and influenced by total carbon.

Key words: Trees, Soil macrofauna, Mid Infrared diffuse Reflectance (MIR), Soil properties

#### **4.0. Introduction**

Agricultural landscapes contain a number of land uses largely defined by the natural variation in soil properties and land use history. Land and soil management practices are designed to reduce inherent constraints to agricultural productivity (Giller *et al.*, 1997). Among the major land uses in the in tropical agricultural landscapes (Zomer *et al.*, 2014) is agroforestry, which is defined as the interaction of trees with agriculture (Sinclair, 2004). Trees influence soil organic matter flows and dynamics through litter fall and root decomposition (Barrios *et al.*, 1997; Rhoades, 1997), and also modify soil nutrient availability (Schroth *et al.*, 2003). They also modify microclimate by reducing direct sun-light on the soil surface which moderates soil temperature extremes and potential evaporation losses and alter moisture availability (Lin, 2010). The soil ecological changes due to trees can have significant impacts on the abundance and diversity of soil organisms as well as their spatial distribution and function (Giller, *et al.* 1997; Pauli *et al.*, 2010, 2011; Barrios *et al.* 2012).

Soil macrofauna contribute to different soil functions and may be used as indicators of soil quality (de Bruyn, 1999; Murage *et al.* 2000; Barrios *et al.* 2006). Agricultural practices that reduce or eliminate soil macrofauna are unlikely to support sustainable crop production (Lee and Pankhurst, 1992). Knowledge of functional importance of soil biodiversity has been largely developed in temperate climates and high-input agriculture; however, there is limited knowledge on how concepts and methods apply

to low-input systems in tropical regions (Ayuke *et al.* 2011b). The development of tools for understanding above-ground/below-ground biodiversity interactions and the effects of scale in designing land use systems that conserve tropical soil biodiversity have been highlighted as important challenges in sustainable agricultural intensification research (Giller *et al.*, 2005; Wagg *et al.* 2014). While plant biodiversity influences life in the soil, soil biota mediates decomposition of organic materials and soil organic matter synthesis, modifies soil structure, and thus indirectly regulates plant growth and community composition by determining soil nutrient and water availability (Hooper *et al.* 2000; Wardle *et al.* 2004; Bardgett *et al.* 2005; van der Putten *et al.* 2009). In order to study plant/soil biota interactions over large areas, Barrios (2007) proposed focusing on perennial plants as hotspots of soil biological abundance and activity. The rationale is that trees, within their zones of influence, create hotspots of soil biological activity promoted by continuous supply of carbon inputs, recycling of nutrients from deeper soil horizons, and buffering microclimatic conditions (Barrios *et al.* 2012).

The objective of this study was therefore to assess the effects of agroecological variables (tree presence, land use, soil moisture), and key soil properties on soil macrofauna diversity and spatial distribution. It is hypothesized that, soil macrofauna are not randomly distributed but aggregated near carbon sources and a more favorable micro-habitat, therefore greater tree presence will promote increased soil macrofauna abundance and diversity in agricultural landscapes.

## 4.1 Materials and methods

### 4.1.1 Study site and design

The study was conducted at the Kiberashi Sentinel Site, AfSIS (Africa Soil Information Services, 2012). Sentinel sites are landscape scale study areas where a nested sampling design has been established thus allowing cross-scale comparisons. The Sentinel Site is located in Tanzania, between Latitude 5°18'S and 5°23'S and longitude 37°26'E and 37°30'E and at an altitude of 1000 m above sea level (Amani Forest Inventory and Management Plan Project, 1988; National Bureau of Statistics and Tanga Regional Commissioner's Office, 2008). The area is underlain by crystalline rocks with the prevailing rock being gneiss and mixed biotite and hornblende. Soils are well drained, moderately deep to deep, dark reddish brown, yellow red or red sandy loams and sandy clays (rhodic luvisol) (FAO/UNESCO, 1988) with weak or moderate structure and low natural fertility. In the valley bottom they are deep, while on the ridges they are shallow with extensive rock outcrops (Pauw, 1984; Mlingano Agricultural Research Institute, 2006). Rainfall is bimodal with long rains usually occurring from March to May and short rains from October to December with a mean annual rainfall of 1000 mm. The mean maximum temperature is 24 °C, while mean minimum temperature is 19 °C (National Bureau of Statistics and Tanga Regional Commissioner's Office, 2008).

Forests in the Kiberashi sentinel site are dominated by indigenous trees and shrubs which are also found scattered in areas converted to farming. The dominant indigenous trees found in the site include: *Acacia tortilis*, *A. nilotica*, *A. seyal*, *Albizia amara*, *Brachystegia bussei*, *B. spiciformis*, *Combretum molle*, *Dalbergia melanoxylon*, *Dombeya rotundifolia*, *Erythrina abyssinica*, *Euclea divinorum*, *Ficus*

*sycomorus*, *F. thonningii*; *Grewia similis*, *Kigelia africana*, *Markhamia obtusifolia*, *Milicia excels* and *Vangueria infausta*, (Mbuya *et al.*, 1994).

The study design was based on the Land Degradation Surveillance Framework (LDSF) which involves a nested sampling approach in Sentinel Sites of 100 Km<sup>2</sup> (10 km x 10 km). Each sentinel site has sixteen randomly distributed clusters (circular shape, area= 1 km<sup>2</sup>), each containing ten randomly distributed plots (circular shape, area= 1000 m<sup>2</sup>), and each plot consists of four sub-plots each of 100 m<sup>2</sup> (Figure 2). The center point of each cluster in the LDSF is randomly placed within a tile measuring 2.5 km × 2.5 km (Figure 2). Sampling plots (geo-referenced) are then randomized around each cluster center point, resulting in a spatially stratified, randomized sampling design (Vagen *et al.*, 2010).

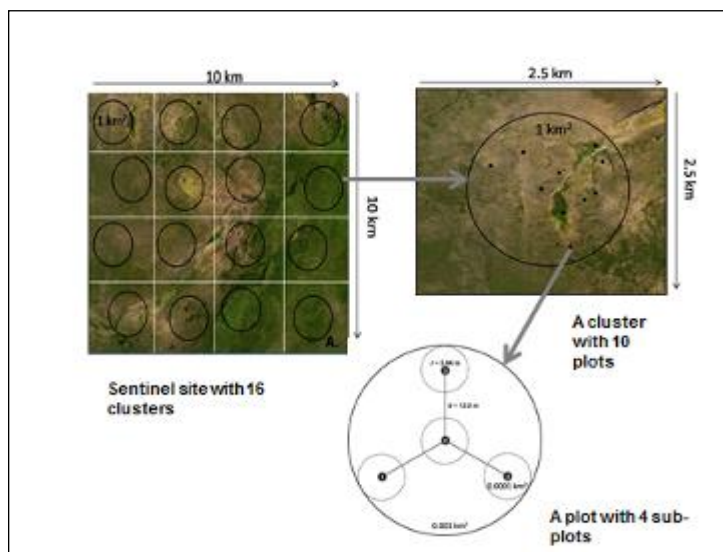


Figure 2: Sentinel site sampling framework

#### 4.1.2 Sampling of soil and macrofauna

The diversity, abundance and spatial distribution of dominant soil macrofauna groups (e.g. ants, beetles, centipedes, earthworms, millipedes and termites) were determined. Sampling was conducted during the long rains of 2011 when the individuals were

most active and easily sampled. At each sub-plot described earlier, soil macrofauna were sampled using a modified monolith sampling method described by Anderson and Ingram, (1993). Sampling involved hand-sorting of litter and excavation of soil monoliths of measurements 25cm x 25 cm and 10 cm deep (Sanabria *et al.*, 2014). With four samplings per plot, a total of 40 monoliths were collected from each cluster giving a total of 640 randomly distributed soil monoliths. All soil macrofauna collected (except earthworms) were preserved in 75% alcohol, while earthworms were initially placed in 75% alcohol and then fixed in 4% formaldehyde. These samples were then transported in sealed vials to the laboratory for identification to order or class level, enumeration and grouping into six larger units, i.e. ants (*Hymenoptera*), beetles (*Coleoptera*), centipedes (*Chilopoda*), earthworms (*Oligochaeta*), millipedes (*Diplopoda*) and termites (*Isoptera*), and other soil macrofauna, prior to biomass determination (Anderson and Ingram, 1993). The number and biomass of each category of soil macrofauna were expressed on an area basis (per square metre). Monolith soil was passed through a 10 mm sieve and a subsample of about 500 grams were placed in zip-lock bags and transported to the laboratory for soil physical and chemical analyses.

#### **4.2 Measurement of selected agroecological factors**

In this study, three agroecological factors were selected, namely: tree presence, soil moisture and land use. Tree density and wood cover estimates were made at the scale of the plot (1000 m<sup>2</sup>), but these did not turn out to be good predictors of soil biota in the study. As such, tree presence at the sub-plot level was used instead, which was categorized into two classes, under tree and away from the tree canopies. Soil moisture content at the time of sampling was divided into five categories based on the judgment of the sampling researcher, namely: 1=wet, 2=75% moisture, 3=50%

moisture, 4=25% moisture and 5=dry. Finally, land use was divided into plots under agricultural and non-agricultural use. Agricultural plots were defined as those under crop production while non-agricultural plots comprised of open grassland, forested areas and farm homesteads.

### **4.3 Soil analyses**

The Mid Infra-Red (MIR) spectroscopy soil analysis method was used because it can handle large numbers of samples and is a rapid and low-cost method.

#### **4.3.1 Reference soil sample analysis**

Reference soil samples were collected from each subplot and pooled (composited) into one sample for each plot, resulting in a total of 160 standard soils. They were then scanned using near infrared (NIR) spectroscopy for selection of 10% of the samples (Kennard and Stone, 1969) for soil chemical analysis. The data generated by reference soil chemical analysis was used to generate a calibration curve to predict the MIR results in all the soil monolith samples.

#### **4.3.2 Prediction of soil chemical properties by Mid Infrared spectroscopy technique**

Sample preparation for MIR analysis is relatively simple because it does not require pre-processing or chemical extractants (Reeves *et al.*, 2002, 2006). The 640 soil samples corresponding to monoliths collected at each of the subplots were analyzed using MIR spectroscopic techniques (Shepherd and Walsh, 2007). Fine ground soil samples were loaded into four replicate wells, each scanned 32 times, using Bruker, Tensor 27 Fourier-Transform spectrometer attached to a High-Throughput Screening (HTS-Xt) extension unit with robotic arm, Bruker Optics, Karlsruhe, Germany

(Shepherd and Walsh, 2007). The four spectra were averaged to account for within-sample variability and differences in particle size and packing density. The measured wavebands ranged from 4000 to 600  $\text{cm}^{-1}$  with a resolution of 4  $\text{cm}^{-1}$  and zero filling of 2. The resulting spectral and reference values were read into R statistics software for computation of the partial least squares (PLS) model. All the spectral data were pre-processed using the first derivatives. Calibration was then determined using a double-cross validation on the remaining samples and finally used for predicting the values of the test set samples. Calibration for prediction of soil properties was done using the first four principal component factors which accounted for 83% of the observed values resulting in good calibrations with  $r^2$  ( $> 0.73$ ) values obtained.

#### **4.3.3 Soil chemical analysis**

Soil samples were ground for a minute to 0.5mm size using Retsch RM 200 mill prior to carbon (C) analysis. Total carbon was then analyzed by thermal oxidation (Skjemstad and Baldock, 2008) using a CN-Analyzer (Flash EA 1112 NC, CE Instrument, Thermo-quest). Soil pH was measured in soil/water suspension consisting of 20 g air-dried soil and 40 milliliters of demineralized water by use of pH meter (Anderson and Ingram, 1993). Mehlich 3 extraction method was used to analyze for exchangeable bases and available P, because it allowed analyses of multiple elements from one extractant using inductively-coupled plasma spectroscopy (ICP) (Mehlich, 1984).

#### **4.3.4 Soil particle analysis**

For particle size distribution, soil samples were air-dried, passed through a 2-mm sieve, then mixed thoroughly and sub-sampled, and finally subjected to particle size analysis on wet mode (sodium hexametaphosphate) using Horiba model LA-950V'2

Laser Diffraction Particle Size analyzer with a detectable size range of 0.01 – 3000  $\mu\text{m}$  (Arriaga *et al.*, 2006).

#### **4.4 Data analysis**

Exploratory analysis of soil physical and chemical data was performed using the Principal Component Analysis (PCA) of the R statistical software (R Development Core Team, 2012). Spatial distribution plots were used to examine the spatial variation of individual variables across the sentinel site. Relationships between soil macrofauna presence/absence and land use, tree influence, soil moisture, soil clay content, and chemical properties (e.g. total C, available P, soil pH, exchangeable Al and exchangeable bases) were explored using logistic mixed models. The random effects of the mixed models were included to account for the clustering in the sampling design. Two-way associations between the presence of different soil macrofauna groups were explored by including presence/absence of one group in the logistic mixed model for the other group. A sequence of models (1 to 5) was fitted to examine the association between groups A and B such that the linear part of the model for A was:

- 1) B
- 2) B + agroecological variables
- 3) B + soil variables
- 4) B + agroecological variables + soil variables
- 5) B + agroecological variables + soil variables + cluster

Where: B= model with six soil macrofauna; AE= Agro ecological variables (tree influence, soil moisture and land use)

For each model the z-value for the coefficient of B was examined, with large values ( $z > 1.8$ ,  $p < 0.05$ ) taken as indicating association. The corresponding model for group B as a function of A was also fitted. Since the models give near symmetric dependence of A on B and B on A, the average z-value for the two models was used. Overall associations are measured by model 1 and the variables that explain them deduced from models 2-5.

## **4.5 Results**

### **4.5.1 Spatial distribution of soil macrofauna**

Soil macrofauna distributions in terms of both abundance and biomass at subplot level ( $n=640$ ) were extremely skewed with high proportions of zeros ( $>50\%$  for all soil macrofauna except termites) and some plots with very high values. The mean count of termites and ants showed that they were present in large numbers (Table 1) and widely distributed (Figure 3) although they were absent in about 50 % of the subplots. The extreme skewness in numbers and biomass suggested that any statistical methods based on means would not be useful. Parametric models that would describe the distribution of biomass or counts was searched for, but found none, so analysis was restricted to presence/absence of soil macrofauna. It was found that there were no strong correlations between the six taxa in presence/absence and hence analyzed the occurrence of each taxon separately and also looked at their associations.

The patchiness of the distribution of each taxon was examined by fitting a logistic mixed model to presence/absence data with random effects for variation at different scale. The null model assumed subplots were independent. Variance components for plot and cluster scale allowed for patchiness. For social groups, like ants and termites, all the variation occurred at the subplot level, with subplots apparently independent.

For other taxa the occurrence was patchy with variation at the cluster scale and (with the exception of centipedes) at the plot scale (Table 1). Further analysis therefore explored the spatial variation explained by soil and ecological variables.

Table 1: Spatial clustering patterns of soil macrofauna at Kiberashi Sentinel Site

Taxa	Percentage presence of soil macrofauna in the subplots	Mean count (all data)	Variance components			AIC	
			Cluster	Plot	Subplot	null	model
Earthworms	13	4.60	1.36	1.33	1	492.0	446.2
Termites	55	188.00	0.17	0.46	1	882.4	882.8
Ants	48	101.00	0.00	0.01	1	888.6	892.5
Millipedes	26	7.40	0.26	0.26	1	730.4	715.6
Centipedes	13	4.00	0.21	0.00	1	530.4	500.9
Beetles	40	11.50	0.34	0.12	1	861.0	847.9

AIC= Akaike Information Criterion

Earthworms favoured the eastern clusters of the sentinel site (Figure 3), whereas centipedes and millipedes were preferentially distributed on the northwestern and southeastern clusters (Figure 3), and beetles on the northern clusters (Figure 3). Conversely, ants and termites did not show any particular distribution pattern, but were distributed across all the clusters of the sentinel site (Figure 3).

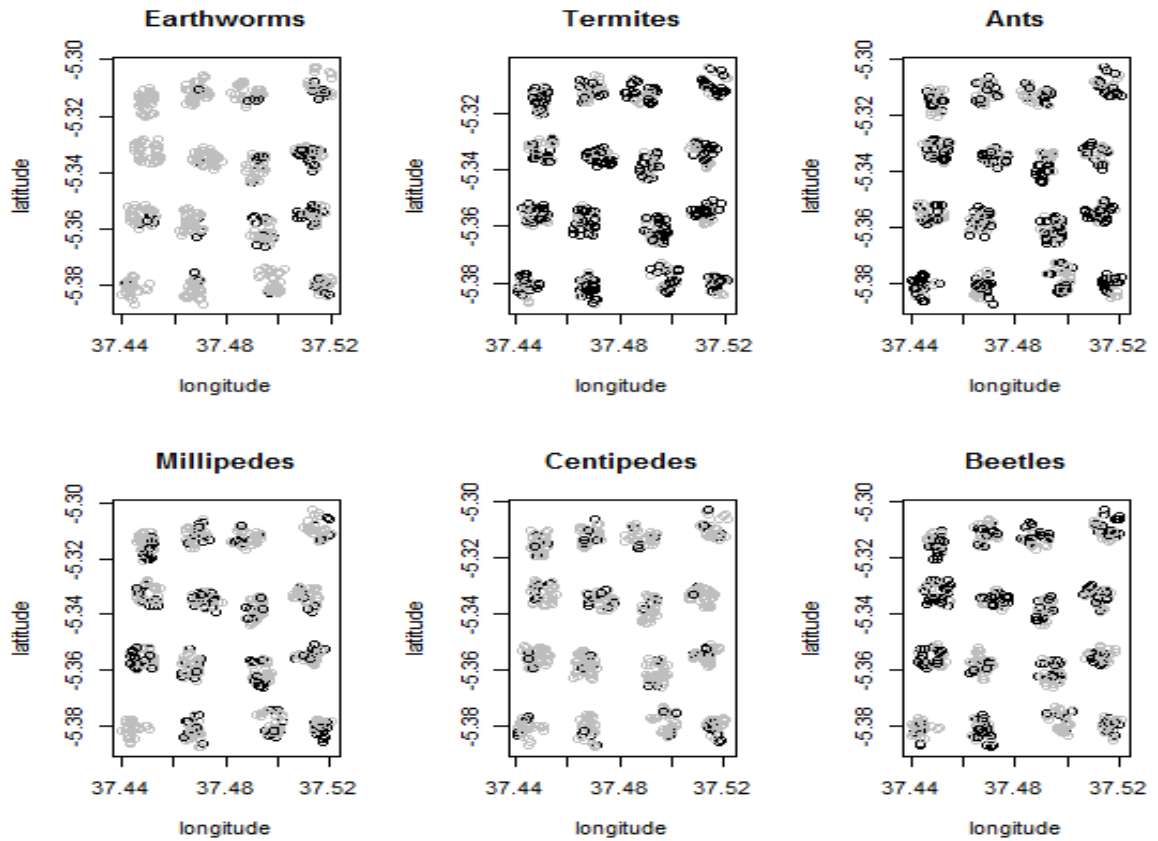


Figure 3: Spatial distribution of soil macrofauna at Kiberashi Sentinel Site (grey=absence, black=presence)

#### 4.5.2 Effects of agroecological variables on the spatial distribution of soil macrofauna

Trees did not significantly influence the distribution of the six soil macrofauna (Table 2). Moisture had a significant effect on the distribution of earthworms ( $p=0.02$ ), but there were no significant effects detected on the other soil macrofauna. There were lower occurrences of earthworms in moderately moist than in wet subplots; while there were no earthworms found in dry subplots (Table 2).

Land use (plots under crops) played a significant role in the distribution of beetles ( $p=0.009$ ) as well as millipedes ( $p=0.03$ ), but no significant effects were detected on the other soil macrofauna. Higher and lower occurrence of millipedes and beetles

respectively were found in agricultural compared to non-agricultural subplots (Table 2).

#### **4.5.3 Effects of soil properties on the spatial distribution of soil macrofauna**

Soil pH significantly influenced the distribution of earthworms ( $p=0.007$ ) and beetles ( $p=0.001$ ). As soil pH increased, the occurrence of beetles increased, while earthworms decreased. Total carbon had a significant effect on the distribution of ants ( $p=0.02$ ), beetles ( $p=0.02$ ), millipedes ( $0.01$ ) and termites ( $p=0.03$ ). Beetles, millipedes and termites decreased, whereas ants increased with an increase in total carbon. Clay content significantly influenced the distribution of ants ( $p=0.02$ ) and termites ( $p=0.03$ ), whereas termites increased, while ants decreased with an increase in clay content. Available phosphorus significantly influenced the distribution of centipedes ( $p=0.002$ ), millipedes ( $p=0.01$ ) and termites ( $p=0.02$ ). There was a decrease and increase in centipedes and termites respectively with an increase in available P, whereas millipedes increased to a maximum then decreased with an increase in available P. Occurrence of beetles ( $p=0.005$ ) and centipedes ( $p=0.05$ ) increased with an increase in exchangeable bases. In this study, exchangeable aluminium did not show significant effect on the distribution of soil macrofauna.

Table 2: Agroecological variables and soil properties influencing distribution of soil macrofauna

		Tree	Moisture	Land use	Total C	Clay	pH	P	ExBas	Al
Non-social	<b>Bt</b>	ns	ns	+ 0.009	\ 0.02	ns	/ 0.01	ns	/ 0.005	ns
	<b>Cp</b>	ns	ns	ns	ns	ns	ns	\ 0.002	/ 0.05	ns
	<b>Ew</b>	ns	- 0.02	ns	ns	ns	\ 0.007	ns	ns	ns
	<b>Mp</b>	ns	ns	- 0.03	\ 0.01	ns	ns	∩ 0.01	ns	ns
Social	<b>At</b>	ns	ns	ns	/ 0.02	\ 0.02	ns	ns	ns	ns
	<b>Tm</b>	ns	ns	ns	\ 0.03	/ 0.03	ns	/ 0.02	ns	ns

Where: The data represent p values;

/= increase in soil macrofauna with an increase in soil variable; \ = decrease in soil macrofauna with an increase in soil variable; ∩= increase to the maximum and then decrease in soil macrofauna with an increase in soil variable; At=Ants; Bt=Beetles; Cp=Centipedes; Ew=Earthworms; Mp=Millipedes; Tm=Termites; P=Phosphorus; TotalC=Total Carbon; ExBas=Exchangeable bases; Al=. Exchangeable aluminium ; +/- indicate higher and lower mean respectively; ns=non significant

#### 4.5.4 Factors affecting associations between soil macrofauna taxa

Exploration of different models (Table 3) started with agroecological factors, and it was observed that association between beetles and millipedes (Bt-Mp) was due to agroecological factors (land use); the association between centipedes and ants (Cp-At) and that between millipedes and centipedes (Mp-Cp) was due to factors that were not measured (e.g. competition, predation and degree of affinity between them) (Table 3). When exploration of different models started with soil factors, it was found that association between Cp-At and Mp-Cp was again due to factors that were not measured. When looking at Bt and Mp separately it was noted that both taxa were significantly influenced by land use and this probably was the agroecological factor

driving this association. While, the association between Mp-At was negative and looking at the taxa separately, it was observed that both were significantly affected by total carbon hence soil factor was driving this association. On the other hand, an Ew-Mp association was positive when agroecological and soil factors model were used (Table 3), but when looking at Ew and Mp separately, it was observed that none of the agroecological and soil factors was independently driving this association. Mp-Cp and Cp-At associations were consistently independent of the model examination pathway used.

Table 3: Associations between soil taxa, agroecological and soil variables

Models	Associations between soil taxa					
	Bt-Mp	Mp-Cp	Cp-At	Ew-At	Ew-Mp	Mp-At
B	+	+	-	0	0	0
B+AE	+	+	-	-	0	0
B+Soil	0	+	-	0	0	-
B+AE+Soil	0	+	-	0	+	0
B+AE+Soil+Cluster	0	+	-	-	0	0

B= model with six soil macrofauna; AE= Agro ecological variables; Bt=Beetles; Ew=Earthworms; Mp= Millipedes; Cp= Centipedes; At= Ants; +=positive; -=negative; 0=no significant association

## 4.6 Discussion

### 4.6.1 Influence of agroecological variables on soil macrofauna and their distribution

Agroecological factors affect different soil macrofauna with different magnitudes.

This study looked at three agroecological factors: tree, soil moisture and land use.

Millipedes are major saprophagous macroarthropods in temperate and tropical ecosystems and their density at the Kiberashi sentinel site reached up to 240 individuals  $m^{-2}$ . They were distributed on the northwestern and eastern clusters which

had moderate to wet soil moisture conditions as compared to the northwestern clusters which were drier. Millipedes require moist environments to avoid desiccation since their cuticle lacks a water-proof layer (Ashwini and Sridhar 2006). Trees often provide milder microclimatic conditions through cool temperatures, litter cover, moist environment and protection from solar radiation. These conditions are important for the survival of millipedes, although trees did not significantly influenced the distribution of millipedes, but may have indirectly influenced their spatial distribution through other factors such as temperature, humidity and shade.

Ants would locate their nests away from the trees to avoid higher soil moisture as well as the disturbance by heavy drops from the canopy and also the ease of movement of food materials to the nesting site. Tree canopies can hold large quantities of water in a rainy day which is then released as larger drops. Thus, the high occurrence of ants away from trees may be attributed to their preference for nesting in low moisture soils and this is consistent with studies by Lafleur *et al.* (2005) and Pauli, (2008).

Soil moisture played a role in the distribution of earthworms. Their density reached as many as 208 individuals  $m^{-2}$  and they were mainly distributed in the forested eastern clusters which coincided with moderate to wet soil moisture conditions. While no significant direct effect of tree presence on earthworm distribution was detected; trees may have contributed to favorable moist niches in the eastern clusters. Soil moisture plays an important role in the movement of the earthworms within the soil profile in search for food, survival, growth and sexual development. Earthworms have soft and moist bodies, and therefore require moist environment to live and feed in (Lavelle and Spain, 2001). In dry soils, water would be drawn from the earthworm's bodies into the soil. Absence of earthworms in dry

soils may be attributed to their movement into deeper soils that could have been missed by soil sampling depth (10 cm). Furthermore, soil moisture might have preconditioned the litter (e.g. decomposition and softening of the litter) and soil for ease of earthworms' feeding and movement in the moist soils. These observations agree with the studies by Fragoso and Lavelle, (1992) Auerswald *et al.* (1996) Wever *et al.* (2001) Blackburn *et al.* (2002); Lafleur *et al.* (2005) and Ackerman *et al.* (2007).

Land use played a significant role in the distribution of millipedes and beetles, but did not show significant effect on ants, centipedes, earthworms and termites. Millipedes are detritivores and feed on decaying leaves, other dead plant matter and also on agricultural crops such as sweet potato, groundnuts, cassava and beans. In Kiberashi maize, beans, cassava and sweet potatoes were the main crops grown by the farmers. The presence of crops such as cassava and sweet potatoes may have contributed to the higher occurrence of millipedes in cultivated subplots where they are pests. This is consistent with observations by Ebregt *et al.* (2004). Similarly, beetle distributions were also influenced by land use and were more prevalent in the non-agricultural plots. They were mainly distributed in the northern clusters which coincided with lower soil moisture conditions. The Maasai community living in the area graze their livestock in the northwestern side of the sentinel site hence the high incidence of the beetles may be attributed to availability of food (cow dung) and the movement by cows in search for pastures may have disturbed the beetles' enemies. On the other hand, soil disturbance regime found in agricultural plots, where tillage practices incorporate plant residues into the soil beyond the reach of soil macrofauna (Ashwini and Sridhar, 2006; Sileshi and Mafongoya, 2006; Hendrickx *et al.* 2007), may have contributed to reduction of food resources. Soil disturbance may also kill or

injure and/or expose the saprophagous and phytophagous beetles and their larva to predators thus resulting in low occurrence of beetles in the cropped fields.

#### **4.6.2 Effects of soil properties on soil macrofauna and their distribution**

Soil is home to an extremely diverse community of organisms, and provides with food, habitat and shelter from predators (Barrios 2007). Soil physical and chemical properties influence the distribution of organisms within the soil. This study assessed the degree to which soil carbon influenced the distribution of soil macrofauna and revealed that it had a significant effect on the distribution of termites', beetles', ants' and millipedes. Incorporation of tree litter and animal fecal matter into the soil coupled with decomposition by microorganisms and other decomposer organisms contributed to increase in total carbon. Termites are mobile organisms that search for available food resources (wood, litter, soil, dung/manure and grass) and carry them to their nests often located elsewhere leading to increased total carbon contents. Similarly, soil feeding termites ingest soil organic matter and return fecal pellets which are rich in carbon contents into the soil thus increasing total carbon. The findings of this study were consistent with the observations by several authors (Kuperman 1996; Fall *et al.* 2001; Fall *et al.* (2001); Li *et al.* 2006; Ackerman *et al.* 2007; Ackerman *et al.* (2007); Sarcinelli *et al.* (2009); Jimenez *et al.* (2008) and Ayuke *et al.* 2011a).

As termites forage for food, they collect clay from the lower soil horizons for making runways that protects them from solar radiation, rainfall and predators (galleries and sheetings). Similarly, the ants while building their nests would also bring clay from the lower soil horizons. The soil brought up from the lower soil horizons may have led to increased clay content and this was consistent with the

studies by Lavelle and Spain, (2001), Jouquet *et al.* (2007), Mujinya *et al.*, (2010) and Ruckamp *et al.* (2012).

Soil pH strongly affects soil macrofauna abundance and distribution (Kuperman 1996; Ayuke *et al.* 2009; Sarcinelli *et al.*, 2009; Auclerc *et al.* 2012). Soil pH significantly affected earthworm and beetle taxa distribution. Earthworms' thrive best in soil with a pH range of between 4.5 and 7.0. The lower and upper limits of Kiberashi soil was 5.3 and 7.9 respectively. This upper limit was higher than what most earthworms' species could thrive best in. It was observed that earthworms decreased with an increase in soil pH. The observed trend may be attributed to soil pH above 7.0 which may not be conducive for earthworms' survival. The high soil pH may have affected the availability of soil nutrients (e.g. available phosphorus) which determine availability of food source for the earthworms. These were consistent with the findings by Fragoso and Lavelle, (1992) and Marichal *et al.* (2012). Similarly, the results showed that occurrence of centipedes decreased with an increase in soil pH. Centipedes are predators and feed on other soil fauna (e.g. collembola and earthworms). The effect of soil pH indirectly affected their occurrence by influencing availability of food substrates and the distribution of their prey.

The higher occurrence of beetles in the northern clusters may be attributed to the presence of cow dung which provided food for the beetles and also had an effect on the soil pH (Whalen *et al.* (2000).

Soil pH, total carbon, phosphorus and exchangeable bases are correlated and may have had a combined effect on the occurrence of millipedes. Soil pH played an important role in the availability of exchangeable bases and phosphorus. Millipedes require calcium for their exoskeleton development (Ashwini and Sridhar 2008) and availability of calcium in soils is pH dependent. An increase in soil pH will trigger an

increase in calcium and other exchangeable bases as well as available phosphorus. Exchangeable bases and phosphorus are also important nutrients for plant growth, triggering increased vegetative growth resulting in increased litter. Since millipedes feed on litter (e.g. decaying leaves and other dead plant matter) an increase in litter inputs may have resulted in increased abundance of millipedes and other litter-feeding organisms (Berg and Hemerick, 2004). The increased abundance may have led to competition for the available food resulting to depletion, hence decreased millipedes' abundance.

#### **4.6.3 Influence of agroecological indicators and soil properties on soil macrofauna associations**

The ecological community dynamics that drive species to have different associations is governed by patterns (positive or negative effect of one species on the occurrence of another) and strength of those associations. In terms of the strength of associations, there can be differences in relative abundance of weak versus strong interactions within the web (i.e. differences in the frequency distribution of interaction strengths). Thus, the distribution of one species can depend on interactions with other species through competition, predation, mutualism, and commensalism (Lane *et al.* 2014).

The associations between Bt-Mp, Ew-At, Ew-Mp and Mp-At were influenced by measured factors i.e. agroecological and soil factors, whereas associations between Mp-Cp and Cp-At were influenced by unmeasured factors.

Millipedes and centipedes showed positive associations between each other and seemingly this was due to factors not assessed in this study. There is likelihood that one or more of these factors not assessed for example temperature, C/N ratio, litter quality and relative humidity may have contributed in the positive association

between the two organisms (Blackburn *et al.* (2002), Berg and Hemerik (2004) and Tajovsky and Wytwer (2009).

A negative association between ants and centipedes (At and Cp), was observed in this study. Both of the species are predators (Moya-Larano and Wise, 2007), and may compete for the same prey resulting in competitive exclusion of one species by the other. Their association may likely be explained by the factors which were not assessed such as the degree of competition as well as predation. Ants and centipedes are competitors and likewise ants are predators of centipedes. These factors may have had an effect on the density and distribution of the prey as well as the centipedes' abundances resulting in the negative associations between the two organisms (Masuko (2010) and Dejean and Lachaud, (2011).

## **Conclusions**

This study revealed that soil moisture and land use influenced occurrences of earthworms and beetles respectively. While, total carbon influence significantly ants, beetles, millipedes and termites. Soil pH influenced significantly the occurrence of earthworms and beetles.

Available phosphorus influenced significantly the occurrences of centipedes, millipedes and termites, whereas, clay influenced significantly the occurrences of ants and termites. On the other hand, exchangeable bases influenced significantly the occurrences of beetles and centipedes.

The associations between soil macrofauna were either positive or negative. The association between beetles and millipedes being positive and was influenced by land use while that between ants and millipedes being negative and was influenced by total carbon.

## CHAPTER FIVE

### EVALUATION OF FARMERS' KNOWLEDGE ON TREES, SOIL MACROFAUNA AND THEIR INTERACTION IN MIOMBO WOODLANDS

#### Abstract

Farmers' local knowledge is a powerful tool for identifying leverage points for research into areas in which farmers know they will benefit.

Data for the study of farmers' local knowledge was collected using focus group discussions and semi-structured individual interviews conducted with the local farmers. Farmers representing different communities located in the Kiberashi Sentinel Site were sampled to participate in a workshop to identify and classify local knowledge about trees, soil macrofauna and their interactions following the participatory methodology. Key informants were identified for more detailed evaluation of local knowledge through case studies conducted in the selected households on their farms for each village. Semi structured questionnaires were used to gather information on influence of tree cover and indigenous trees on the spatial and temporal distribution of soil macrofauna.

During the study, farmers identified trees that positively influenced the distribution of soil macrofauna and among them were *Dombeya rotundifolia*, *Acacia tortilis*, *Albizia anthelmintica*, and *Ficus thonningii* as indigenous tree with good attributes that help improve soil fertility, influence soil macrofauna abundance and improve crops' growing conditions.

Farmers identified nine soil types based on soil colour and textural properties. They also identified soil good for each crop, and according to them, soil with clay and loam

texture favoured maize and beans, while sandy and silty texture favoured root crops such as cassava.

Factors that influenced the spatial and temporal distribution of soil macrofauna were identified and ranked based on their importance as follows: microhabitat; weather; access to food; protection from predators and body structure. Majority of the farmers were aware that most soil macrofauna were found under tree canopies.

Regarding soil management practices, farmers were aware that pesticide application and burning of crop residues killed soil macrofauna, while use of organic manure increased soil macrofauna abundance.

*D. rotundifolia* was identified as the best indigenous tree with good attributes that help improved soil fertility, influenced positively the distribution of soil macrofauna and improved crop's growing conditions. This tree would benefit the farmers if adopted as agroforestry tree in their farms.

Key words: Farmer's local knowledge; soil macrofauna; indigenous trees

## **5.1 Introduction**

Experimental research provides information on agronomic and farm management practices that can help farmers make better decisions. However, given that scientific approaches alone are often insufficient for addressing the challenges associated with the sustainable management of agro-ecosystems, many studies have acknowledged the value of farmer's local knowledge as a key source of relevant information required to complement scientific understanding and come up with accurate solutions to challenges faced by the farmers in their agricultural production (Birang *et al.* 2003; Oliver *et al.*, 2012).

Local knowledge also referred to as ethno-science is knowledge which is acquired by local people through the accumulation of experiences and informal experiments, and through an intimate understanding of the environment in a given cultural context. This kind of knowledge is transferred orally from one person to another and from generation to generation and is dynamic, flexible, logical, and receptive to innovation (Rist and Dahdouh-Guebas, 2006). Ethno-science comprises ethno-ecology which is the science of how people understand the relationship between humans, animals, plants and physical elements of a local environment (Davison-Hunt, 2000). Small-scale farmers are commonly left out of the formal agricultural research process as sources of information and innovation (Birang *et al.* 2003; Grossman, 2003; Barrios *et al.* 2006). This can result in inaccurate diagnosis of agricultural problems and creation of technologies that neither meet the needs of the farmer nor are suitable for their production environment. Therefore, farmers' local knowledge is a useful tool for identifying leverage points for research into areas in which farmers know they will benefit. It is also possible that local practices exist that can be built upon to address farmers' needs and also provide scientists with some understanding on how research could be conducted in order to address the farmers needs and constraints (Joshi *et al.* 2004).

Local farmers, who depend on the land for their livelihood, often exhibit detailed agro-ecological knowledge, developed over many generations of agricultural activity. Some of the recent ethno-pedological studies on farmers' perceptions of soil fertility and soil quality mention soil macrofauna as an important bio-indicator (Barrios and Trejo 2003; Grossman 2003; Barrios *et al.* 2006). It is thus important to understand how soil macrofauna are perceived and valued by local farmers, as part of their agricultural practices. According to Murage *et al.* (2000), smallholder farmers' in

Central highlands of Kenya view the presence of earthworms and beetle larvae in the soil as bio-indicators of productive land. Furthermore, studies by Birang *et al.* (2003) in Southern Cameroon showed that activity of soil macrofauna and the presence of earthworm cast was regarded as indicators of soil fertility. Whereas, studies by Barrios and Trejo (2003) in Honduras revealed that soil macrofauna (principally earthworms and beetle larvae) were ranked as the second most important indicator (after soil nutrient status) when assessing the soil quality. This evidence suggests that farmers are most likely to use soil macrofauna groups or taxa as bio-indicators of soil quality because they can easily be seen in the field.

Although many studies mention soil macrofauna as indicators of soil fertility (Barrios and Trejo 2003; Grossman 2003; Birang *et al.* 2003; Barrios *et al.* 2006), less attention has been paid to farmers' local knowledge and perceptions on the effects of trees on the distribution and abundance of soil macrofauna in Miombo Woodlands..

The aim of the study was to evaluate farmer's local knowledge on the indigenous tree species, soil macrofauna and their interactions in Miombo Woodlands.

It was hypothesized that; most farmers have valuable knowledge about trees and the attributes that influence the spatial distribution of soil macrofauna abundance, diversity and activity.

## **5.2 Materials and methods**

### **5.2.1 Study site**

The study was conducted in Kiberashi sentinel site in the month of February 2012. Further details were described in section 4.1.1, page 32.

Six villages found in two wards: Kibirashi and Kisangasa were involved in the study. Four villages Elerai (5°21'S, 37°25'E), Kibirashi (5°22'S, 37°26'E),

Kwamaligwa (5°22'S, 37°28'E) and Nkoa (5°22'S, 37°29'E) are found in Kibirashi ward, while two villages Kwediswati (5°21'S, 37°30'E) and Mgera (5°23'S, 37°31'E) are in Kisangasa ward.

The predominant agricultural practice is small-scale mixed subsistence farming.

Average land-holdings in the six villages are less than ten hectares. Land is prepared using hand hoes, ox-drawn plough, while others use tractors. The main crops grown are maize (*Zea mays*) and beans (*Phaseolus vulgaris*). Livestock keeping is practiced by the northern villages of Elerai and Kwamaligwa by the Maasai community, where they keep livestock (cattle, goats, sheep and donkeys).

### **5.2.2 Data collection**

#### **Sampling of the farmers**

Farmers representing the six villages were sampled to participate in a workshop to identify and classify local knowledge about trees, soil macrofauna and their interactions following the InPaC-S knowledge sharing tool (Barrios *et al.* 2012). Village leaders guided the selection of farmers in the Kiberashi Sentinel Site using the following criteria: i) Farmers experience in the area; ii) Farmers who were knowledgeable about the indigenous vegetation; iii) Those who actively practice agroforestry or have trees on their farms; iv) Those who spend considerable time inside the forested areas; v) Farmers who had knowledge on soil macrofauna and their interactions with trees; vi) those who had farms distributed across the sentinel site (Pauli *et al.* 2012; Grossman, 2003). Based on these criteria, fifty-four farmers (nine from each village) were sampled to participate in focus group discussions held at Kiberashi in February 2012.

### **Focus group discussion forum**

Six focus group discussions were conducted simultaneously with representatives from the six villages namely; Elerai, Kibirashi, Kwamaligwa, Kwediswati, Mgera and Nkoa, to elicit farmer's local knowledge. Each focus group was assigned a local extension officer who spoke the local language and facilitated knowledge sharing dynamics using a set of guiding questions and also recorded the proceedings. Farmers identified and deliberated on the factors that influenced the spatial and temporal distribution of soil macrofauna and explained in their own words/understanding how they defined and classified these factors. This was followed by ranking of these factors by each village/focus group. The synthesis matrix tool (Barrios *et al.* 2012) guided the pooling and synthesis of ranked factors from all village/focus groups. The integration matrix tool (Barrios *et al.* 2012) then guided the consensus building process of bringing together local knowledge and perceptions of farmers, with technical knowledge of extension agents and researchers on the most important factors influencing the spatial and temporal distribution of soil macrofauna.

### **Data collection**

During the workshop most knowledgeable farmers were identified and selected as key informants (three from each village; totaling eighteen farmers) for more detailed evaluation and triangulation of local knowledge through case studies conducted at their respective farms. Questionnaires were used to gather additional information from the farmers on influence of tree cover and specific trees on the spatial and temporal distribution of soil macrofauna.

In each case study, a map (Figure 4) was prepared with the help of the farmer showing the soil types, trees in the farm, crops and other uses of the farm. This was done for all the 18 farms.

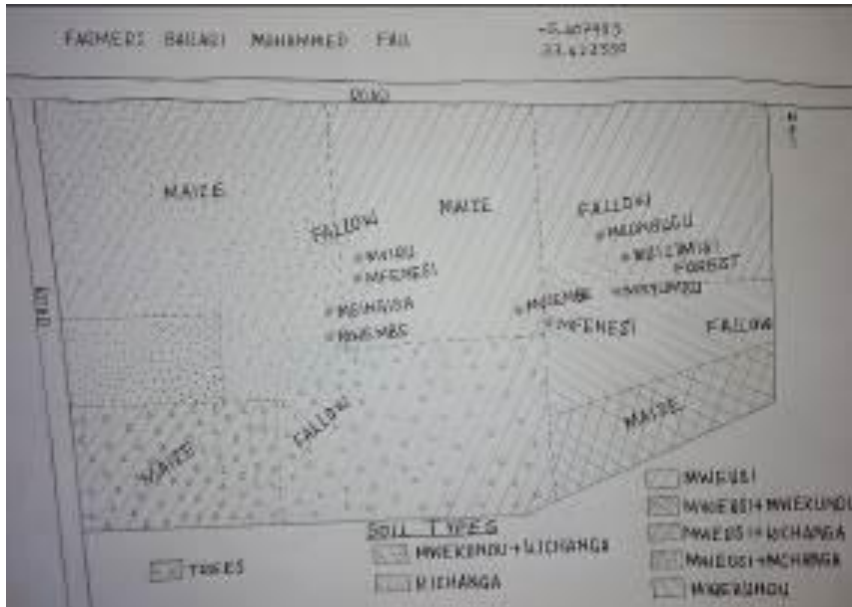


Figure 4: : Sketch map drawn by farmers showing soil types, and tree distribution, crops and other farm uses of selected farms in Kiberashi Sentinel Site

### 5.3 Data processing and analysis

Frequency distribution of data on farmers' perceptions based on village, gender and age strata against the factors influencing spatial and temporal distribution of soil macrofauna were analyzed using Statistical Package for Social Sciences (SPSS). Specific trees were classified based on the positive or negative effects on soil and crops if at least 2 of the interviewed farmers agreed with the classification, the remaining were classified as neutral.

### 5.4 Results

The interviewed farmers have lived within Kiberashi and interacted with their environment for a good length of time and could therefore possess substantial knowledge on soil biota by tree interactions. The results of the study could therefore

be compared to and compliment the results obtained from analyzing the soil collected from Kiberashi sentinel site.

#### 5.4.1 Local perceptions of key factors affecting soil macrofauna distribution

During the semi-structured interviews, the farmers identified six soil macrofauna taxa, ranging between 3-6 taxa per farmer. The taxa mentioned by farmers were: ants, beetles, centipedes, earthworms, millipedes and termites. The ants were named by 100% of the farmers, while beetles were named by 94.4%, centipedes by 33.3%, earthworms by 66.7%, millipedes by 44.4% and termites by 94.4%.

The farmers identified main factors affecting soil macrofauna distribution and these were categorized in broad groups and ranked in the order of importance: microhabitat (where the soil macrofauna lives), access to food, weather, and protection from predators, and body structure (Table 4). The majority of the farmers (78%) mentioned that most macrofauna were found under tree canopies, 6% of the farmers believed that they were found away from trees, while 17% believed that soil macrofauna were found both under and away from trees for example the ants and termites (Table 5).

Table 4: Factors influencing soil macrofauna distribution as ranked by farmers

Factors	Elerai	Kibirashi	Kwamaligwa	Kwediswati	Mgera	Nkoa	Total	Rank
Microhabitat	2.5	2	0	2.7	2	2.5	11.7	1
Access to Food	3	2	3	0	3	1	12	2
Weather	2	0	1	6	1	6	16	3
Protection from predators	0	0	3	7	4	4	18	4
Body structure	5	0	5	3.5	5.5	6	25	5

Table 5: Distribution of soil macrofauna around the trees

Location of soil macrofauna	Percentage of farmers
Under the tree	77.8(14)
Away from trees	5.6(1)
Under and away from trees	16.7(3)
Total	100.0

Values in parenthesis are number of farmers

#### 5.4.2 Effect of indigenous trees on soil quality, soil macrofauna and crop performance

Farmers identified, characterized and ranked indigenous tree species based on the effect on soil and soil macrofauna distribution (Table 6). A good tree attribute for example, is that the litter fall from that particular species improves soil quality under its canopy, and has high abundance of soil macrofauna, while no undergrowth, high root density and poor fertility under the tree canopy were considered as negative tree attributes. The percent shown against each tree species depicts the proportion of farmers that selected a particular tree species to have positive or negative effects. *Acacia tortilis* (local name: Mkungugu) (27.8%), *Acacia spp. 1* (Mgungamaji) (27.8%), *Ficus exasperata* (Mkuyu) (22.2%) and *Dombeya rotundifolia* (Mnuati) (22.2%) were identified as the preferred indigenous trees which contributed to increased soil fertility through litter fall.

Farmers also identified indigenous trees harboring high soil macrofauna abundance under their canopies which include *Albizia anthelmintica* (Mfuleta) (22.2%), *Acacia spp. 1* (22.2%), *A. tortilis* (22.2%) and *D. rotundifolia* (22.2%) (Table 6).

Many indigenous trees are found in Kiberashi Sentinel Site, and among the common ones found in the farms are: *Albizia amara*, *Acacia seyal*, *Combretum molle*, *D. rotundifolia*, *Vangueria infausta*, *Kigelia Africana*. Some trees were identified as

having positive effect on crops in the following ways: providing good microclimatic conditions to the crops and shedding of leaves which are subjected to decomposition leading to improved soil fertility and these include *D. rotundifolia* (33.3%), *F. thonningii* (Mkuyu) (22.2%), *K. africana* (Mvungwe) (22.2%), *Euphorbia candelabrum* (Ganga) (16.7%) and *Albizia versicolor* (Mkingu) (16.7%). However, some trees were identified as having negative effects on crops in the following ways: having dense shade, high root density, harbor insect pests and showing harmful competitive effects and include the following; *Brachystegia microphylla* (Msane) (27.8%), *A. anthelmintica* (22.2%), *Acacia spp.2* (Mgungakundu) 22.2%) and *A. tortilis* (16.7%) (Table 6).

#### **5.4.3 Soil types and their characteristics**

Farmers use diverse terminologies to describe soils and to express the fertility status (Table 7). Nine different soil types were identified by farmers in Kiberashi based on their color, textural properties' workability and crop's suitability. The soils that were identified by farmers as being red and black were considered as soils which were fertile and good in retaining of soil moisture. The black soil was most commonly named by the farmers interviewed and was said to be dark in color, fertile and retained moisture. Whereas, the red soil "Mfinyanzi/mwekundu" was said to be hard, sticky, required more rains and good in water retention. Soils with clay and loam texture were considered good for maize, beans, sunflower, cow peas and pigeon peas, while those with a sandy and silty texture were said to be good for growing root/tuber crops such as cassava.

Table 6: Indigenous trees identified by the farmers as indicators for soil quality and their effect on crops and soil macrofauna abundance

Scientific names	Local names	Indicator for SQ		Presence of SM	Effect on crops	
		Positive	Negative		Positive	Negative
		%Farmers	%Farmers	%Farmers	%Farmers	%Farmers
<i>Dombeya rotundifolia</i>	Mnuati	22.2	0.0	22.2	33.3	0.0
<i>Acacia</i> spp 1	Mgungamaji	27.8	5.6	22.2	11.1	11.1
<i>Kigelia africana</i>	Mvungwe	16.7	0.0	11.1	22.2	0.0
<i>Ficus thonningii</i>	Mvumo	11.1	0.0	16.7	5.6	0.0
<i>Albizia gummifera</i>	Mvumbili	5.6	0.0	22.2	5.6	0.0
<i>Acacia seyal</i>	Mgunga	22.2	0.0	0.0	11.1	0.0
<i>Albizia harveyi</i>	Msisimisi	11.1	11.1	22.2	11.1	0.0
<i>Acacia tortilis</i>	Mkungugu	27.8	0.0	22.2	0.0	16.7
<i>Albizia amara</i>	Mchala	11.1	0.0	16.7	0.0	0.0
<i>Lannea schweinfurthii</i> var <i>stuhlmannii</i>	Mumbu	5.6	0.0	11.1	11.1	0.0
<i>Vagueria infausta</i>	Mviru	5.6	0.0	5.6	11.1	0.0
<i>Albizia versicolor</i>	Mkingu	0.0	0.0	5.6	16.7	0.0
<i>Euphorbia candelabrum</i>	Ganga	11.1	0.0	0.0	16.7	5.6
<i>Juliberardia globiflora</i>	Mtondolo	16.7	0.0	5.6	5.6	11.1
<i>Commiphora africana</i>	Mtwintwi	5.6	0.0	11.1	0.0	0.0
<i>Ricinus communis</i>	Mbono	11.1	0.0	0.0	5.6	0.0
<i>Erythrina burtii</i>	Mbilimisi	5.6	0.0	0.0	5.6	0.0
<i>Combretum molle</i>	Mlama	11.1	5.6	0.0	5.6	0.0
<i>Acacia nilotica</i>	Mgelegele	16.7	0.0	0.0	0.0	5.6
<i>Ficus exasperata</i>	Mkuyu	22.2	0.0	5.6	22.2	0.0
<i>Brachystegia microphylla</i>	Msane	11.1	11.1	5.6	0.0	27.8
<i>Acacia</i> spp.2	Mgungakundu	22.2	11.1	0.0	5.6	22.2
<i>Albizia anthelmintica</i>	Mfuleta	0.0	0.0	22.2	0.0	22.2

Where: SQ=soil quality; SM=soil macrofauna

Table 7: Common soil types with their characteristics

Local soil type	Texture	Soil characteristics	Soil moisture	Crop suitability
1.Mfinyanzi/ mwekundu	Clay	Red in color, hard and sticky, require more rains, good water retention	Retain	All crops
2. Mchanganyiko wa mwekundu na mweusi	Clay loam	Sticky and become hard when dry	Retain	Maize, Beans
3. Mweusi	Loam	Black in color, fertile soil	Retain	Maize, Beans, Sunflower
4. Mchanganyiko wa mwekundu na mchanga	Sandy clay	Fertile, soft, loose and sticky	Retain	Cassava, Sweet potatoes, Peanuts
5. Mchanganyiko wa mwekundu na kichanga	Silty clay	Fertile, soft and sticky	Retain	Peanuts, Sorghum, Bananas
6. Tifutifu	Silty loam	Fertile, soft, loose and not sticky, not good during dry period	Dry faster	Maize, Beans, Pigeon peas, cow peas
7. Mchanganyiko wa mweusi na mchanga	Sandy loam	Fertile, loose, dry faster	Dry faster	Maize
8. Kichanga cheke	Silt	Soft, loose, Soil dry faster, non-sticky,	Dry faster	Cassava, Maize, potatoes, Peanuts
9. Mchanga/ Changarawe	Sand	None fertile	Do not retain	Cassava, but not good for other crops

#### 5.4.4 Effect of agricultural practices on soil macrofauna

Farm management practices applied in Kiberashi include fertilizer application, use of pesticides and burning of crop and tree residues. All these practices were recognized as having significant effects on soil macrofauna (Table 8). The majority of the farmers had the knowledge that application of organic manure increased the abundance of most macrofauna and that application of pesticides killed beneficial soil organisms. Most of them (61%) indicated that use of fertilizers on the farm increased soil macrofauna, while 61% indicated that pesticide application on farms killed soil

macrofauna. The farmers understood the effect of burning on soil macrofauna and 89% of the farmers indicated that burning killed soil macrofauna.

Table 8: Effects of soil management practices on soil macrofauna, crops and soil

<b>Soil management practices</b>	<b>% farmers (No. farmers)</b>
<b>Effects of fertilizer application on soil macrofauna</b>	
Increase in soil macrofauna	61.1(11)
Decrease in soil macrofauna	5.6(1)
No effect on the soil macrofauna	16.7(3)
No idea	16.7(3)
<b>Effects of pesticide application on soil macrofauna</b>	
Kill soil macrofauna	61.1(11)
No effect on soil macrofauna	27.8(5)
No idea	11.1(2)
<b>Effects of burning on soil macrofauna</b>	
Kill soil macrofauna	88.9(16)
No effect	5.6(1)
No idea	5.6(1)

Values in parenthesis are number of farmers

## **5.5 Discussion**

### **5.5.1 Farmers perceptions on soil macrofauna and factors influencing their distribution**

According to the farmers interviewed, soil macrofauna are important indicators of soil quality. Farmers were able to relate that most macrofauna were found under the tree canopies. Microhabitat was identified as one of the main factors affecting the distribution of soil macrofauna. This factor included the following, soil types, shade, moisture, cool temperatures and litter. High abundance of soil macrofauna was said to be found under tree canopies. Trees provide shade, litter, moist soils around them, cool temperatures, protection from sun's radiation and many soil fauna. The litter fall from trees are subjected to decomposition by the soil organisms leading to increased

soil fertility and soil moisture. Increased soil fertility led to increased soil macrofauna abundance and diversity. Soil macrofauna e.g. centipedes being predators would increase due to increased prey because of availability of substrates and good microhabitat. These findings were in agreement with observations by Lavelle and Spain (2001).

The soil's ability to provide nutrients and moisture to the macrofauna was highly dependent on the soil characteristics (Barrios, (2007) and Pauli *et al.* 2012).

### **5.5.2 Farmers local knowledge on soils**

Farmers in Kiberashi Sentinel site used easily identifiable soil characteristics such as soil colour and texture to determine the type of soil. According to them, soils that are black in colour are fertile and support their main food crops such as maize and beans. Trees play great roles in maintaining soil fertility as well as crop production. Litter fall from these trees when incorporated into the soil, are subjected to decomposition by soil organisms forming soil organic matter. Soils high in SOM are black in colour, retain moisture for longer periods and release nutrients through mineralization by soil organisms. Similarly farmers in this region had the knowledge that soils with clay content had good soil moisture retention capacity and containing nutrients thus supporting a majority of crops. On the other hand, soils that were considered to be sandy were infertile and only support crops like cassava. The soil with this texture was low in soil bulk density and could allow tubers to increase in size. Soils of high bulk density restrict size of the tubers formed leading to low quality tubers. This was consistent with studies by Dawoe *et al.* (2012) and Barrios (2006).

### **5.5.3 Farmers local knowledge on trees**

Indigenous trees were considered to be very important in the farmer's fields due to variety of factors. The trees provided litter, maintained higher soil moisture, undergrowth, shade and host many soil organisms which were linked to increased crop productivity. The litter fall from the trees were subjected to decomposition by soil organisms forming soil organic matter which improved soil fertility levels and led to increased abundance of soil macrofauna. One such tree mentioned was *D. rotundifolia*, which was considered to affect soil positively. The formed SOM increased soil moisture and therefore preconditioned the soil for soil macrofauna such as earthworms and beetle larvae to increase in abundance. The presence of these organisms would improve soil fertility through faecal deposits rich in carbon and other soil nutrients. These organisms would also make tunnels in the soil and hence increase infiltration rate around the trees and aerate the soil. Farmers use tree species as indicators of sites that would be favourable or unfavourable for the establishment of new cropping fields. Farmers also had detailed knowledge of plant indicators of soil quality and the effects of different tree species on soil properties. The presence of trees in the farm improved conditions of crop production, while providing numerous economic and ecological benefits. This was consistent with studies by Sileshi *et al* (2008), Bayala *et al.* (2008), Neufeldt *et al* (2009) and Pauli *et al.* (2012).

### **5.5.4 Effect of soil management practices on soil macrofauna**

Many farmers in Kiberashi understood the effect of burning on soil fertility during land preparation. They had variable understanding of the effect of burning on the soil and soil macrofauna. They recognized that burning would kill soil macrofauna and affect soil fertility resulting in crops' stunted growth's They also recognized the fact

that stunted crops produce low yields and therefore they need to buy food to sustain their families. This concurs with a research done by Pauli *et al.* (2012). Farmers understood that application of organic fertilizer in the farm increased the population of soil macrofauna by increasing availability of food, while improving the soil conditions for soil macrofauna survival and crop's growth (Bunemann and McNeill 2004). They also associated improved soil fertility with soil macrofauna, e.g. the beetle larvae. This was in agreement with studies carried out by Nare *et al.* (2014).

## **Conclusion**

During ranking of factors influencing distribution of soil macrofauna, farmers singled out microhabitat as the most important factor and majority of them understood that soil macrofauna were mainly found under tree canopies.

Farmers identified many trees and their attributes that influence the distribution of soil macrofauna and singled out *D. rotundifolia* as the best indigenous tree with good attributes that help improved soil fertility, influenced positively the distribution of soil macrofauna and improved crop's growing conditions.

Different types of soils based on soil texture, colour and crops' suitability were identified by the farmers. They mentioned that different soil types favoured different crops, with clay and loam textured favouring maize and beans, while silt and sandy textured soils favoured root crops such as cassava.

Use of organic fertilizers led to increased soil macrofauna, while burning and use of pesticides killed them.

## CHAPTER SIX

### EVALUATING THE EFFECT OF INDIGENOUS TREE SPECIES ON SOIL MACROFAUNA, CARBON DYNAMIC AND NUTRIENT AVAILABILITY IN MIOMBO WOODLANDS

#### Abstract

Use of indigenous trees in agroforestry system is not commonly practised, though they may alter soil quality hence macrofauna communities. However, there is limited knowledge about how these indigenous trees affect soil macrofauna population. In this study the abundance of soil macrofauna, soil aggregates fractions and carbon contents were measured under five dominant indigenous tree species, *Acacia seyal* Delile, *Albizia amara* Boivin, *Combretum molle* R. Br. ex G. Don, *Dombeya rotundifolia* Planch and *Vangueria infausta* Burch. The area around each tree was subdivided into four concentric zones: zone A (1.5 m), Zone B (1.9 – 3.4 m), zone C (3.7 – 6.8 m) and zone D (5.6 – 10.2 m, away from the tree canopy).

The study revealed that *A. amara* increased significantly the abundance of beetles and earthworms as well as earthworm biomass, while *A. seyal* increased significantly the abundance and biomass of millipedes and termites. The abundances of all the six soil macrofauna decreased with increase in distance from tree trunk. *A. seyal* and distance from tree trunk (zone) increased significantly mean weight diameter and quantities of total macroaggregates, while *C. molle* and zone significantly influenced increase in quantities of microaggregates and microaggregates within macroaggregates. The quantities of microaggregates increased with increase in distance from tree trunk. Regarding carbon storage, *Acacia seyal* increased significantly the contents of carbon

in whole soil and total macroaggregate and the total carbon contents decreased with increase in distance from the tree trunk.

Correlation analysis showed that total macroaggregates and mean weight diameter (MWD) significantly correlated with millipedes and termites, while microaggregates within macroaggregates with millipedes and centipedes abundances. Likewise, total carbon contents in total macroaggregates, microaggregates and microaggregates within macroaggregates were significantly correlated with millipedes and termites abundances.

These findings have shown that soil macrofauna especially termites and millipedes played great role in soil macroaggregate formation and carbon storage. Whereas *A. seyal* increased significantly the abundances of millipedes and termites and also quantities of total macroaggregates, mean weight diameter and contents of total carbon.

Key words: Soil macrofauna, carbon contents, aggregate fractions, *A. seyal*, *A. amara*, *C. molle*, *D. rotundifolia* and *V. infausta*

## **6.1 Introduction**

The study of the spatial distribution pattern of soil biota and those factors influencing these patterns will help in understanding the structure and function of soil biodiversity and their relationships with above-ground processes (Ettema and Wardle, 2002). Soil organisms' exhibit patchy distributions at the scale of centimeters to meters, even where topography and soil texture are relatively uniform (Bruckner *et al.* 1999). Generally, species distributional patterns are likely to be controlled by many factors acting at different scales both in time and space. The spatial distribution of soil organisms is influenced by the plant cover resulting in a horizontal mosaic of areas

subjected to gradients of nutrient availability and microclimatic conditions. Spatial aggregation is also influenced by intrinsic population processes, such as dispersal, reproduction and competition for the soil microbiota, while for the more mobile macrofauna, such as earthworms, might be spatially structured at plot and field scales primarily as a result of population processes (Ettema and Wardle, 2002). In forests, spatial distribution of soil biota often reflects the zone of influence and positioning of single trees, such that patch sizes are one to several meters for soil microbes, nematodes and micro-arthropods (Klironomos *et al.* 1999). In mixed forests, differences in litter quality among tree species may lead to restructuring whereby plant species becomes key drivers of the spatial patterning of soil organisms and processes. With decreasing zones of plant influence, patch sizes of soil organisms decline correspondingly (Ettema and Wardle, 2002). Land use management and agricultural practices determine plant community composition and soil nutrient status, (Tilianakis *et al.* 2008), and together with soil organisms they may also be affected by changes in soil heterogeneity. Although tree spatial distribution have been found to be influenced by soil type and soil properties (John *et al.* 2007), the same tree will influence activities and spatial distribution of the belowground biodiversity due to changes that occur affecting the physical and chemical properties of soil around it (Zinke, 1962, Rhoades, 1997, Saetre, 1999; Pauli *et al.* 2010). Spatial heterogeneity in soil organism distributions occurs on nested scales, and is shaped by a spatial hierarchy of environmental factors, population processes and disturbance (Ettema and Wardle, 2002).

Horizontal distribution of soil macrofauna are less well documented than are vertical gradients, and most spatial studies report data integrated over soil cores (Ettema and Wardle, 2002).

Organic resource quality plays a great role in soil aggregate formation, carbon sequestration and nutrient release in the soil. The major resource quality parameters influencing nutrient release from plant residues are nitrogen (N), lignin and soluble polyphenol concentrations (Palm *et al.* 2001). Plant materials containing at least 2.5% N are usually described as being of high quality (e.g. *Gliricidia sepium*), where the application of these materials to soil is likely to result in net release of nitrogen if lignin and polyphenol are <15% and <4%, respectively. On the other hand, plant materials containing <2.5% N are considered to be of low quality (e.g. *Calliandra calothyrsus*) as they are likely to temporarily immobilize N during decomposition (Mafongoya *et al.* 1998a; Palm *et al.* 2001). Organic materials rich in N, and low in soluble polyphenols and lignin, readily release nutrients once incorporated into the soil. Organic materials low in nitrogen and high in lignin and polyphenol contents are likely to immobilize nitrogen during decomposition (Tian *et al.* 1992; Constantinides and Fownes, 1994). The Lignin + Polyphenol/N ratio has been used as an indicator of organic resource quality (Barrios *et al.* 1997; Palm *et al.* 2001).

The objective of this study was to investigate the influence of indigenous tree species on spatial distribution of soil macrofauna abundance and diversity around the tree crown and how the tree-soil macrofauna interactions affect soil aggregate stability and carbon storage.

It was hypothesized that, some tree species have a positive effect on aggregate-protected soil carbon, and therefore promote net carbon storage.

## 6.2. Materials and methods

### 6.2.1 Study site

The study was conducted in Kiberashi sentinel site. Further details were described in section 4.1.1, page 32.

### 6.2.2 Study design

Spatial studies were designed to isolate the effects of single indigenous tree species. Five dominant indigenous tree species, *A. seyal* Delile, *A. amara* Boivin, *C. molle* R. Br. ex G. Don, *D. rotundifolia* Planch. and *V. infausta* Burch. were targeted for the study based on the results of farmers' local knowledge study (Chapter five of this thesis). The choice of the five trees was based on the different tree families and trees commonly found in the farmers' farms. Each selected tree was replicated three times and the area around each tree was subdivided into four concentric zones: zone A: 0–2m from the trunk (the first monolith was taken at 1.5 m), zone B from 2 m to half diameter of the crown (1.9 - 3.4 m), zone C: from half diameter to the edge of the crown (3.7 - 6.8 m), and zone D: from the edge of the crown plus half diameter of the crown (5.6 – 10.2) (Figure 5).

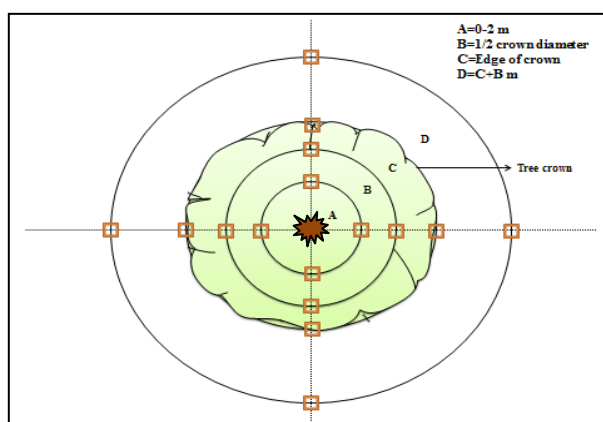


Figure 5: Spatial distribution of soil macrofauna and soil sampling around each tree studied

## **Field activities**

Measurements around each tree species included: collection of litter at each point where monolith was located and determination of their weights, soil macrofauna abundance and diversity, recording of tree identity, height and diameter at breast height (dbh), collection of tree leaves for chemical analyses and collection of soil samples for soil aggregate and Mid Infrared diffuse Reflectance (MIR) spectrometric analyses.

Full monoliths were located in each zone (A-D) in the four directions (at 90 ° to each other) (Figure 5). From each position of the full monolith in each zone, litter was first collected, put in the zip-lock bags before commencing excavation and brought to the laboratory for weight determination. All full monoliths were then excavated to a depth of 20 cm starting from the first concentric ring in zone A to D. The excavated soil monoliths (25 × 25 × 20 cm) were hand sorted for soil macrofauna. The soil macrofauna that were collected were the ones most frequently reported on agricultural soils, namely: ants, beetles, centipedes, earthworms, millipedes and termites. All soil macrofauna (except earthworms) collected were preserved in 75% alcohol, while earthworms were killed in 75% alcohol and fixed in 4% formaldehyde. These were transported in sealed vials to the laboratory for enumeration and biomass determination. After sorting of soil macrofauna, soil was then mixed and a sub-sample of 500 grams from each monolith were put in zip-lock bags for MIR analyses.

After excavation of each soil monolith to extract soil macrofauna, an additional 8 × 8 × 20 cm soil monolith was excavated from one of its walls. These soil monoliths were broken up along natural planes of weakness and gently passed through 10 mm sieve, and a sub-sample of 500 grams was put in a zip-lock bag, air dried and packed in a 7

cm (diameter tube) × 15 cm, and cotton wool put on both ends using masking tape to avoid soil aggregates crushing during transport.

### **6.3 Laboratory analyses**

#### **6.3.1 Soil aggregate protected Carbon**

Soil was separated into four water stable aggregate size fractions (Figure 9) (i) large macroaggregates (>2000 µm, LM), (ii) small macroaggregates (250 µm-2000 µm, SM), (iii) microaggregates (53–250 µm), and (iv) silt + clay sized particles (<53 µm, s+c), by use of mechanical wet sieving method, following a modification of method described by Elliot (1986) and Six *et al.* (1998). Thirty two grams of air-dried soil were transferred to 2 mm sieves, placed in recipients filled with de-mineralized water, and left to slake for 5 minutes. After 5 minutes, the 2 mm sieves were moved up and down 100 times over 3 minutes using wet sieving apparatus (Eijkelkamp Agrisearch Equipment). The procedure was repeated using the material that passed through the 2 mm sieve, using a 250 µm sieve and subsequently a 53 µm sieve (one by one). Soil aggregates retained on each sieve was backwashed into pre-weighed containers, oven-dried at 60 °C for two days and weighed. A representative 250 ml subsample was taken from the suspension containing the <53 µm silt and clay sized particles to determine the weight of the smallest fraction.

The amount of large macroaggregates (LM) was very small in some subplots, and therefore, it was combined with small microaggregates (SM) to obtain total macroaggregates (TM) and these were subsampled and subjected to fractionation analysis using microaggregate isolator

(Six *et al.* 2000) (Figure 6).

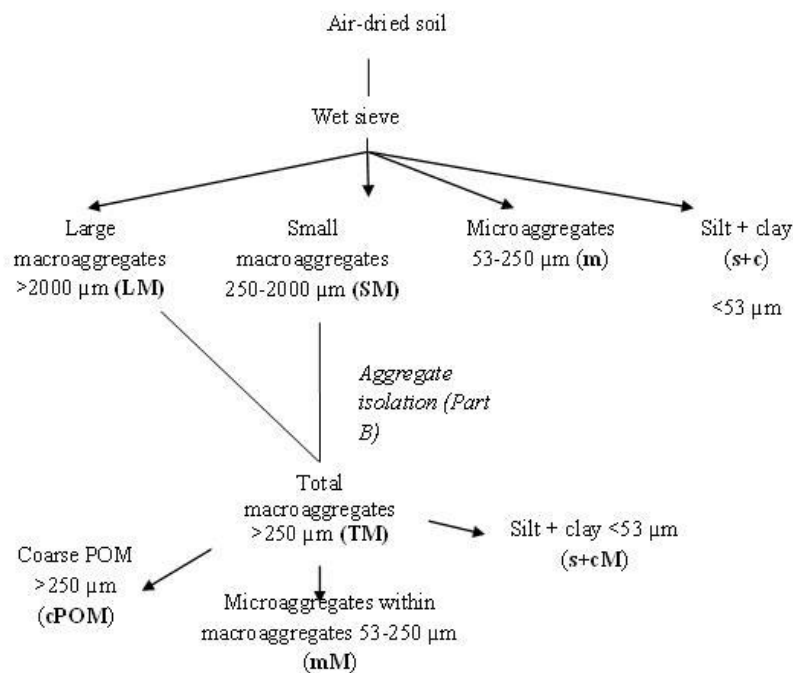


Figure 6: Fractionation scheme for separation of whole soil into aggregate fractions

Where: TM=Total macroaggregates (LM=Large macroaggregates + SM=Small macroaggregates); m=microaggregates; s+c=Silt+Clay; cPOM=Coarse particulate organic matter; mM=microaggregates within macroaggregates; s+cM=silt+clay occluded in macroaggregates

A five grams subsample of TM was placed on a 250 µm mesh screen on top of the device and shaken with 50 glass beads (4 mm in diameter) for 3 minutes until all macroaggregates were broken. Water was allowed to flow continuously through the microaggregate isolator such that the microaggregates were flushed immediately through the 250 µm sieve onto a 53 µm sieve. Once all the macroaggregates were broken down, sand and coarse particulate organic matter (cPOM) retained on the top of the 250 µm mesh were backwashed into a pre-weighed container. The sieve (53 µm) holding the microaggregates was manually moved up and down 50 times over 2 minutes in the suspension containing <53 µm fraction (Six *et al.* 2000). A representative 250 milliliters subsample was taken from the suspension containing the <53 µm silt and clay sized particles to determine the weight of the smallest fraction. Three fractions were obtained (Figure 6) namely: coarse POM + sand (> 250 µm,

cPOM), microaggregates within macroaggregates (53-250  $\mu\text{m}$ , mM), and silt and clay occluded in macroaggregates ( $< 53 \mu\text{m}$ , s+cM), and all were oven dried at 60 °C for two days and weighed. All the fractions inclusive of whole soil were ground and analyzed for total carbon using a CN-Analyzer (Flash EA 1112 NC, CE Instrument, Thermo-quest).

The weights of macro- and microaggregates were corrected for the sand content of the same size as the aggregates because sand of the same size as the aggregate is usually not part of an aggregate and should consequently not be weighed as an aggregate. The proportion of microaggregate (53-250  $\mu\text{m}$ ) weight within macroaggregates (250-200  $\mu\text{m}$ ) was calculated as in equation 1:

$$\frac{\text{Microaggregate weight} - \text{weight of } 53\text{-}250 \mu\text{m sized sand}}{\text{Macroaggregate weight} - \text{weight of } 250\text{-}200 \mu\text{m sized sand}} \quad \text{Equation 1}$$

### **6.3.2 Soil pH determination**

Dry whole soil from each treatment were sub-sampled (in duplicate), mixed thoroughly and ground to pass through a 2 mm sieve. Ten grams of soil sample were drawn from each sub-sample and were put in a separate 100 ml bottle and 25 milliliters of distilled water was added to each bottle. The mixture were mounted on a reciprocal shaker and shaken for ten minutes at 200 rpm and were left to stand for 30 minutes, then stirred for two minutes. The pH of the supernatant liquid was measured using a pH meter and as described in Anderson and Ingram, (1993).

### **6.3.3 Mean weight diameter (MWD) of soil particles**

Mean weight diameter (MWD) is an index that characterizes the structure of the whole soil and is a measure of aggregates that remained on each sieve,  $>2000 \mu\text{m}$ , 250-2000  $\mu\text{m}$ , 53-250  $\mu\text{m}$  and  $<53 \mu\text{m}$ . MWD calculation was done using equation 2:

$$\text{MWD} = \frac{\sum xiwi}{W} \quad \text{Equation 2}$$

Where:  $xi$  is the mean diameter of any particular size range of aggregates separated by sieving, and  $wi$  is the weight of aggregates in that size range as a fraction of the total dry weight of soil used ( $W$ ) (Six *et al.* 2000).

#### **6.3.4 Chemical characterization of the tree prunings**

The prunings collected from the five tree species were ground and analyzed for the following: i) Total nitrogen and total carbon by CN-Analyzer (Flash EA 1112 NC, CE Instrument, Thermo-quest); (ii) Total soluble polyphenols by the Folin-Ciocalteu method (Constantinides and Fownes 1994); (iii) Lignin analysis was done using TSBF method based on the acid detergent fibre method (ADF) (Anderson and Ingram 1993).

#### **6.4 Data analysis**

The data on the effects of indigenous trees and tree zone on soil aggregate fractions, mean weight diameter, soil macrofauna and total carbon were subjected to a two way analysis of variance (ANOVA) using GenStat 12.1 (2009) statistical package. Correlation analyses were conducted to establish the relationship between soil macrofauna and soil aggregate fractions and also between soil macrofauna and total carbon using XLSTAT PRO (XLSTAT, 2009). Separation of means was tested using Tukey's significance difference with a significance level of  $P \leq 0.05$ .

## 6.5 Results

### 6.5.1 Soil characterization

The initial soil characteristics which was done prior to the study showed that soil pH ranged from 5.66 to 6.05 while total nitrogen contents ranged from 0.7 to 1.9 g/kg, and total carbon from 10.2 to 23.8 g/kg. Available potassium and calcium contents ranged from 155 to 358 mg/kg and 991 to 1776 mg/kg of soil. Phosphorus on the other hand ranged from 6.0 to 13.7 mg/kg soil (Table 9). The soil texture with sand ranging from 66 to 83%, silt from 5 to 11% and clay from 9 to 27% was considered as loamy sand (Table 9).

Table 9: Baseline characteristics of soil in the study area under selected trees

Tree species	<i>Albizia amara</i>	<i>Acacia seyal</i>	<i>Combretum molle</i>	<i>D. Rotundifolia &amp; V. infausta</i>
Total Carbon (gkg <sup>-1</sup> )	18.7	14.2	10.2	23.8
Total Nitrogen (gkg <sup>-1</sup> )	1.4	1.1	0.7	1.9
Ca (mg/kg soil)	1291.22	1264.52	990.94	1776.04
K (mg/kg soil)	134.88	358.16	170.12	114.92
Mg (mg/kg soil)	241.56	386.43	340.83	224.09
Na (mg/kg soil)	28.01	35.12	41.32	25.79
P (mg/kg soil)	13.69	6.01	8.62	13.4
pH	5.95	5.86	5.66	6.05
%Sand	83	66	84	80
%Silt	8	7	5	11
%Clay	9	27	11	9

### 6.5.2 Soil macrofauna distribution as influenced by tree species and tree zone

The response of soil macrofauna to presence of the tree depends on the tree species, the distance from the tree trunk (zone), quality and quantity of litter produced.

In this study, it was observed that tree species had significant effect on beetle abundance ( $p=0.002$ ), with higher abundance of beetles in soil sampled around *A. amara* than the other soil macrofauna. Trees did not influence significantly beetle

biomass (Table 10). Zone showed significantly high ( $p < 0.001$ ) effect on beetle abundance with zone A (closer to tree trunk) recording more beetles compared to the other zones, whereas zone D had lower abundance (Figure 7). Similarly, the interaction between tree species and zone influenced significantly ( $p = 0.03$ ) beetles' abundance.

Tree species did not significantly influence centipedes abundance and biomass, but the zone (distance from tree trunk) influenced their abundance significantly ( $p = 0.039$ ) with more centipedes being recorded in zone A than the other zones (Figure 7).

Tree species highly significantly influenced ( $p < 0.001$ ) the abundance and biomass of earthworm. *A. amara* had higher earthworm abundance compared with the other tree species, while *C. molle* had the lowest abundance. On the other hand, tree zone had no influence on the abundance of earthworm, though earthworm abundance was higher in zone B compared with the other zones (Figure 7).

Tree species significantly influenced millipedes abundance ( $p = 0.002$ ) and biomass ( $p = 0.004$ ) with *A. seyal* recording the highest abundance compared to other tree species. Similarly, tree zones significantly influence their abundance ( $p = 0.002$ ) and biomass ( $p = 0.02$ ) with more millipedes recorded in zone A (Table 10).

Table 10: Influence of tree species and distance from tree trunk on soil macrofauna abundances and biomasses

Soil macrofauna		Tree species					Level of significance and SED					
		<i>Acacia seyal</i>	<i>Albizia amara</i>	<i>Combretum molle</i>	<i>Dombeya rotundifolia</i>	<i>Vangueria infausta</i>	P (Tree)	SED (Tree)	P (Zone)	SED (Zone)	P (Inter)	SED (Inter)
Abundance counts/m <sup>-2</sup>	Atind	105.5	121.5	105.0	94.0	27.7	0.28	45.80	0.01	40.90	0.15	91.50
	Btind	21.4 <sup>b</sup>	39.0 <sup>a</sup>	23.3 <sup>ab</sup>	20.7 <sup>b</sup>	16.7 <sup>b</sup>	0.002	5.77	<0.001	5.16	0.03	11.50
	Cpind	4.0	2.0	2.3	4.0	5.3	0.45	2.02	0.04	1.80	0.78	4.03
	Ewind	26.7 <sup>a</sup>	34.4 <sup>a</sup>	3.0 <sup>c</sup>	3.3 <sup>c</sup>	22.3 <sup>ab</sup>	<0.001	6.40	0.41	5.73	0.88	12.81
	Mpind	32.7 <sup>a</sup>	16.0 <sup>ab</sup>	6.4 <sup>b</sup>	7.7 <sup>b</sup>	7.3 <sup>b</sup>	0.002	7.49	0.002	6.70	0.16	14.99
	Tmind	387.5 <sup>a</sup>	305.3 <sup>ab</sup>	51.3 <sup>b</sup>	71.5 <sup>b</sup>	48.5 <sup>b</sup>	<0.001	96.90	0.07	86.60	0.21	193.70
Biomass g/m <sup>-2</sup>	Atbiom	0.2	0.2	0.2	0.4	0.04	0.33	0.15	0.22	0.13	0.31	0.30
	Btbiom	1.9	5.0	2.7	4.3	3.4	0.13	1.29	0.88	1.16	0.77	2.58
	Cpbiom	0.1	0.004	0.02	0.1	0.01	0.15	0.06	0.68	0.06	0.73	0.12
	Ewbiom	0.2 <sup>b</sup>	1.1 <sup>a</sup>	0.2 <sup>b</sup>	0.1 <sup>b</sup>	0.3 <sup>b</sup>	<0.001	0.19	0.35	0.17	0.23	0.38
	Mpbiom	3.8 <sup>a</sup>	2.1 <sup>a</sup>	0.8 <sup>b</sup>	0.3 <sup>b</sup>	0.6 <sup>b</sup>	0.004	1.01	0.02	0.91	0.27	2.02
	Tmbiom	0.7 <sup>a</sup>	0.7 <sup>a</sup>	0.1 <sup>b</sup>	0.1 <sup>b</sup>	0.02 <sup>b</sup>	<0.001	0.21	0.05	0.18	0.24	0.41

Means followed by the same lowercase letters are not significantly different at p<0.05

At=Ants; Bt=Beetles; Cp=Centipedes; Ew=Earthworms; Mp=Millipedes; Tm=Termites; ind=Abundance; biom=Biomass; Inter=Interaction; Interaction=Interaction between tree and zones

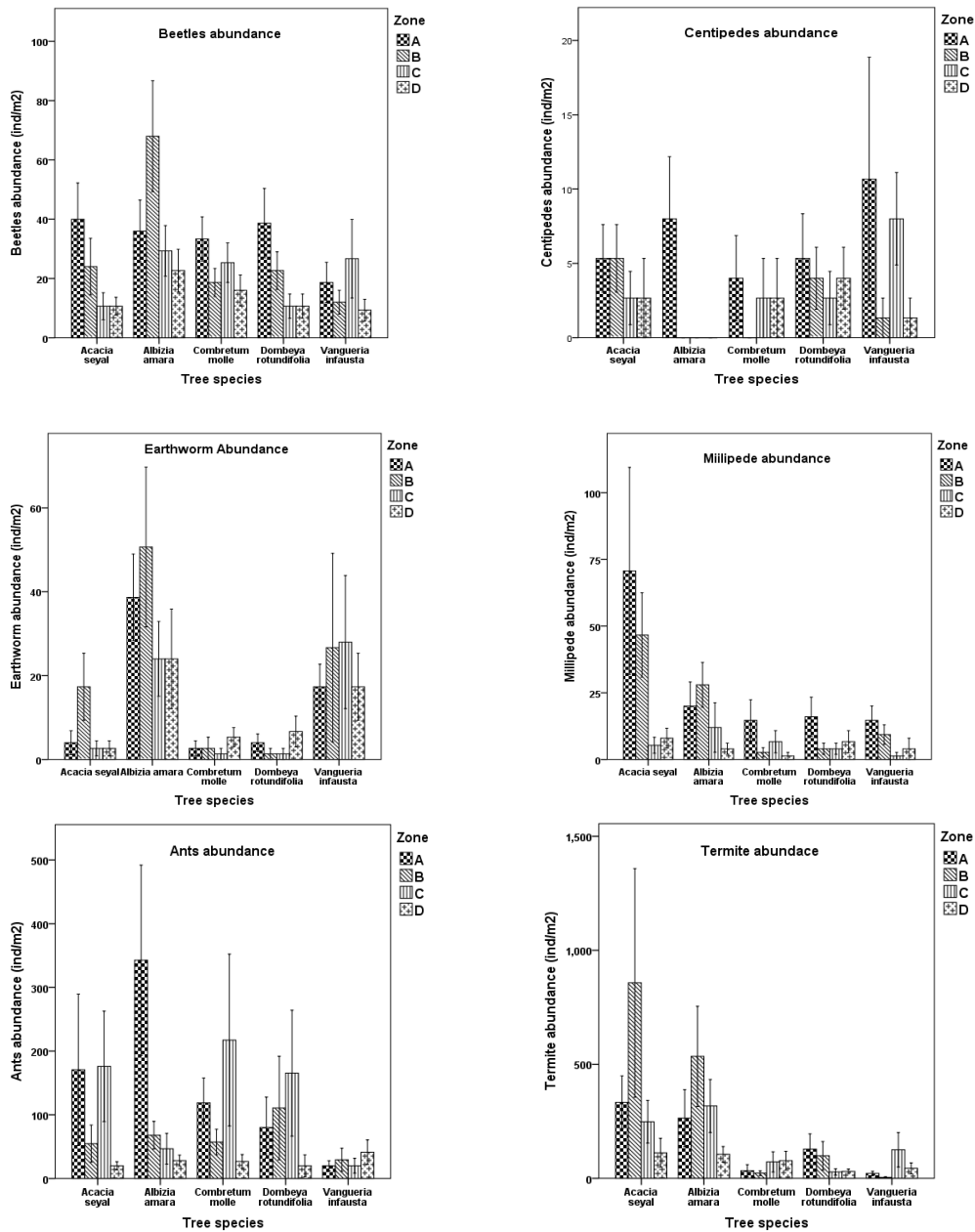


Figure 7: Influence of tree species and distance from tree trunk on spatial distribution of soil macrofauna.

ABC is the tree zone under tree canopy; D=away from tree canopy (Section 4.2.2)

Tree species did not significantly influence ants' abundance ( $p=0.28$ ) and biomass ( $p=0.33$ ), but the zone significantly influenced their abundance ( $p=0.01$ ) but not their biomass (0.22) (Figure 7).

Tree species significantly influenced the abundance and biomass ( $p<0.001$ ) of termites, with *Acacia seyal* recording more termite abundance than the other tree

species while *Vangueria infausta* had lower termite abundance (Table 10). Tree zone on the other hand influenced termite biomass ( $p=0.05$ ) significantly but not their abundance ( $p=0.07$ ). Although tree zone did not influence the abundance of termites, zone B recorded higher abundances and decreased with an increase with distance from the tree trunk (Figure 7).

### **6.5.3 Water stable aggregation**

The percentage of total macroaggregates was significantly affected by tree species ( $p<0.001$ ). Higher quantities of TM (38.4 g/100 g soil) were found in soil sampled under *A. seyal* canopy than other tree species (Table 11). Lower quantities of TM were found in soil sampled under *C. molle*, whereas *V. infausta* showed an increase in TM with an increase in distance from the tree trunk. Tree zone on the other hand did not significantly influence the quantities of TM (Figure 8).

Tree species influenced significantly the quantities of microaggregates ( $p<0.001$ ), with *C. molle* recording higher quantities of microaggregates than all other tree species. Similarly tree zone highly significantly influenced the quantities of microaggregates and this increased with distance from the tree trunk ( $p<0.001$ ) (Figure 9). Whereas the interaction between tree species and distance from the tree trunk (zone) significantly influenced the distribution of microaggregate ( $p=0.01$ ) (Table 11).

Table 11: Influence of tree species and distance from tree trunk on soil aggregate fractions and mean weight diameter

Soil aggregate fractions	Tree species					Level of significance and SED					
	<i>Acacia seyal</i>	<i>Albizia amara</i>	<i>Combretum molle</i>	<i>Dombeya rotundifolia</i>	<i>Vangueria infausta</i>	P (Tree)	SED (Tree)	P (Zone)	SED (Zone)	P (Inter)	SED (Inter)
TM (> 250µm)	38.4 <sup>a</sup>	19.7 <sup>bc</sup>	16.8 <sup>c</sup>	18.5 <sup>c</sup>	22.9 <sup>b</sup>	<0.001	1.31	0.85	1.17	0.44	2.62
m (53-250 µm)	10.7 <sup>bc</sup>	11.8 <sup>ab</sup>	12.5 <sup>a</sup>	7.9 <sup>d</sup>	9.9 <sup>c</sup>	<0.001	0.53	<0.001	0.47	0.01	1.05
s+c (<53 µm)	0.9 <sup>bc</sup>	1.1 <sup>b</sup>	1.3 <sup>a</sup>	0.8 <sup>c</sup>	1.0 <sup>bc</sup>	<0.001	0.83	0.04	0.07	0.16	0.17
mM (53-250 µm)	0.3 <sup>d</sup>	0.7 <sup>ab</sup>	0.8 <sup>a</sup>	0.5 <sup>bc</sup>	0.5 <sup>c</sup>	<0.001	0.05	0.001	0.04	0.003	0.10
s+cM (<53 µm)	5.7 <sup>a</sup>	4.1 <sup>b</sup>	4.2 <sup>b</sup>	4.0 <sup>b</sup>	4.6 <sup>b</sup>	<0.001	0.26	0.58	0.23	0.36	0.52
MWD	2.0 <sup>a</sup>	1.0 <sup>c</sup>	0.9 <sup>c</sup>	1.0 <sup>c</sup>	1.2 <sup>b</sup>	<0.001	0.07	0.85	0.06	0.47	0.13

Means followed by the same lowercase letters are not significantly different at p<0.05

TM=Total macroaggregates; m=Microaggregates; s+c=silt + clay; mM=Microaggregates within macroaggregate; s+cM=Silt & Clay within macroaggregates;

MWD=Mean weight diameter; Interaction=tree species\*zone; Inter=Interaction

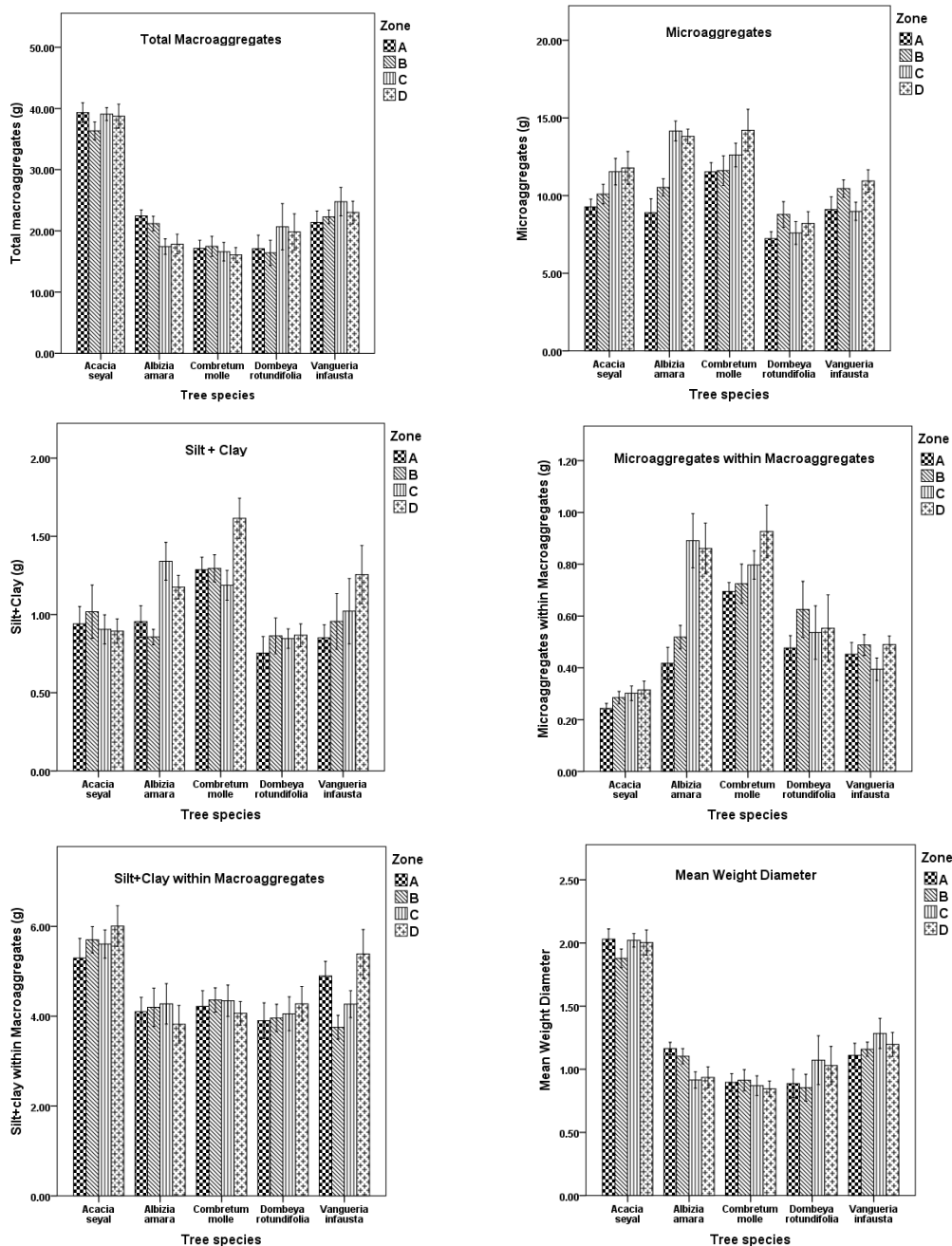


Figure 8: Influence of tree species and distance from tree trunk (zone) on soil aggregate fractions and mean weight diameter. ABC is the tree zone under tree canopy; D=away from tree canopy (Section 4.2.2)

Tree species highly significantly influenced the quantities of silt+clay ( $p < 0.001$ ) with *C. molle* recording significantly higher quantities of silt+clay. Also tree zone recorded significant influence on the quantities of silt+clay (0.04), with zone D having higher silt+clay quantities compared with the other trees' zones.

Tree species highly significantly influenced the quantities of micraggregates within macroaggregates (mM) with *C. molle* having higher mM compared to other tree species ( $p < 0.001$ ). Similarly, quantities of mM increased with distance from the tree trunk, with zone D recording higher quantities of mM ( $p = 0.001$ ). The interaction between tree species and the zone significantly influenced the quantities of mM ( $p = 0.003$ ).

Tree species highly significantly influenced the quantities of silt+clay occluded in macroaggregates (scM) with *A. seyal* having higher scM compared to other tree species ( $p < 0.001$ ). Tree zone on the other hand did not significantly ( $p = 0.58$ ) influence the quantities of scM (Figure 8).

#### **6.5.4 Mean weight diameter**

Tree species influenced significantly ( $p < 0.001$ ) mean weight diameter of the soil, while zone did not have significant effect (0.85). Soil sampled around *A. seyal* had higher mean weight diameter (MWD) compared to the ones sampled around other tree species. MWD decreased in the following order: *A. seyal* > *V. infausta* > *A. amara* > *D. rotundifolia* > *C. molle* (Table 11).

#### **6.5.5 Carbon dynamics, tree species and distance from tree trunk**

Tree species and distance from tree trunk significantly ( $p < 0.001$  and  $p = 0.03$  respectively) influenced total carbon (TC) contents in whole soil (Table 13). Total carbon contents in whole soil decreased with an increase in distance from the tree trunk with *A. seyal* recording more TC contents in soil sampled around it than the other four tree species (Figure 9). Likewise, TC contents in total macroaggregates (TM) were highly significantly ( $p < 0.001$ ) influenced by tree species and distance from tree trunk ( $p = 0.03$ ) with *A. seyal* recording the highest TC in TM. Likewise, the

interaction between tree species and zones did not significantly ( $p=0.06$ ) influence TC in TM.

TC in microaggregates was highly significantly ( $p<0.001$ ) influenced by tree species with *A. seyal* recording more TC in microaggregate fractions than the other tree species. TC decreased with an increase in distance from the tree trunk, though tree zone did not have significant ( $p=0.40$ ) effect on TC in microaggregates, but the interaction between tree species and zone significantly ( $p=0.03$ ) influenced TC in microaggregates.

TC in silt and clay was significantly ( $p<0.001$ ) influenced by tree species with *A. seyal* recording more TC in s+c than the other tree species (Table 13). Likewise, tree zone influenced significantly ( $p= 0.04$ ) the contents of TC in s+c with zone A recording higher TC in s+c than all other tree zones.

Tree species highly significantly ( $p<0.001$ ) influenced TC in microaggregate within macroaggregate (mM) with highest contents in soil collected around *A. seyal*. Distance from tree trunk significantly ( $p=0.03$ ) influenced the contents of TC in mM with soil samples collected in zones under tree canopies recording higher TC in mM. Similarly, the interaction between tree species and zone significantly ( $p=0.02$ ) influenced TC in mM.

TC in silt+clay within macroaggregate (scM) was significantly ( $p<0.001$ ) influenced by tree species with soil around *Acacia seyal* recording the highest TC in scM compared to the other tree species. Tree zone did not significantly ( $p=0.06$ ) influenced the contents of TC in scM.

Table 12: Total carbon in aggregate fractions as influenced by tree species

Soil aggregate fractions	Tree species					Level of significance and SED					
	<i>Acacia seyal</i>	<i>Albizia amara</i>	<i>Combretum molle</i>	<i>Dombeya rotundifolia</i>	<i>Vangueria infausta</i>	P (Tree)	SED (Tree)	P (Zone)	SED (Zone)	P (Interaction)	SED (Interaction)
Whole soil	22.6 <sup>a</sup>	16.45 <sup>c</sup>	10.21 <sup>d</sup>	16.16 <sup>c</sup>	19.26 <sup>b</sup>	<0.001	0.78	0.03	0.7	0.14	1.56
TM (>250µm)	5.30 <sup>a</sup>	2.65 <sup>c</sup>	1.24 <sup>d</sup>	3.00 <sup>bc</sup>	3.60 <sup>b</sup>	<0.001	0.26	0.03	0.23	0.06	0.51
m (53-250 µm)	6.50 <sup>a</sup>	4.56 <sup>c</sup>	2.66 <sup>d</sup>	4.68 <sup>c</sup>	5.42 <sup>b</sup>	<0.001	0.25	0.40	0.23	0.03	0.5
s+c (<53 µm)	10.81 <sup>a</sup>	9.24 <sup>bc</sup>	6.31 <sup>d</sup>	8.49 <sup>c</sup>	10.24 <sup>ab</sup>	<0.001	0.4	0.04	0.36	0.69	0.08
mM (53-250 µm)	1.94 <sup>a</sup>	0.59 <sup>c</sup>	0.28 <sup>d</sup>	0.84 <sup>b</sup>	0.92 <sup>d</sup>	<0.001	0.1	0.03	0.09	0.02	0.19
s+cM (<53 µm)	2.98 <sup>a</sup>	1.99 <sup>c</sup>	0.92 <sup>d</sup>	2.03 <sup>b</sup>	2.60 <sup>ab</sup>	<0.001	0.16	0.06	0.14	0.15	0.31

Means followed by the same lowercase letters are not significantly different at  $p < 0.05$

TM=Total macroaggregates; m=Microaggregates; s+c=silt + clay; mM=Microaggregates within macroaggregate; s+cM=Silt & Clay within macroaggregates;

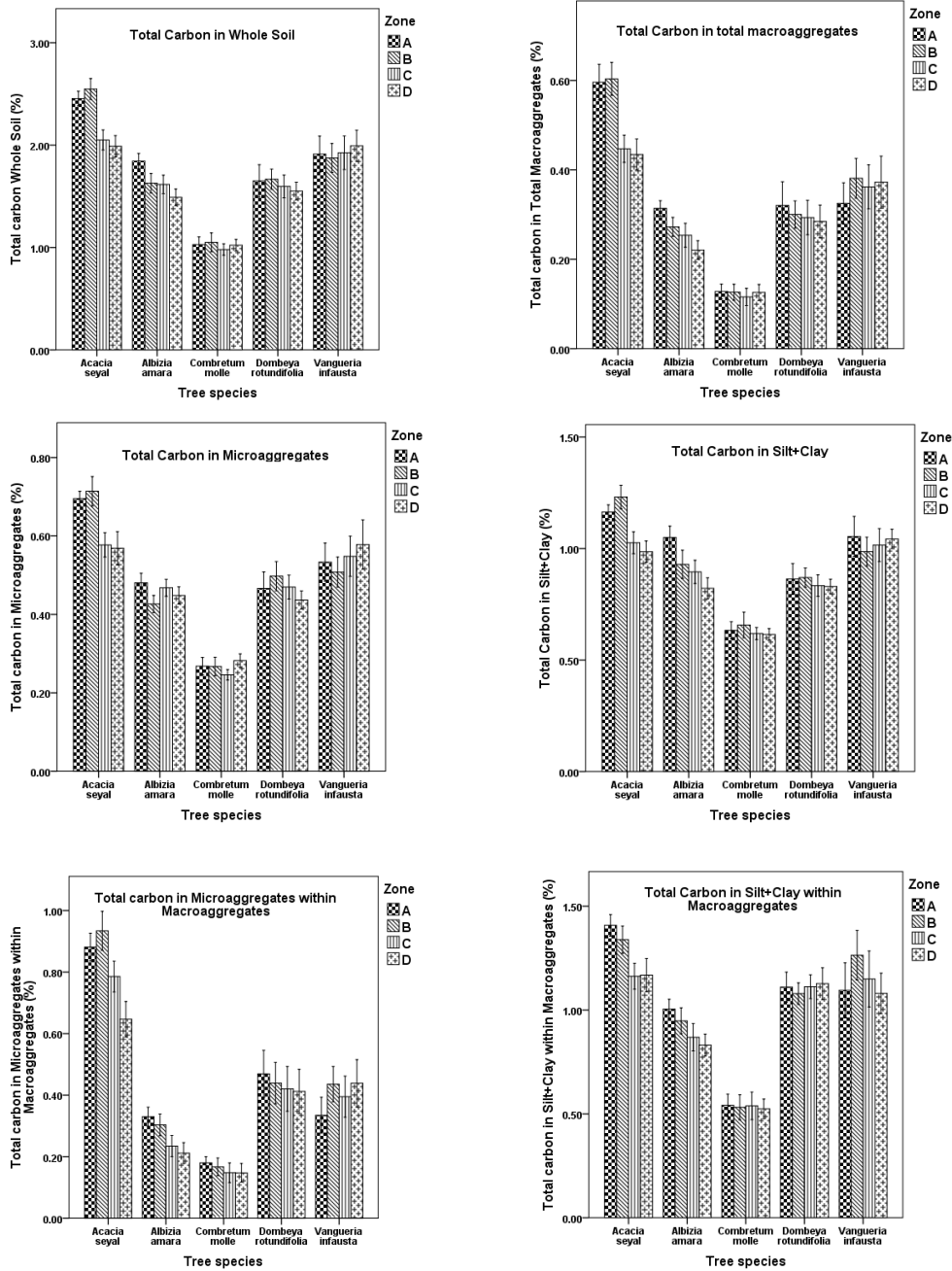


Figure 9: Influence of tree species and distance from tree trunk on total carbon in whole soil and aggregate fractions.

ABC is the tree zone under tree canopy; D=away from tree canopy (Section 4.2.2)

### 6.5.6 Soil chemical properties

Soil chemical properties were highly significantly influenced by tree species ( $p < 0.001$ ). *A. seyal* highly significantly influenced total nitrogen ( $p < 0.001$ ), Al ( $p < 0.001$ ), potassium ( $p < 0.001$ ) and phosphorus sorption index ( $p < 0.001$ ), whereas *A.*

*seyal* and *D. rotundifolia* highly significantly influenced contents of calcium and magnesium (Table 13).

*A. seyal*, *D. rotundifolia* and *V. infausta* highly significantly ( $p < 0.001$ ) influenced contents of phosphorus, but no significant difference at  $p < 0.05$  between the three tree species. Similarly, *C. molle*, *D. rotundifolia* and *V. infausta* highly significantly ( $p < 0.001$ ) influenced contents of sodium, but no significant difference at  $p < 0.05$  between the three tree species (Table 13).

Table 13: Soil chemical properties as influenced by tree species

Soil chemical properties	Tree species					P value	SED
	<i>Acacia seyal</i>	<i>Albizia amara</i>	<i>Combretum molle</i>	<i>Dombeya rotundifolia</i>	<i>Vangueria infausta</i>		
						P (Tree)	SED (Tree)
TN (mg/kg soil)	1.38 <sup>a</sup>	0.72 <sup>c</sup>	0.67 <sup>c</sup>	0.98 <sup>b</sup>	1.05 <sup>b</sup>	<0.001	0.09
Al (mg/kg soil)	1318.53 <sup>a</sup>	937.45 <sup>c</sup>	1027.97 <sup>b</sup>	1086.00 <sup>b</sup>	1026.70 <sup>b</sup>	<0.001	46.89
Ca (mg/kg soil)	1219.50 <sup>a</sup>	888.90 <sup>c</sup>	851.79 <sup>c</sup>	1138.69 <sup>a</sup>	1043.62 <sup>b</sup>	<0.001	61.56
K (mg/kg soil)	329.07 <sup>a</sup>	144.33 <sup>c</sup>	174.56 <sup>b</sup>	195.75 <sup>b</sup>	176.91 <sup>b</sup>	<0.001	20.93
Mg (mg/kg soil)	315.02 <sup>a</sup>	226.95 <sup>c</sup>	278.65 <sup>b</sup>	284.44 <sup>a</sup>	265.03 <sup>b</sup>	<0.001	17.18
Na (mg/kg soil)	37.48 <sup>b</sup>	35.37 <sup>c</sup>	39.70 <sup>a</sup>	39.65 <sup>a</sup>	39.38 <sup>a</sup>	<0.001	0.83
P (mg/kg soil)	45.01 <sup>a</sup>	30.65 <sup>b</sup>	31.96 <sup>b</sup>	41.51 <sup>a</sup>	41.73 <sup>a</sup>	<0.001	3.78
PSI	57.78 <sup>a</sup>	26.66 <sup>c</sup>	41.18 <sup>b</sup>	35.64 <sup>b</sup>	31.92 <sup>c</sup>	<0.001	4.40

Means followed by the same lowercase letters are not significantly different at p<0.05

TN=Total Nitrogen; Al=Aluminium; Ca=Calcium; K=Potassium; Mg=Magnesium; Na=Sodium; P=Phosphorus; PSI=Phosphorus Sorption Index

### 6.5.7 Quality of residue from trees

*D. rotundifolia* had significantly ( $p < 0.001$ ) higher quantities of leaf litter which decreased as distance from the tree trunk increased (Figure 10). Zone A, B and C recorded higher litter quantities compared to zone D (away from tree canopy).

*D. rotundifolia* and *A. amara* residues had significantly ( $p < 0.001$ ) higher contents of lignin compared to those from other tree species (Table 14).

Carbon contents in *Acacia seyal* residues was significantly higher ( $p < 0.001$ ) than residues of the other tree species (Table 14).

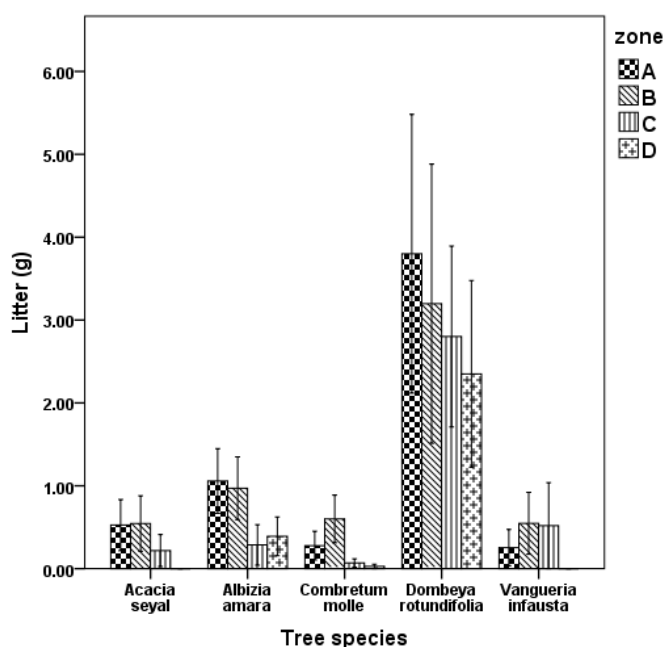


Figure 10: The distribution of tree litter around each tree species and quantities collected.

ABC is the tree zone under tree canopy; D=away from tree canopy (Section 4.2.2)

Table 14: Residue quality of five indigenous trees

Residue quality	Tree species						P	SED
	A. <i>seyal</i>	A. <i>amara</i>	C. <i>molle</i>	D. <i>rotundifolia</i>	V. <i>infausta</i>	(Tree)		
%N	1.97	3.14	1.84	2.14	2.50	<0.001	0.05	
%C	45.50	46.36	45.20	40.74	42.47	<0.001	0.10	
%PP	25.58	4.25	8.38	4.05	3.91	<0.001	0.51	
%LIG	18.57	30.06	27.31	30.04	22.54	<0.001	0.91	
C/N	23.23	14.76	24.66	19.13	17.54	<0.001	0.36	
PP/N	12.90	1.35	4.60	1.94	1.59	<0.001	0.20	
LIG/N	9.53	9.59	14.86	14.12	8.86	<0.001	0.40	
(PP+LIG)/N	22.43	10.94	19.46	16.06	10.46	<0.001	0.45	

PP=Polyphenol; LIG=Lignin; N=Nitrogen; C=Carbon

Significantly high N content was recorded in *A. amara* residues compared to the other tree species residues. The C/N ratio for *A. amara* was the lowest compared to all other tree species while *C. molle* had the highest. On the other hand, the residue quality of the tree species decreased in the order based on lignin/N ratio: *V. infausta* > *A. seyal* > *A. amara* > *D. rotundifolia* > *C. molle* (Table 14).

### 6.5.8 Correlation analyses

The quantities of total macroaggregates were significantly correlated with termite and millipede abundance ( $r=0.144$  and  $r=0.209$  respectively), while silt and clay occluded in macroaggregate was also significantly correlated with termite and centipedes abundance ( $r=0.151$  and  $r=0.154$  respectively). Similarly, MWD was significantly correlated with termite and millipede abundance ( $r=0.144$  and  $r=0.208$  respectively). It was also found that microaggregate within macroaggregate were significantly (negatively) correlated with millipede and centipede abundance ( $r=-0.172$  and  $r=-0.130$  respectively).

No significant correlations were observed between soil aggregate fractions with ants, beetles and earthworms (Table 15a).

Table 15: Correlations between soil macrofauna counts, soil aggregate fractions and total carbon in soil aggregate fractions

a). Soil fraction	Soil macrofauna					
	Ewind	Tmind	Atind	Mpind	Cpind	Btind
TM	0.277	<b>0.144*</b>	0.867	<b>0.209**</b>	0.083	0.645
m	0.365	0.907	0.097	0.486	0.942	0.513
s+c	0.872	0.146	0.140	0.252	0.478	0.408
mM	0.527	0.112	0.529	<b>-0.172**</b>	<b>-0.130*</b>	0.466
s+cM	0.477	<b>0.151*</b>	0.740	0.305	<b>0.154*</b>	0.385
MWD	0.273	<b>0.144*</b>	0.855	<b>0.208**</b>	0.083	0.641

#### b). Total Carbon

aggregate fractions	Soil macrofauna					
	Ewind	Tmind	Atind	Mpind	Cpind	Btind
Total carbon in TM	-0.013	<b>0.157*</b>	-0.012	<b>0.300***</b>	<b>0.265***</b>	0.010
Total carbon in m	0.074	<b>0.196**</b>	-0.031	<b>0.198**</b>	<b>0.239***</b>	0.015
Total carbon in s+c	<b>0.146*</b>	<b>0.277***</b>	0.010	<b>0.168*</b>	<b>0.291***</b>	0.078
Total carbon mM	-0.085	<b>0.140*</b>	0.006	<b>0.233***</b>	<b>0.207**</b>	-0.040
Total carbon scM	-0.025	0.056	-0.035	<b>0.216**</b>	<b>0.297***</b>	-0.033

Values in bold are significantly different with a significance level \*p < 0.05, \*\*p < 0.001, \*\*\*p < 0.0001

Where: Ew=Earthworm; Tm=Termites; At=Ants; Mp=Millipedes; Cp=Centipedes; Bt=Beetles; ind=Abundance; TM=Total macroaggregates; m=microaggregates; s+c=Silt and Clay; mM=microaggregate within macroaggregates; scM=Silt+clay within macroaggregates

Total carbon contents in total macroaggregates, microaggregates, silt+clay and microaggregates within macroaggregates were significantly correlated with termites (r=0.157, r=0.196, r=0.277 and r=0.140 respectively). Similarly total carbon contents in total macroaggregates, microaggregates, silt+clay, microaggregates within macroaggregates and silt+clay occluded in macroaggregates were significantly correlated with millipedes (r=0.300, r=0.198, r=0.168, r=0.233 and r=0.216 respectively). On the other hand, total carbon contents in total macroaggregates, microaggregates, silt+clay, microaggregates within macroaggregates and silt+clay occluded in macroaggregates were significantly correlated with centipedes (r=0.265,

$r=0.239$ ,  $r=0.291$ ,  $r=0.207$  and  $r=0.297$  respectively), while in silt+clay ( $r=0.146$ ) it was significantly correlated with earthworms (Table 15b).

## **6.6 Discussions**

### **6.6.1 Spatial distribution of soil macrofauna as affected by tree species and distance from tree trunks**

The low lignin/N ratio of the residues may have contributed to high abundance of beetles and earthworms present under *A. amara* and that of millipedes and termites under *A. seyal* canopies. Millipedes are known to be selective feeders with a preference for high calcium content and relative humidity. Their presence under the *A. seyal* canopies may have been influenced by high calcium contents in soil sampled around it coupled with reduced solar radiation due to shade provided by the canopy (Moco *et al.* 2010).

It is evident that litter quality and quantities may have played important roles in the distribution of soil organisms through substrate provision, increased carbon resources and increased soil moisture retention, as well as better microclimatic conditions for the soil macrofauna. Lignin/N ratio of the tree residues influenced earthworm distribution. There was high abundance of earthworm under trees with low lignin/N ratio, showing that the factor that was driving earthworm distribution was lignin/N ratio. On the other hand, earthworms' favours soil with higher moisture and this was possible under the tree canopy. Tree species may have provided good microclimatic condition that favoured the high abundance of earthworms. The observed higher abundance of earthworm in zone B of this study is consistent with the studies by Scheu and Poser (1996) and Sileshi and Mafongoya (2007). On the other hand, there was increased centipede abundance near the tree trunks due to the increase in

substrate and favourable microclimate for the prey under the tree canopy. The findings are consistent with studies by Scheu and Poser (1996). Similarly, the high abundance of ants near the tree trunks may be attributed to the movement of ants up the tree in search for food especially the honeydew released by aphids during their feeding. This was in agreement with the findings by Katayana *et al.* (2013), and Florein *et al.* (2002).

### **6.6.2 Influence of tree species on soil aggregates and soil macrofauna distribution**

The observed high quantities of total macroaggregates found under *A. seyal* could be attributed to high polyphenol/N and low lignin/N ratio, while higher s+c and microaggregates quantities recorded under *C. molle* may be attributed to high lignin/N ratio of their residues. High lignin/N ratio residues depict very slow decomposition of the residues hence slow soil aggregate formation. Incorporation of residues into the soil provides particulate organic matter (POM) which acts as nucleation site for the formation of macroaggregates around intra-aggregate particulate organic matter (iPOM). This iPOM is further decomposed and fragmented into smaller particles which become encrusted with minerals particles and microbial by-products, leading to formation of microaggregates within macroaggregates (Martens, 2000 and Samahadthai *et al.* 2010).

*Acacia* species are found inhabiting the drier regions of Miombo woodland; their extensive roots could have favored physical binding of smaller sized aggregates into macroaggregates. Similarly, the exudates from their roots may have stimulated the microbial activities which play a role in producing binding agents (Angers and Caron, 1998). Mechanisms by which plant roots influence soil structure can include

the physical enmeshment of soil particles by roots and associative organisms (mycorrhizae), inputs of organic matter (e.g. exudates, dead roots) that stimulate microbial activity and the production of bonding agents.

Higher litter quantities as well as higher soil macrofauna abundance near the tree trunk may have led to high macroaggregates quantities. Soil macrofauna e.g. earthworms through their activities ingest organic matter and produce casts held together into aggregates thus increasing soil organic matter (SOM). An increase in SOM is known to enhance proliferation of endophytes like mycorrhizal fungi (MF). The hyphal network of these organisms coupled with secretion of cementing sugars helps in binding of soil into aggregates. The results were in agreement with the findings by Miller *et al.* (1995) and Rillig *et al.* (2001).

### **6.6.3 Carbon associated aggregates**

The higher total carbon near the tree trunk may be attributed to higher litter quantities near as opposed to lower litter quantities away from tree trunk, similarly, higher soil macrofauna abundance especially termites and millipedes near tree trunk. The litter incorporated into the soil, acted upon by soil organisms to form soil organic matter. These are fed on by soil macrofauna and excreted as faecal matter which then may have led to increase in total carbon. On the other hand, substrate quality (e.g. nitrogen, polyphenol and lignin contents) play a role in consumption of the substrates by soil macrofauna. The higher the quality, the higher the feed consumed and likewise the higher the faecal pellets produced, which are then acted upon by soil organisms leading to higher total carbon in soil aggregate fractions. These findings are consistent with the studies by Tian *et al.* (1993, 1995), Martens, (2000), Six *et al.* (2002), Kong *et al.* (2005) and (Denef *et al.* 2007).

#### **6.6.4 Correlation between soil macrofauna, total carbon and soil aggregate fractions**

The study demonstrated that total macroaggregates, microaggregates, silt+clay and microaggregates within macroaggregates significantly correlated with termites and millipedes. Millipedes and termites feed on the soil and mix with plant residue materials in their guts, the physical compression of the soil gut contents while extracting nutrients forms faecal pellets which when egested would stabilize the soil aggregates. Soil ingesting termites and millipedes are known to increase macroaggregates as well as total carbon in the soil aggregates fractions. Similarly, during tunneling, they mix soil with salivary contents and these bind soil particles into aggregates leading to increased macroaggregates. Furthermore, the fungi which live in symbiotic relationship with some termites functional groups help them breakdown lignin and polyphenol contents in some of the tree residues. These are then egested as pellets which protect carbon thus increasing total carbon. For example the results showed that there was high termite abundance under *A. seyal*, while their residues had high lignin and polyphenol contents. This was consistent with studies by Lavelle and Spain (2001).

#### **Conclusion**

*A. amara* and *A. seyal* influenced significantly the abundance of beetles, earthworms, millipedes and termites. Total macroaggregates were significantly influenced by *A.seyal* while smaller sized aggregates were significantly influenced by *C. molle*. *Acacia seyal* influenced significantly mean weight diameter, carbon contents in total macroaggregates, microaggregates, silt and clay and microaggregate within

macroaggregates, contents of nitrogen, phosphorus, potassium, calcium and magnesium.

Therefore, *A. seyal* played a great role in the abundances of millipedes and termites and the formation of soil structure and carbon storage.

## CHAPTER SEVEN

### INFLUENCE OF RESIDUE QUALITY ON THE PHYSICAL STABILITY OF EARTHWORM CASTS AND CARBON ACCUMULATION: A MICROCOSM STUDY

#### Abstract

Earthworms play important roles in soil structure and soil organic matter (SOM) dynamics. A microcosm experiment was conducted to assess the effect of plant residues from *Vangueria infausta* and *Dombeya rotundifolia* trees on *Pontoscolex corethrurus* earthworm cast production and carbon accumulation. The treatments were: 100% *V. infausta*, 75% *V. infausta*+25% *D. rotundifolia*, 50% *V. infausta*+50% *D. rotundifolia*, 25% *V. infausta*+75% *D. rotundifolia*, 100% *D. rotundifolia* and control with no substrates applied. They were replicated three times in a randomized complete block design giving a total of 18 microcosms. Earthworm cast aggregate stability was assessed by wet-sieving and separated into three aggregate groups i.e. Total macroaggregates (>250 µm), microaggregates (53 – 250 µm) and silt+clay. Further fractionation into microaggregate within macroaggregate and silt+clay occluded in macroaggregate size fractions to assess aggregate composition and carbon storage was done.

Treatment with higher proportions of *D. rotundifolia* increased the quantities of microaggregates and microaggregates within microaggregates. While, treatment with higher proportions of *V. infausta* residues increased the quantities of silt+clay fraction in the cast aggregates.

Furthermore, treatment with 100% *D. rotundifolia* led to higher total carbon contents in macroaggregates, microaggregates and microaggregates within macroaggregates. It

was also observed that high quality residue from *V. infausta* led to higher cocoon production, while low quality residues from *D. rotundifolia* played a great role in soil structure formation as well as carbon storage.

*V. infausta* substrates were of high quality, while that of *D. rotundifolia* were of low quality. Earthworm fed with increased *D. rotundifolia* substrates influenced significantly the quantities of microaggregates and microaggregates within macroaggregates. Similarly, treatments with increased *D. rotundifolia* residues led to higher contents of total carbon in total macroaggregates, microaggregates and microaggregates within macroaggregates.

Key words: Earthworm cast; *P. corethrurus*; *V. infausta*; *D. rotundifolia*; total carbon

## **7.1 Introduction**

Organic resources play pivotal role in maintaining soil quality and are recommended as an integral part of soil fertility management in research and development in Africa (Vanlauwe *et al.* 2004). The quality of organic resource inputs influences decomposition processes that result in nutrient release and soil organic matter formation (Barrios *et al.* 1997; Cadish and Giller, 1997). Organic matter influences nutrient availability in soil by promoting mineralization-immobilization patterns of the organic resources, nutrients additions, and energy source for microbial activities, precursors of soil organic matter and by reducing phosphorus sorption of the soil (Palm *et al.* 1997).

Soil biota have been shown to significantly influence a number of soil functions that underpin soil-based ecosystem services such as nutrient cycling and soil structure maintenance (Barrios, 2007). Relationships of earthworms and soil properties have been well-documented for agricultural systems (Decaens *et al.* 2004; Winsome *et al.* 2006) and forests (Marhan and Scheu, 2005).

Earthworm functions directly by ingesting, altering and mixing organic matter and mineral soils and affect the ecosystem structure by physical and chemical properties of their environment through their continuous burrowing and casting activities (Edwards, 2004; Jouquet *et al.* 2006). Earthworms produce organo-mineral structures termed as biogenic structures or casts. The casts which results from organic matter passing through earthworm digestive tract constitute microsites where a number of physical and bio-chemical changes occur. These structures affect fundamental processes such as the organic material cycle (Brown *et al.* 2000), the activation of microflora (Barrois and Lavelle 1986) and changes in structural properties (Blanchart *et al.* 1993). Earthworm casts can positively affect plant growth due to higher concentrations of plant available nutrients in casts than in the soil (Pashanasi *et al.* 1996; Asawalam and Hauser 2001; and Bisht *et al.* 2006). Cast production therefore is an indicator of burrowing activity and soil turnover. Although, casts are produced both at surface as well as beneath the soil in their burrows or in other soil spaces (Lee, 1985), surface castings often serve as a direct indicator of earthworm activity (Pauli *et al.* 2010) and may also serve as an indicator of soil compaction (Kretzschmar, 1991; Scharenbroch and Johnston, 2011). From an ecological point of view, earthworm communities are divided into three functional groups, namely epigeic, endogeic and anecics. These classifications are based on their habitat, food choice, feeding behaviour and ecophysiology. *P. corethrurus* are endogeic earthworms which forage below the soil surface in horizontal, branching burrows. These species ingest large amounts of soil, plant residues and dead roots in the soil, showing a preference for soil rich in organic matter. As a result, their casts often have much higher content of SOM and nutrients than the surrounding soil (Lee, 1985) and these contributes to soil aggregation (Bossuyt *et al.* 2005).

The aim of the study was to investigate how *V. infausta* and *D. rotundifolia* residue consumed by *P. corethrurus* influence the stability of cast and total carbon contents.

It was hypothesized that; quality of litter consumed by *P. corethrurus* would influence its productivity and hence high production of casts with higher carbon content.

## **7.2 Materials and Methods**

### **7.2.1 Experimental design**

A microcosm experiment was established at the ICRAF Soil Ecology Facility to investigate the influence of contrasting plant residue qualities consumed by *P. corethrurus* on the water stability of their casts and carbon storage. The facility's roof was made of corrugated translucent perspex sheet and the walls made of nylon net material, which allowed free air circulation and the temperature and humidity at ambient conditions. The experiment combined different features from methods used by Zhang *et al.* (2009), Chapuis-Lardy *et al.* (2010) and Fonte *et al.* (2010) in an optimized microcosm experimental design (Figure 11). Microcosms used consisted of PVC columns measuring 25 cm height, and 11 cm diameter with nylon mesh at the bottom to hold content in place and allow for drainage and on top to prevent earthworms escaping. The soil used in the microcosms was collected from Kiberashi sentinel site, Tanzania. All the litter on the surface of the reference soil horizon was removed before excavation of the top 20 cm soil for use during incubations.

Soils were air-dried and sieved to pass through 2 mm sieve, while the plant residues were dried at 50 °C and cut to <2 cm sizes. Five grams of plant residues were mixed with two kilograms of soil before placing them in each microcosm. Each microcosm had a 2 cm coarse sand layer at the bottom and soil mixed with plant residues were placed to a height of 20 cm above coarse sand layer and with a 3 cm air space above

it. Soil/plant residue in the microcosms was compressed to an approximate bulk density of  $1 \text{ gm/cm}^3$ . De-ionized water was added up to 40% of soil moisture by weight and further water additions made every two days to maintain 40% moisture content until the end of the experiment.

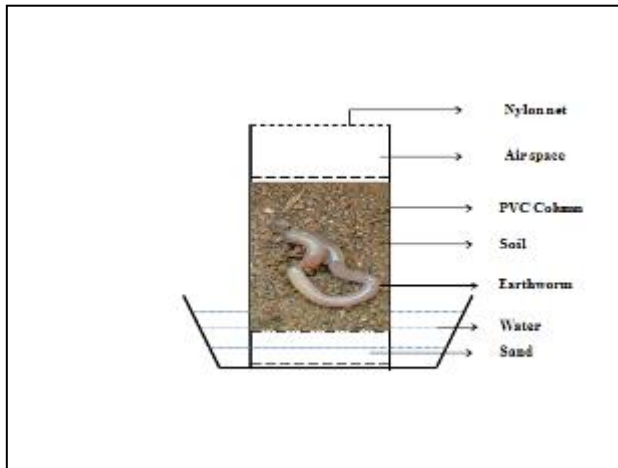


Figure 8: Microcosm design used for the incubation of earthworms

The prunings from *D. rotundifolia* (low quality) and *V. infausta* (high quality) collected were used as organic inputs for the microcosm study. After collection, they were oven dried at  $50 \text{ }^\circ\text{C}$  and cut to  $<2 \text{ cm}$  sizes.

*P. corethrurus* used in the experiment were collected from Kenya Agricultural Research Institute farm in Embu (Kenya) and inoculated in soil for a period of 8 days to acclimatize before being transferred to the microcosms. Earthworms were placed on wet filter paper in a petri dish before being rinsed with deionized water, blotting dried, weighed (with gut contents not evacuated) and introduced to the microcosms

Six treatments were done as follows; 100% *V. infausta* (T1), 75% *V. infausta*+25% *D. rotundifolia* (T2), 50% *V. infausta*+50% *D. rotundifolia* (T3), 25% *V. infausta*+75% *D. rotundifolia* (T4); 100% *D. rotundifolia* (T5) and control (no substrates applied). The treatments were replicated three times in a randomized complete block design giving a total of 18 microcosms.

One adult of *P. corethrurus* was inoculated into each microcosm and their tops covered with nylon net to prevent them from escaping. Casts deposited daily on the soil surface of each microcosm were manually collected using tweezers, counted, fresh weight taken and then oven dried at 60 °C before determining the dry weight. The experiment continued for a period of 30 days. At the end of the experiment, the soil + plant residues + earthworms were removed from microcosm and internal cast were collected, counted and oven dried at 60 °C before determining their dry weight. After 30 days the pots were destructively sampled by hand sorting of the soil to locate the earthworms. For each pot, *P. corethrurus* were placed on wet filter paper in a petri dish before being rinsed with deionized water, blotting dried and weighed. The total numbers of cocoons produced in each microcosm were counted and their weights determined.

### **7.2.2 Determination of cast aggregate protected carbon**

Casts were separated into four water stable aggregate size fractions (i) large macroaggregates (>2000 µm), (ii) small macroaggregates (250 µm-2000 µm), (iii) microaggregates (53–250 µm), and (iv) silt + clay sized particles (<53 µm), by use of mechanical wet sieving method, following a modification of method described by Elliot (1986) and Six *et al.*, (1998). Large macroaggregates and small macroaggregates were combined to form total macroaggregates because quantities of large macroaggregates in some cases were very little. Thirty two grammes of air-dried cast were transferred to 2 mm sieves, placed in recipients filled with de-mineralized water, and left to slake for 5 minutes. After 5 minutes, the 2 mm sieves were moved up and down 100 times over 3 minutes using wet sieving apparatus (Eijkelkamp Agrisearch Equipment). The procedure was repeated using the material that passed

through the 2 mm sieve, using a 250  $\mu\text{m}$  sieve and subsequently a 53  $\mu\text{m}$  sieve (one by one). Casts aggregates retained on each sieve were backwashed into pre-weighed containers, oven-dried at 60 °C for two days and weighed. A representative 250 ml subsample was taken from the suspension containing the <53  $\mu\text{m}$  silt and clay sized particles to determine the weight of the smallest fraction.

Macroaggregates was subjected to fractionation analysis using microaggregate isolator (Six *et al.*, 1998 & 2000). Five grams of total macroaggregates (LM+SM) was placed on a 250  $\mu\text{m}$  mesh screen on top of the device and shaken with 50 glass beads (4 mm in diameter) for 3 minutes until all macroaggregates were broken. Water was allowed to flow continuously through the microaggregate isolator such that the microaggregates were flushed immediately through the 250  $\mu\text{m}$  sieve onto a 53  $\mu\text{m}$  sieve. Once all the macroaggregates were broken down, sand and coarse particulate organic matter (cPOM) retained on the top of the 250  $\mu\text{m}$  mesh were backwashed into a pre-weighed container. The sieve (53  $\mu\text{m}$ ) holding the microaggregates was manually moved up and down 50 times over 2 minutes in the suspension containing <53  $\mu\text{m}$  fraction (Six *et al.*, 2000). A representative 250 milliliters subsample was taken from the suspension containing the <53  $\mu\text{m}$  silt and clay sized particles to determine the weight of the smallest fraction. Three fractions obtained were: (i) coarse POM + sand (> 250  $\mu\text{m}$ ), (ii) microaggregates within macroaggregates (53-250  $\mu\text{m}$ ), and (iii) silt and clay within macroaggregates (< 53  $\mu\text{m}$ ), and all were oven dried at 60 °C for two days and weighed. All the cast fractions inclusive of whole cast were ground and analyzed for total carbon using a CN-Analyzer (Flash EA 1112 NC, CE Instrument, Thermo-quest).

### 7.2.3 Chemical characterization of the tree residues

Analysis of *D. rotundifolia* and *V. infausta* substrates was done. Further details are described in section 4.3.4, page 67.

### 7.3 Data analysis

The data were subjected to a one way analysis of variance (ANOVA) using GenStat 12.1 (2009) statistical package. Separation of means was tested using Tukey's significance difference with a significance level of  $P \leq 0.05$ .

### 7.4 Results

#### 7.4.1 Characterization of tree residue quality

*V. infausta* substrates had significantly higher quality with nitrogen contents recording 2.5%, lignin contents 22.54%, PP+LIG/N 10.46% and lower Lignin/N ratio of 8.86, while *D. rotundifolia* residues was of low quality with nitrogen contents recording 2.14%, lignin contents 30.04%, PP+LIG/N 16.06% and Lignin/N ratio of 14.12 (Table 16).

Table 16: *D. rotundifolia* and *V. infausta* substrate quality characteristics

Tree species	<i>D. rotundifolia</i>	<i>V. infausta</i>	P value	SED
%N	2.14	2.5	<0.001	0.07
%C	40.74	42.47	<0.001	0.13
%PP	4.05	3.91	0.52	0.22
%LIG	30.04	22.54	<0.001	1.05
C/N	19.13	17.54	0.002	0.50
LIG/N	14.12	8.86	<0.001	0.30
PP/N	1.94	1.59	0.003	0.12
(PP +LIG)/N	16.06	10.46	<0.001	0.37

PP=Polyphenol; LIG=Lignin; N=Nitrogen; C=Carbon

#### 7.4.2 Effect of tree residue quality on earthworm cast production

*V. infausta* leaf residues fed to the earthworms led to higher quantities of cast produced ( $p=0.07$ ), while the control had the lowest total cast quantities. It was observed that cast produced decreased with increase in percentage of *D. rotundifolia* (low quality) residues (Figure. 12).

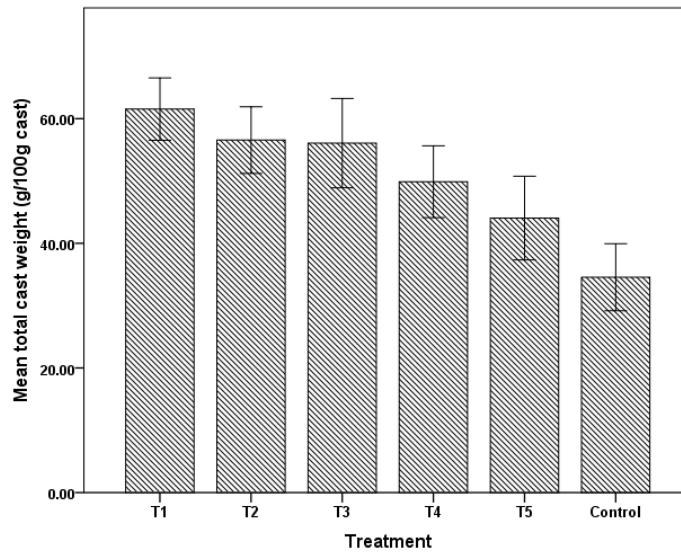


Figure 129: Effects of residue quality on the earthworm cast (weight)

Where: T1=100% *V. infausta*; T2=75% *V. infausta*+25% *D. rotundifolia*; T3=50% *V. infausta*+50% *D. rotundifolia*; T4=25% *V. infausta*+75% *D. rotundifolia*; T5=100% *D. rotundifolia*; Control=no residues

#### 7.4.3 Effects of tree residue quality on cast aggregate fractions

Treatments with higher proportions of *D. rotundifolia* significantly influenced the quantities of microaggregates ( $p=0.01$ ) and microaggregates within macroaggregates ( $p=0.01$ ) (Table 17). It was observed that control had significant effect on total macroaggregate (TM), but when subjected to fractionation, it produced more quantities of silt+clay occluded in macroaggregates, showing that the cast TM was not water stable. On the other hand, treatments with higher proportions of *V. infausta* residues, significantly ( $p=0.03$ ) increased quantities of silt+clay fraction in the cast aggregates.

Table 17: Cast's aggregate fractions as influenced by tree residue quality

Aggregate cast fractions (g/100gm total cast)	Treatment						Level of significance and SED	
	T1	T2	T3	T4	T5	Control	P value	SED
TM (250µm-2.0 mm)	38.55 <sup>b</sup>	36.05 <sup>b</sup>	36.46 <sup>b</sup>	36.21 <sup>b</sup>	35.91 <sup>b</sup>	50.04 <sup>a</sup>	0.009	3.28
m (53-250 µm)	6.95 <sup>b</sup>	9.39 <sup>ab</sup>	10.00 <sup>ab</sup>	10.88 <sup>a</sup>	11.09 <sup>a</sup>	6.42 <sup>b</sup>	0.01	1.21
s+c (≤53 µm)	1.85 <sup>a</sup>	1.99 <sup>a</sup>	1.24 <sup>b</sup>	1.14 <sup>b</sup>	1.47 <sup>b</sup>	1.09 <sup>b</sup>	0.01	0.23
mM (53-250 µm)	0.18 <sup>b</sup>	0.26 <sup>b</sup>	0.28 <sup>a</sup>	0.30 <sup>a</sup>	0.31 <sup>a</sup>	0.14 <sup>b</sup>	0.006	0.04
scM (≤53 µm)	0.53	0.42	0.45	0.41	0.44	0.45	0.93	0.11
MWD	1.99 <sup>b</sup>	1.86 <sup>b</sup>	1.88 <sup>b</sup>	1.87 <sup>b</sup>	1.86 <sup>b</sup>	2.57 <sup>a</sup>	0.009	0.17

Where: T1=100% *V. infausta*; T2=75% *V. infausta*+25% *D. rotundifolia*; T3=50% *V. infausta*+50% *D. rotundifolia*;  
T4=25% *V. infausta*+75% *D. rotundifolia*; T5=100% *D. rotundifolia*; Control=no substrates

#### 7.4.4 Influence of tree residue quality on total carbon contents

Treatment with 50% *V. infausta*+50%, *D. rotundifolia* residues had higher total carbon content compared with the other residue proportions in total macroaggregates. Similarly, treatment with 100% *D. rotundifolia* residues recorded the highest total carbon in microaggregates compared to the other treatments. On the other hand, treatment with 100% *V. infausta* recorded high contents of total carbon in silt+clay fraction compared with the other proportions of residue qualities, while 100% *D. rotundifolia* residues recorded the lowest content of total carbon in silt+clay (Table 18).

Treatment using 100% *D. rotundifolia* residues had high contents of total carbon in microaggregate within macroaggregates compared with the other treatments. Similarly, treatments using 50% *V. infausta*+50% *D. rotundifolia* had higher contents of total carbon in silt+clay occluded in macroaggregates compared with the other treatments (Table 18).

Table 18: Total carbon in earthworm cast aggregate fractions and whole cast as influenced by earthworms and tree residue quality

Earthworm cast fractions	Treatments						Level of significance and SED	
	T1	T2	T3	T4	T5	Control	P value	SED
TCwhole cast	21.28	21.03	21.41	19.92	21.11	19.36	0.14	0.81
TCTM	5.53	5.40	5.72	5.11	5.63	4.80	0.15	0.34
TCm	5.37	5.37	5.83	4.96	5.99	5.01	0.14	0.41
TCs+c	10.38	10.21	9.86	9.86	9.49	9.56	0.26	0.40
TCcPOM	0.15	0.12	0.13	0.17	0.15	0.14	0.44	0.02
TCmM	2.05	2.05	2.10	2.12	2.15	1.79	0.27	0.15
TCscM	3.34	3.27	3.49	2.82	3.33	2.87	0.07	0.23

Where: T1=100% *V. infausta*; T2=75% *V. infausta*+25% *D. rotundifolia*; T3=50% *V. infausta*+50% *D. rotundifolia*; T4=25% *V. infausta*+75% *D. rotundifolia*; T5=100% *D. rotundifolia*; Control=no residues; TC=Total carbon; TM=Total Macroaggregates; m=microaggregates; s+c=silt and clay; mM=microaggregates within macroaggregates; scM=silt+clay occluded in macroaggregates;

### 7.4.5 Effects of residue quality on earthworm cocoon production

Treatments with higher proportions of *V. infausta* had the higher cocoon count than the other treatments (Figure 13), which means that cocoon production decreased with increase in percentage residues of *D. rotundifolia*.

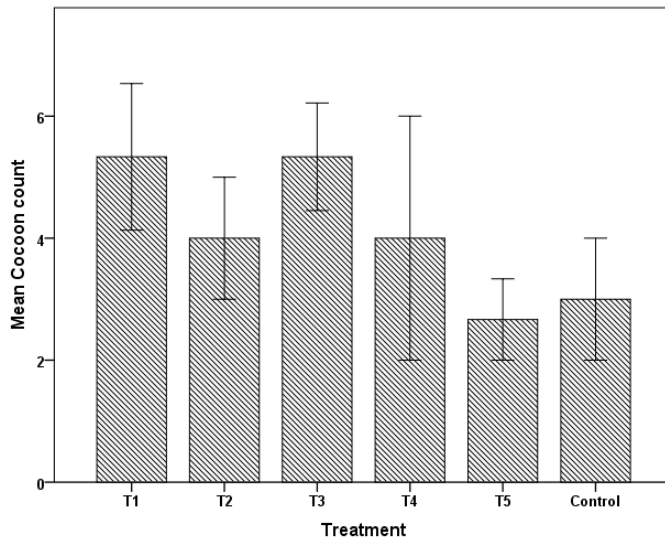


Figure 103: Effects of tree residue quality on number of cocoon produced

Where: T1=100% *V. infausta*; T2=75% *V. infausta*+25% *D. rotundifolia*; T3=50% *V. infausta*+50% *D. rotundifolia*; T4=25% *V. infausta*+75% *D. rotundifolia*; T5=100% *D. rotundifolia*; Control=no residues

## 7.5 Discussion

### 7.5.1 Varying qualities of *D. rotundifolia* and *V. infausta* substrates

*D. rotundifolia* and *V. infausta* produced substrates of varying qualities with the latter producing high while the former low quality substrates. Substrates from *V. infausta* were preferred by *P. corethrurus*. The preferential ingestion of plant residues by *P. corethrurus* was linked to the quality of the substrates and this may have been due to the low lignin and higher nitrogen contents of the *V. infausta* residues. This was consistent with studies by Barois and Lavelle (1986).

### **7.5.2 Number of earthworm cast**

*P. corethrurus* are known to feed more on high quality residues and this may be attributed to their selective nature on organic particles they ingest and/or palatability of the substrates. The more palatable the substrates the more the earthworm consume and this may explain the fact that, where high quality substrates such as *V. infausta* were fed to *P. corethrurus*, higher cast quantities were produced, similarly when low quality *D. rotundifolia* substrates were used lower cast quantities were produced. This was depicted by reduced cast production with increase in *D. rotundifolia* substrates showing that *P. corethrurus* preference for high quality substrates as opposed to low quality substrates. This was consistent with studies by Lee (1985), and Barois and Lavelle (1986).

### **7.5.3 Cast aggregate fractions**

*V. infausta* substrates produced high quantities of macroaggregates (TM). Although control produced higher quantities of macroaggregates, when this was subjected to fractionation, it produced mainly silt+clay showing that the formed TM was composed mainly of silt+clay and not microaggregates within macroaggregates. It is known that microaggregates within macroaggregates are formed by the soil microorganisms in presence of plant residues. Plant residues form sites for the formation of microaggregates. No substrates were added to the control hence low soil organic matter and thus lower quantities of microaggregate within macroaggregates formed. Furthermore, our observations showed that *D. rotundifolia* substrates had a significant influence on microaggregates within macroaggregates due to the low quality of substrates which played a major role in formation and stability of macroaggregates. This may be attributed to the

high lignin/N and high C/N ratios. The casts that results from these sustrates may play a role in soil structure stabilization (Shipitalo and Protz 1988 and Jongmans *et al.* 2003).

#### **7.5.4 Total carbon contents**

Incorporated organic residues into the soil are ingested and mixed in the gut of the earthworms with the extraction of nutrients and the amount of carbon which is consumed and not assimilated is excreted as cast material. The low digestibility of low substrate quality consumed and not assimilated may have contributed to an increase in carbon in the cast. Earthworms through their activities ingest organic matter and produce casts held together into aggregates. They also incorporate soil organic matter within aggregates and hence store carbon. The microaggregate structure as described above, protect carbon and make it unavailable for decomposition by microorganisms. The findings were consistent with studies by Six *et al.* (2000) and Jouquet *et al.* (2009).

#### **7.5.4. Earthworm cocoon production**

*P. corethrurus* preferred high quality substraetes which may be of higher nutritive value. Their increased nutrition may be linked to increased cocoon production. It was observed that cocoon production decreased with increase in *D. rotundifolia* residues. This was consistent with the observations by Garg and Kaushik (2005) and Eriksen-Hamel *et al.*, (2009).

### **Conclusion**

*V. infausta* sustrates were of high quality, while that of *D. rotundifolia* were of low quality. Earthworm fed with increased *V. infausta* led to higher cast production as well as

cocoon count. Whereas earthworm fed with increased *D. rotundifolia* substrates influenced significantly the quantities of microaggregates and microaggregates within macroaggregates. Similarly, treatments with increased *D. rotundifolia* substrates led to higher contents of total carbon in total macroaggregates, microaggregates and microaggregates within macroaggregates.

## **CHAPTER EIGHT**

### **8.0 GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS**

#### **8.1. Influence of trees and soil properties on soil macrofauna abundance and spatial distribution**

Among the various land uses are the forests that provide tree cover which influence soil organic matter flows and dynamics through litter fall and root decomposition and also modifies soil nutrient availability. Trees did not influence the distribution of soil macrofauna most likely because of the scale at which sampling was done or may have indirectly influenced through modified microclimatic conditions, which were not assessed in this study. However, land use management practices and soil moisture played important roles in the spatial distribution of soil macrofauna. For example, in the agricultural plots, tillage was practiced and this may have disturbed soil macrofauna killing and/or exposing soil macrofauna to their natural enemies, while others moved away from the area of disturbance. This may have contributed to lower incidences of soil macrofauna in the farmlands. To take advantage of the ecosystem services provided by soil macrofauna, no-till farming practice or incorporation of organic residues into the soil should be practiced.

#### **8.2 Farmers' local knowledge on trees and soil macrofauna**

Scientific approaches alone are not sufficient to address the challenges associated with the sustainable management of agro-ecosystems and it is prudent that farmer's local knowledge is considered as a source of relevant information on interaction of soil

macrofauna and farming practices including conservation of indigenous trees on farm in order to complement scientific understanding and come up with accurate solutions to challenges faced by the farmers in their agricultural production. This was taken into consideration in this study where information on how the farmers viewed benefits of soil macrofauna and trees on their farming fields and was captured through surveys. Farmers were aware that soil macrofauna are indicators of soil quality and that higher abundance of soil macrofauna are found under tree canopies due to the high amounts of litter. The farmers also determine soil quality depending on trees growing on their farms. Some of the farmers still continue to burn residues on their farms during land preparation and this practice kill soil macrofauna or are forced to migrate away from the burnt area. Farmers knowledge is sometimes excluded during the design of development programmes and projects, this knowledge is important in evaluating the interaction between agroforestry and soil macrofauna on soil fertility and crop productivity.

### **8.3 Effects of tree species on soil macrofauna and soil organic matter dynamics**

Indigenous tree species influenced significantly the distribution of soil macrofauna, which was attributed to the residue quality. For example it was observed that *A. amara* increased significantly the abundance of beetles and earthworms, while *A. seyal* influenced the distribution of millipedes and termites. Earthworms are known to select higher quality residues, while termites which live in symbiosis with fungi in their guts will feed on residues with high C/N and lignin/N ratios. On the other hand, millipedes are known to be selective feeders and select residues with higher calcium content and dwell in place with higher relative humidity. Abundance of soil macrofauna and litter was higher near tree trunk and these were related to total macroaggregate and total carbon

contents. The findings from this study have shown that soil macrofauna especially termites and millipedes play great roles in soil macroaggregate formation and carbon storage. Higher total macroaggregate quantities observed near the tree trunk was due to higher soil macrofauna abundance (termites and millipedes) and higher litter quantities. The factors shown above prove that the selected trees go along way in improvement of soil structure and carbon sequestration.

#### **8.4 Influence of residue quality on earthworm casts**

In the microcosm study, earthworms fed with high and low quality substrates produced high and low quantity cast respectively. Furthermore, low quality substrates led to production of cast with high total carbon compared to other treatments. When earthworms feed on the soil mixed with residues, the existing soil structure is destroyed and new structure is formed where some organic components are protected. This results in the formation of microaggregates within macroaggregates. Casts produced tend to have higher stability depending on the substrates consumed. As was found in the study, low quality substrates fed to the earthworm produced cast which were more water stable and had more carbon content. Casts are very important in reducing crust formation due to its increased stability. Casts have higher organic contents and are enriched in nutrients which would support proliferation of microorganisms on the casts leading to increased stability. The high lignin/N and high C/N ratios played a big role in the formation of casts which were water stable and these casts once incorporated into the soil will play a role in stabilization of soil structure.

## **Conclusions**

The study on the importance of trees on soil carbon dynamics and spatial distribution of soil macrofauna provided information on how to utilize indigenous trees to improve soil fertility and take advantage of the ecosystem services provided by soil macrofauna.

The study revealed that low quality residues fed on by earthworms improved soil structure stability as well as carbon sequestration.

## **Recommendations**

Associations between centipedes and ants and that between millipedes and centipedes were caused by factors which were not assessed in this study. Therefore, further research need to be done to identify those factors not assessed in by this study.

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## APPENDICES

### Appendix 1: questionnaire on local knowledge

#### A CASE STUDY ON LOCAL KNOWLEDGE ABOUT TREES, SOIL MACROFAUNA AND THEIR INTERACTION IN AGRICULTURAL LANDSCAPES

Questionnaire No. \_\_\_\_\_

Name of the farmer (*Jina la mkulima*) \_\_\_\_\_

Country (*Nchi*) \_\_\_\_\_

Province (*Mkoa*) \_\_\_\_\_

District (*Wilaya*) \_\_\_\_\_

Ward (*Kata*) \_\_\_\_\_

Village (*Kijiji*) \_\_\_\_\_

Georeference \_\_\_\_\_

Name of Interviewer (*Jina la anayehoji*) \_\_\_\_\_

Date of Interview (*Siku ya mahojiano*) \_\_\_\_\_

#### 1. Information about the farm:

a) Do you own land (*Je, unamiliki ardhi/shamba*)?                      1= Yes (*Ndio*)                      2 = No

(*La*)

[If yes] How much land [*Kama ndio, unatoshana vipi*]?

b) How long have you cultivated this farm (*Umelima shamba hili kwa muda wa kiasi gani*)? \_\_\_\_\_.

Is it all cultivated (Je umelilima shamba lote)? Yes (*Ndio*) \_\_\_\_ No (*La*) \_\_\_\_

You cultivate (*Unalima, asilimia*) \_\_\_\_\_% Fallow (*Kitivo, asilimia*) \_\_\_\_\_%

Forest (*Msitu, asilimia*) \_\_\_\_\_%

c) Do you keep any livestock (*Je, unafuga mifugo*)? \_\_\_\_\_ Yes (*Ndio*) \_\_\_\_\_ No  
(*La*)

If yes, how much land is left for the livestock (*Kama ndio, unatoshana vipi*)?  
\_\_\_\_\_ acres (*ekari*)

If yes, which livestock do you keep and how many of each and their use (*Kama ndio, mifugo wa aina gani unafuga, wangapi, matumizi wao*)?

Type of livestock ( <i>Aina ya mifugo</i> )	Number ( <i>Wangapi</i> )	Use (1=home use; 2=sale; 3=both) ( <i>Matumizi</i> )
Cows ( <i>Ng'ombe</i> )		
Sheep ( <i>Kondoo</i> )		
Goats ( <i>Mbuzi</i> )		
Poultry ( <i>Kuku</i> )		
Other ( <i>Wengine</i> )		

History of the use of the various plots as long as you can recall. [*Elezea kwa kifupi, historia ya matumizi ya ploti mbalimbali kama unavyokumbuka*]

\_\_\_\_\_c) How much land is allocated to? [*Taja ulivyotenga shamba kulingana na ukulima wa*]

Crop [ <i>Mmea</i> ]	Size [ <i>Kiasi</i> ]	Age and other details [ <i>Umri na historia</i> <i>Nyingineyo</i> ]
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Maize (*Mihindi*)

Cassava (*Mihogo*)

Beans (*Miharagwe*)

Pasture (*Malaji ya mifugo*)

Agroforestry

(*Ukuzaji miti na mmea mingine*)

Secondary Forest

(*Misitu*)

Other

d) What quantity of the crops do you get?

Crop	Quantity
Maize	
[ <i>Mahindi</i> ]	
Cassava	
[ <i>Mihogo</i> ]	
Beans	
[ <i>Maharagwe</i> ]	
Others	

## 2. Soils [*Udongo*]

i. Are there various soil types in the region and on your farm? [*Je, kuna aina tofauti za udongo katika eneo hili au katika shamba lako?*]

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ii. What kinds of soils do you have within your farm? [*Kuna aina zipi za udongo katika shamba lako*]

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iii. What are the characteristics of each kind of soil type? [*Fafanua jinsi unavyoweza kutambua kila aina ya udongo*]

(For example, colour, fertility, tree species, stones, depth, texture, water retention, types of soil fauna) [*Kwa mfano; rangi, rotuba, aina ya miti, mawe, aina ya wanyama wa udongo*]

**Soil Type [Aina ya udongo]**

**Characteristics**

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## 3. Farm participatory mapping

Prepare a map with the farmer showing the various types of soils (good-intermediate-poor), indicating slope, soils which dry fast or slowly, past and current use with regard to their location on the slope, location of cropping or fallow areas (georeference the uses), presence of weeds, soil organisms (e.g. ants, earthworms, termites, etc.). Use this map to conduct the rest of the interview while observing and sampling the various soil types.

i. Where is each type of soil found within your farm? Participatory mapping (help farmer draw a map of the distribution of different soil types in their farm.

**Soil Type** [*Aina ya udongo*]

**Where found** [*Mahali inapatikana*]

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ii. (For each soil type) Is this type of soil good or bad for growing crops, and why? Which crop grows best in (each type of soil)? [*Kwa kila aina ya udongo, aina hii ya udongo ni nzuri au mbaya kwa upanzi wa mimea? Ni mimea ipi ina nawiri vyema kwa kila aina ya udongo*]?

**Soil Type** (*Aina ya udongo*)

**Good or bad or in between, and why**

(*Nzuri,*

*mbaya, wastani, eleza sababu*

---

#### **4. Trees** (*Miti*)

i. For you, which plants or trees indicate that an area would be good for growing crops (*Toa maoni kuhusu mimea au miti yenye kudhihirisha eneo linafaa katika ukulima*)?

**Plant** (*Mmea*)

**What does it indicate, and why?** (*Mmea*

*wenyewe unadhahirisha nini? Toa sababu.*

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ii. Which plants or trees indicate that an area would not be good for growing crops (*Taja na uelezee mimea au miti inayoonyesha eneo halifai katika kilima*)?

**Plant** (*Mmea*)

**What does it indicate, and why?** (*Mmea*

*wenyewe unadhihirisha nini? Toa sababu.*

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iii. Do the same types of trees grow in all parts of your farm, or are there different species in different parts of the farm (*Je, miti inayomea katika shamba lako ni wa aina moja tu au kuna aina tofauti shambani kote*)?

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iv. Which trees have beneficial effects on crops? Why? (*Ni miti ipi ina manufaa kwa mimea? Toa sababu.*)

**Species (*Aina ya mti*)**

**Effect and why (*Nakili manufaa ukitoa sababu*)**

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v. Which trees have detrimental effects on crops? Why? (*Taja miti inayoweza kudhuru mimea. Toa sababu*)

**Species (*Aina ya mti*)**

**Effect and why (*Nakili manufaa ukitoa sababu*)**

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### **5. Soil Fauna (*Wadudu wa udongo*)**

i. What kinds of animals have you seen that live in the soil in your farm (*Taja aina ya wadudu waishio udongoni katika shamba lako*)?

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ii. (For each type named) Are they beneficial or detrimental to your crops, and why?  
(*Kwa kila aina ya mdudu, fafania faida au hasara zake kwa mimea huku ukitoa sababu*).

**Type (*aina*)**                      **Beneficial or Detrimental Why? (*Faida au hasara, toa sababu*)**

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iii. Are there certain types of soil animals that indicate if land will be good or bad for growing crops (*Je kuna aina ya wadudu ambao hudhihirisha shamba lifaalo katika ukulima ama lisilofaa?*)

**Type [*Aina*]**                      **What does it indicate, and why [*Inadhihirisha nini? Toa sababu*]**

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iv. (For each type of soil animal mentioned) Where do you find them in your farm? Why do they occur there? [*Taja anakopatikana kila mdudu uliyemtaja katika shamba lako. Fafania sababu yao kuwa pale*]

<b>Type (<i>Aina</i>)</b>	<b>where found / not found</b>	<b>why (<i>toa sababu</i>)</b>
	<b>(<i>Inapatikana wapi/Haipatikani</i>)</b>	

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v. Are there more soil animals during dry season or during rainy season? Why? [*Je, wadudu wengi hutokea wakati wa kiangazi au masika? Toa sababu*]

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vi. Are there more soil animals near trees than far away from trees? [*Elezwa kana kwamba huwa kuna wadudu udongo wengi karibu na miti, ikilinganishwa na umbali wa miti*]

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vii. Which trees have the largest number of soil animals in the soil around the base? Why, and which types of soil animal? [*Taja miti inayokuwa na wadudu kwa wingi hasa udongoni karibu kwenye shina. Toa sababu huku ukitaja aina ya wadudu*]

<b>Tree [<i>Miti</i>]</b>	<b>Animal [<i>Mdudu</i>]</b>	<b>Why [<i>Sababu</i>]</b>
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## 6. Management Practices

### a) Fertilizer use [*Matumizi ya mbolea*]

i. Do you use fertilizer in your farm? [*Je, unatumia mbolea katika shamba lako?*]

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ii. Which type of fertilizer do you use? [*Aina gani ya mbolea unayotumia?*]

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iii. When do you apply fertilizer? [*Je, ni wakati gani unatia mbolea?*]

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iv. How do you apply fertilizer? [*Elezea jinsi unvyotia mbolea*]

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v. How much fertilizer do you usually use per acre? [*Unatumia mbolea kiwango kipi kwa kila ekari?*]

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vi. What do you think happens to the soil animals after applying fertilizer? [*Toa maoni yako kuhusu kifanyikacho kwa wanyama wa udongo unapotia mbolea*]

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### b) Pesticide use [*Matumizi ya dawa ya kuuu/kuzuia wadudu*]

i. Do you use pesticides in your farm? [*Je, unatumia dawa ya kuzuia wadudu shambani mwako?*]

---

ii. Which type of pesticide do you use? [*Je, unatumia dawa ya aina gani?*]

---

iii. When do you apply it? [*Dawa yenyewe unaitumia wakati gani?*]

---

iv. How do you apply pesticides? [*Fafanua jinsi unavyoitia dawa shambani mwako*]

---

v. How much pesticide do you usually use per acre? [*Unatumia dawa kiasi gani kwa kila ekari?*]

---

vi. What do you think happens to the soil animals after applying pesticides? [*Toa maoni yako kuhusu kinachotendeka kwa wadudu wa udongo baada ya kutia dawa*]

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**c) Burning [*Kuchoma*]**

i. In previous years, did you burn your farm? [*Katika miaka iliyopita, umewahi kulichoma shamba lako?*]

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ii. How long ago did you stop? [*Uliacha kulichoma lini mwisho?*]

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iii. Why did you burn your farm? [*Kwa nini ulilichoma?*]

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vi. What effect did burning have on the soil? Soil? Soil fauna? Crops? [*Taja na ufafanue athari zinazotokea baada ya kuchoma shamba. Kwa udongo, wadudu wa udongo, na mimea*]

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### **7. General information**

Starting with the head of household, please tell me the number of people living in your household with you, their relationship to the head of household, sex age, marital status, religion, level of education occupation and type of work. [*Huku ukianza na mkuu wa kaya, taja unayoishi nayo, uhusiano wao kwa mkuu wa kaya, jinsia, umri, dini, masomo na aina ya kazi waifanyayo*]

Name [Jina]	Relationship to Head of household [Uhusiano na mkuu wa kaya]	Sex [jinsia]	Age [Umri]	Marital status	Religion [Dini]	Level of Education [Kiwango cha masomo]	Occupational status [Ajira]	Type of work [Aina ya kazi]
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1

2

3

4

5

6

7

**Codes:**

**Relationship to HH:** 1=Household Head; 2=Spouse; 3. Son; 4= Daughter; 5=Brother/Sister; 6= Grandchild; 7=Other relatives; 8= Non-relatives

**Education:** 1=Not attended school; 2=lower primary (1-3); 3=Upper primary (4-8); 4=Secondary; 5=College; 6=University; 7=Not applicable

**Religion:** 1=Catholic; 2=Protestant; 3=Adventists; 4=Muslim; 5=Traditionalist; 6=No religion; 7=Others specify

**Occupational status:** 1=Unemployed; 2=Temporary employment; 3=Permanent employment; 4=Business; 5=Not applicable

**Type of Work:** 1=Farming; 2=Herding; 3=Business; 4=Casual employee; 5=Teacher; 6=Artisan; 7=Others (specify)