SOIL INVERTEBRATE DIVERSITY, ABUNDANCE AND PHYSICOCHEMICAL CHARACTERISTICS AROUND KAKAMEGA FOREST KENYA AS INFLUENCED BY CROPPING SYSTEMS

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A Thesis submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Environmental Biology of Masinde Muliro University of Science and Technology.

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DECLARATION

This thesis paper is my original work prepared with reference to cited sources and has not been presented for degree or any other award.

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CERTIFICATION

The undersigned hereby certify that they have read and recommend for acceptance of Masinde Muliro University of science and Technology as a thesis entitled 'Soil invertebrate diversity, abundance and physicochemical characteristics around Kakamega forest Kenya as influenced by cropping systems'.

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DEDICATION

This work is dedicated to my parents the late Mr. Harry Kivai and Mrs. Joyce Kivai who inspired me to come up with the research topic and pursue it.

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I wish to take this chance to thank my supervisor Dr. Millicent. F.O. Ndonga and Dr. Francis Muyekho for guidance and their effort to ensure that I graduated. I thank Mr. Nyongesa the laboratory technician in MMUST for helping me successfully extract soil invertebrates from the soil. I thank Morris Mutua of National Museum Kenya for his assistance in identification of soil invertebrates. Dr. Dennis Omayio and my colleague Eric Bushuru for their support during writing of my thesis and analysis of data. I thank my wife Shalom Ruth, my sister Dorine Esendi and my mother Joyce Kivai for her prayers and moral support.

ABSTRACT

Soil fertility depletion has been identified as a major cause of food insecurity among households around Kakamega forest. Soil invertebrate abundance and diversity are known to influence fertility level of soil in agricultural farms. In western Kenya there is limited knowledge on the benefit of conserving soil invertebrates among farmers. There is need for conservation of soil invertebrates in cropping systems because they play a role in influencing soil fertility. The general objective of the study was to determine soil invertebrate diversity, abundance and physichochemical characteristics around Kakamega forest Kenya as influenced by cropping systems. Specific objectives were; (i.) to determine levels of biodiversity and abundance of soil invertebrate species in different cropping systems around Kakamega forest, (ii.) to determine levels of selected soil physicochemical properties under different cropping systems and (iii.) to determine the type and levels of relationship between selected cropping systems verses soil invertebrate and physicochemical levels. The hypotheses of the research were that; (i.) there were no levels of biodiversity and abundance of soil invertebrate species in different cropping systems around Kakamega forest, (ii.) there were no levels of selected physicochemical properties under varying cropping systems around Kakamega forest and (iii.) there were no type and levels of relationship between selected cropping systems verses soil invertebrates and physicochemical characteristics. Purposive sampling technique was used where five cropping systems and the forest were selected. The cropping system treatments include pure maize, pure beans, tea, sugarcane, maize/beans intercrop and the forest acted as a control. Data was collected on soil invertebrates and soil chemical properties (pH, Organic carbon, nitrogen and phosphorous).Soil samples were collected and extraction of soil invertebrates done using Berlese tullgren funnel. Identification of invertebrates was done at National Museum Kenya up to genus and species level. Determination of the diversity and abundance of soil invertebrates was done using Shannon diversity index computed using the R version 2.10.0 and Kruskal-wallis test. Nitrogen analysis was done using UV-vis spectrophotometer while phosphorous was done by Mehlich 3 test and organic carbon was done by Walkey-Black method. The relationship between species abundance and nutrient level in the cropping systems was analyzed using a multiple correlation model within the Generalized Linear Method framework. A total of 1,215 individual soil invertebrates belonging to 29 species were collected. The forest had the highest diversity (H'=2.81) for both wet and dry season followed by maize cropping system (H'=2.29) and least was in bean farm (H'=1.78). The highest percentage nitrogen recorded in the maize plantation with a mean of 0.65, followed by the maize and beans intercrop with a mean of 0.585 and tea plantations with a mean of 0.419.Phosphorous was highest in beans farm with 2.20%, followed by tea plantations with 1.68%. The highest organic carbon was recorded in forest ecosystem 3.58% followed by beans 2.18% and maize 2.08%. No correlation was found between diversity and abundance with the physicochemical properties. The findings from this study will enable farmers practice the best cropping systems which have less effect on the diversity of soil invertebrates hence conservation of the invertebrates.

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LIST OF ACRONYMS AND ABBREVIATIONS

MMUST	Masinde Muliro University of Science and Technology.
KALRO	Kenya Agricultural Livestock Research Organization.
SOM	Soil Organic Matter.
NMK	National Museum of Kenya.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

The land use system in western Kenya is diversified to an extent of including but not limited to small holdings in Kakamega and Vihiga counties to the more cash oriented (Rotich *et al*., 1999). A majority farm sizes in western Kenya range between 0.2ha to 2.5ha, this is mainly attributed to continuous inheritance and subdivision due to high population density (KMARD, 2001). Over 20% of the households rely on agriculture for food security and cash income. The remainder comes from remittances from relatives and small amounts of off-farm income (Tittonell *et al*., 2005). With these reduced farm sizes there are some practices done by farmers which tend to interfere with ecology of soil invertebrates.

Soil invertebrates play an important role in the decomposition of organic compounds. Some directly consume detritus, others consume detrivores, whereas others can indirectly control decomposition by their effects on lower levels of food web (Tabaglio *et al.*, 2009). Soil invertebrates are clearly affecting decomposition of litter, and other ecosystem services related to soil ecosystem function and agro ecological conservation (Six *et al*., 2002). Soil invertebrates are also organized for their role in mediating and determining belowground interactions among plants. Earthworms are considered 'soil engineers' with a notable contribution to soil function and structure as well as to plant growth and health (Scheu, 2003, Lavelle *et al*., 2004). They are sometimes used as bioindicators of soil contamination and provide an early warning of decline in soil quality (Shahla and D'Souza, 2010).

According to Vandermeer and Perfecto (1995), biodiversity refers to all species of plants, animals and micro-organisms that live and communicate within the ecosystem. The type and abundance of biodiversity in agriculture can vary depending on the type of farming method. There is in reality, a great variability in basic ecological and agronomic trends among the various dominant agro-ecosystems. In general, the degree of biodiversity in agro-ecosystems depends on four key characteristics of the agro-ecosystem, that is, the diversity of vegetation inside and around the agro-ecosystem, the permanence of different crops within the agro-ecosystem, the strength of management and the extent to which the agro-ecosystem is isolated from natural vegetation (Southwood and Way, 1970; Altieri, 1999) Humans are known to interfere with the environment by agriculture, thereby affecting the biodiversity of soil invertebrates (Bardgett et al., 1998)

In human-dominated environments, land use intensification changes the composition of the soil environment, and anthropogenic disruptions may have long-term impacts on ecosystem services (Dopuey et al., 2002). Owing to their restricted mobility, soil invertebrates are more likely to be impacted by habitat fragmentation. Understanding and maintaining soil ecosystems is of immediate importance to agriculture, forestry and the conservation of biodiversity (Lavelle, 1996). It is commonly agreed that current agricultural practices such as the use of excess fertilizers and pesticides can contribute to a loss of biodiversity (Bianchi et al., 2006). The 1992 Rio de Janeiro Summit addressed the importance of biodiversity in agronomic and environmental policies. The event highlighted the value of biodiversity conservation for sustainable development (CBD,

2001) by showcasing the various benefits that people reap from biodiversity. Soil contains some of the most diverse assemblages of organisms, the vast majority of which are still not described, but whose functions contribute to maintain life on earth (Lavelle, 1996; Altieri, 1999; CBD, 2001).

Preliminary understanding is needed to assess the resilience of agricultural systems in order to meet food demand and the relationship with underground biodiversity (Cock et al., 2012). Most farmers lack awareness and understanding about how to conserve soil biodiversity (Wachira et al., 2014). It is necessary for farmers to understand the best farming practices that enhance the conservation of invertebrate soil communities. Intercropping has made a major contribution to the protection of soil invertebrates. Examples of intercrop systems that have value in building soil biodiversity and managing harmful organisms include maize/bean, cabbage/cowpea and spider plant/egg plant (Wachira et al., 2014).

1.2 Statements of the problem

The growth of agricultural output in Kenya is constrained by many challenges including low productivity, agro-biodiversity loss, and soil nutrient depletion (Mulinge *et al.*, 2016). The ecology of soil invertebrate communities has been affected negatively through continuous cropping and extensive use of inorganic fertilizers by small scale farmers (Evans *et al.*, 2010). Agricultural activities intensification has also led to decline in soil invertebrates hence interfering with organic matter and fertility of soil (Tabaglio *et al.*, 2009). Some studies have been done to evaluate the importance of the soil invertebrates on soil organic matter and fertility (Ayuke, 2010). In western Kenya near

Kakamega forest farmers have limited knowledge on the importance of conserving soil invertebrate species which help replenish soil nutrients in different cropping systems.

1.3 Justification

Most farmers in western Kenya are subsistence farmers, although we have commercial farmers like the tea farming and sugarcane which is grown in large scale (Woomer *et al*., 2004). Most people depend mainly on farming as a source of food and income. However Sanchez *et al*., (1997) state that land degradation and soil fertility depletion in smallholder farms are serious threats to food production and a major cause of poverty amongst rural households (Krishna *et al.,* 2004). Since soil invertebrates play an important role in breaking down organic residues, it is important to protect their diversity (Lavelle *et al*., 1997). It is also important for farmers to know the effects of different cropping systems in conserving their biodiversity, abundance and how this affects soil organic matter and macro nutrients availability. This research will enable farmers use the best cropping systems which have less effect on the diversity of soil invertebrates hence conservation of the invertebrates.

1.4 General Objectives

To determine soil invertebrate diversity, abundance and physicochemical characteristics variations around Kakamega forest as influenced by selected cropping systems in western Kenya.

1.5 Specific objectives

(i.) To determine levels of biodiversity and abundance of soil invertebrate species in different cropping systems around Kakamega forest (ii.) To determine the levels of selected soil physicochemical properties under varying cropping systems around Kakamega forest.

(iii.) To determine the type and the levels of relationship between selected cropping systems verses soil invertebrate and physicochemical characteristics.

1.6 Hypotheses

(i.) There are no levels of biodiversity and abundance of soil invertebrate species in different cropping systems around Kakamega forest.

(ii.) There are no levels of selected physicochemical properties under varying cropping systems around Kakamega forest.

(iii.) There are no type and levels of relationship between selected cropping systems verses soil invertebrates and physicochemical characteristics.

CHAPTER TWO

LITERATURE REVIEW

2.1 Crop production systems in Western Kenya

Agriculture in western Kenya, especially in Kakamega County, is dominated by mixed subsistence farming. Smallholders also grow maize with beans and some grow sugar cane (Ayuke, 2010). In this area, more than fifty percent of the population is living below the poverty level and food insecurity (CBD, 2001). Depletion of soil fertility has been described as a major cause of chronic food insecurity among households in Kakamega County (Ojiem, 2006). The difference between the potential and real yields of maize is limited mainly by the availability of nitrogen and phosphorus (Tittonell et al., 2005). According to Braun *et al.,* (1997) water availability may also be a limiting under conditions of pronounced soil physical degradation, extra-ordinary dry years and/or mid season droughts, resulting in substantial yield losses especially for crop grown on steep sloped field subjects to water run-off.

Sugarcane is also grown by most of the farmers in this region. Low sugarcane productivity has been reported despite release of improved sugarcane varieties (Jamoza, 2005). Declining in soil nutrients is a major factor contributing to low sugarcane productivity in Kenya (Amolo *et al*., 2017). Other reports indicate that the low yields of sugarcane are related to levels of organic matter and soil pH (De Menezes Rodrigues *et al*., 2016). Soil environment is manipulated via cultivation, manipulating soil fauna and application of organic residues which are among the factors affecting SOM dynamics under cropping systems (Six *et al*., 1999, 2002).

2.2 Diversity of soil invertebrates and their functions

Soil is an important source of a wide range of ecosystem services and functions that support human populations (Daily et al., 1997). According to recent estimates, soil animals may account for 23 per cent of the total diversity of living organisms described to date (Decaens et al., 2006). Soil invertebrates are some of the species that control the decomposition and biodegradation of organic residues, the dynamics of soil organic matter, the formation of humus, the release of nutrients and physical parameters, e.g. bulk density, porosity and water availability (Lee and Foster, 1991; Lavalle et al., 1992; Brussard et al., 1993; TSBF, 1994; Black and Okwalol, 1997; Beare et al., 1997).

According to Lavelle et al. (1992), soil invertebrates are an important component of biodiversity in many habitats. In general, soil macrofauna is broken down and organic residues are redistributed in the soil profile, raising the surface area and the supply of organic residues for microbial activity and subsequent deposition of faecal pellets with major ecological consequences (Magro et al., 2013; Vignozzi et al., 2019). Certain macrofauna groups, especially termites and earthworms, may significantly alter the structure of the soil through the formation of macropores and aggregates (Lee and Foster, 1991). It is also valid that the effect of soil fauna on soil structural properties has been considered to be the best long-term measure of soil quality as concluded by Linden et al. (1994). Despite their role in preserving the structure and function of subsurface ecosystems, their significance is often overlooked (Crossley et al., 1992). *Collembola spp*. along with other soil arthropods such as *Acari spp*. are an important component of meso-fauna soil in almost all terrestrial ecosystems (Rusek, 1998). These species are interested in the decomposition of organic matter, the preservation of soil physical structure and the effective cycling of nutrients in the soil (Bardgett et al., 1997). Coleman and Crossley (1996) argue that the bulk of decomposition is due to microbial activity, soil fauna is critical for litter conditioning and for stimulating microbial activity. Earthworms play a significant role in the breakdown of organic matter and are associated with dung degradation (Svendsen et al., 2003).

In certain cases, soil fauna diversity can influence soil function in many ways and can be used as a nutrient status indicator for soil at a given site (Vanlauwe et al., 1996; Doube, B.M., 1997; Rao et al., 1998). Soil invertebrates are the key determinants of soil processes in tropical ecosystems.

2.3 Cropping systems verses soil meso-fauna and macro-fauna

In low-input agricultural systems, soil fauna has been shown to play a key role in the dynamics of soil organic matter, the enhancement of soil physical properties and the release of nutrients for crop production (Ou'edraogo, 2004). The structure, abundance and activity of soil macrofaunas and their impacts on soil processes differ depending on soil residue inputs and soil management activities (Choo and Baker, 1998; Pulleman et al., 2005). Macrofauna species composition, ecosystem structure and population sizes may be influenced positively or negatively by management practices (e.g. crop rotation, tillage, use of organic resources and use of agrochemicals such as pesticides, herbicides and inorganic fertilizers). Some of the negative effects of management practices may result in a decline in the abundance and/or biomass of soil macrofauna populations eliminating or reducing key species, i.e. species that play a disproportionate role in ecosystem processes (Dangerfield, 1993; Beare et al., 1997).

Improving root penetration, water infiltration and soil moisture storage, weed control and nutrient supply from rapid decomposition of organic matter are considered to be the most beneficial contributors to crop production (Lampurlanes and Cantero-Matinez, 2003; Antil et al., 2005). Tillage, such as regular ploughing and tilling, is also considered to adversely affect the biodiversity of arthropods and other invertebrates inhabiting the soil by destroying their habitat. (Roper & Gupta, 1995; Steiner, 2002; Clapperton, 2005).

Studies have shown that soil fauna abundance and distribution can be affected by tillage activities (Farrar and Crossley, 1983; Moore et al., 1984; Chikara et al., 2004). House and Parmelee (1985) and Smith (2001) have shown that soil arthropods and earthworm densities are higher at no tillage than in traditional tillage systems, while Tian et al. (1997) and Chikara et al. (2004) have recorded lower earthworm populations in tilled land than in bush fallow or no tiller land. The underlying causes are the destruction of nests; burrows occupied by soil invertebrates; changes in quantity; location of food source and increased soil moisture and temperature variations due to tillage operations (Kladivko, 2001).

Unaffected agro-ecosystems provide appropriate food and shelter conditions for macrofauna (Barros et al., 2002; Eggleton et al., 2002; Birang et al., 2003). Soil disturbance and increased agricultural intensity negatively affect macrofauna groups (earthworms and termites) by destroying their habitat compared to undisturbed or less controlled habitats such as natural forests or natural fallows (Okwalol, 2000; Eggleton et al., 2002 and Birang et al., 2003).

2.4 Effects of pH and temperature on distribution of soil invertebrates

Along with other physical and chemical properties of soil pH has an effect on soil communities (Griffiths *et al.*, 2011). Extreme change in pH in the soil like high pH affect soil macrofaunal activity, abundance and can also lead to death of these organism (Bardgett, 2005). Distribution of soil organisms such as collembola is greatly affected by very high or very low pH of the soil hence used as bioindicators (Detsis *et al.*, 2000). Studies done by Butt and Briones (2017) show that cut down shrubs in alkaline soils increase abundance of macrofauna but severely reduces the microarthropod populations

Soil temperature and moisture can affect the survival of microorganism in different ways. Moderate soil moisture (3 ml) and temperature (20^{o}C) has been shown to be the most suitable environment for maximal survival of soil invertebrates such as earthworms. Likewise, this moderate moisture and temperature can depress aerobic metabolism (Kamin, 2011). According to Ekesi and Maniana (2003) soil temperature above 20 degrees celcius depresses the growth rate of invertebrate communities. Earthworms are especially important because they are involved in promoting soil quality but are affected by climate change greatly, most notably by the change in soil temperature and moisture (Eggleton *et al.*, 2009). Termites are mostly found in tropical areas where they are involved in promoting soil structural stability against water flux (Jouquet and Dauber, 2006).

2.5 Soil organic matter, phosphorus and nitrogen in different cropping systems

Soil properties deteriorate with change in land use especially from forest to arable land (Oguike and Mbagwu, 2009). Some cropping systems may lead to erosion and leaching of soil nutrients which in turn adversely affect the physicochemical properties of the soil (Yang *et al.,* 2020). Soil structure can be effected by poor land use and this has effect on the distribution of microbes that also contribute to formation of soil organic matter (Gupta and Germida, 1988).

Land use change is also considered to be a significant factor in regulating the storage of soil organic matter as it influences the quantity and consistency of litter, the rate of decomposition of litter and the stabilization of soil organic matter processes (Shepherd et al., 2001). Changes in land use, in particular the cultivation of natural land in tropical areas, have led to a reduction in soil organic matter (Fallahazade and Hajabbasi, 2011). Continuous cultivation, physical properties and soil fertility appear to decline due to a decrease in organic matter content and soil pH (Oguike and Mbagwu, 2009). Yemefack and Nounamo (2002), in their studies on the impact of the fallow period on topsoil in southern Cameroon, showed an increase in humus content and led to an increase in organic carbon, which was consistent with the findings of Kirchhoff and Salako (2000) in southern Nigeria.

Intercropping trees or mixed planting creates improved soil quality due to the combining of litter components and synergistic interactions that are beneficial to the soil (Ekanade, 1990). The most important parameter for organic soil binding may be the amount of standing soil litter that combines litter fall and decomposition and is also necessary for aggregate soil stability (Berhard-Reversat and Loumeto, 2002; Emadi et al., 2008).

Maize production is limited by numerous biotic and abiotic factors, including insufficient mineral nutrition (Abu et al., 2011). According to Sharma et al.

(2012), phosphorus has a significant role to play in sustaining and building up soil fertility, especially under the intensive agriculture system. Farm soils in western Kenya are said to have a phosphorous deficiency due to continuous cultivation without adequate nutrients, especially by small-scale maize-growing farmers (Bunemann, 2003). The deficiency of this phosphorous is an essential chemical factor that restricts plant growth in soils. On the other hand, nitrogen is essential because it mediates the uptake and utilization of other nutrients and contributes to the growth and yield of maize (Onasanya et al., 2009). Sugarcane productivity has been reported to decline in recent years with a decline in soil organic matter and a deterioration in some other physicochemical properties (Speir et al., 2004). In such cases, nutrients such as nitrogen are essential for the nutrition and physiology of sugarcane since, among other functions, it is a component of all amino acids, proteins, enzymes and nucleic acids (De Oliveira et al., 2018). Nitrogen and potassium are consumed in larger quantities by the sugar cane (De Oliveira et al., 2018).

Paustian et al (1997) claims that the impact of cultivation on soil organic matter stores of carbon (C) nitrogen (N) and phosphorus (P) has been evaluated by contrasting soils with neighboring forested or uncultivated prairie soils. Carbon concentrations in the plow layer decrease rapidly as native soils are harvested and gradually stabilize after several years. Continuous cultivation in savannah Alfisols in Northern Nigeria resulted in significant organic P (Po) losses compared to native soil (Agbenin and Goladi, 1997).

2.6 Relationship between soil organic matter and soil invertebrates in different cropping systems

Soil organic matter plays a crucial role in preserving the viability of crop systems by enhancing soil physical, chemical and biological properties (Fageria, 2012). The amounts and forms of soil organic matter are mainly determined by the continuous physical and chemical activity of the soil organism (Wiesmeier et al., 2019). Soil species, such as soil fauna and microbes, are essential for shredding, transformation and decomposition of soil organic matter (Filser et al., 2016). Agricultural systems can be affected in the event of a decline in soil organic matter which causes the loss of functionally supported soil organisms (Gardi et al., 2013; Tsiafouli et al., 2015). Loss of soil biodiversity can threaten key processes that deliver ecosystem goods and services that depend on successful ecological intensification, including decomposition and nutrient cycling (Lavelle et al., 2006; Barrios, 2007).

Abundance and diversity of soil fauna are known to be bioindicators of soil quality as they are very sensitive to soil management. In addition, soil invertebrates may also contribute to soil porosity, interact with other species and play an important role in soil organic matter decomposition and nutrient cycling (Lavelle, 1997; Cezar et al., 2015). Studies have shown that conversion from natural vegetation – especially forest to agriculture – almost always leads to a decrease in soil organic matter content due to non-permanent vegetation, biomass exports and, consequently, a decrease in organic inputs (Poeplau and Don, 2015). The amount and quantity of soil organic matter in various farming systems, such as maize, sugar cane and agro-ecosystems, varies depending on the farmer's management practices (Bot and Benites, 2005).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

The study was done on cropping systems near the showground found around Kakamega forest. Kakamega forest is located in the western province of Kenya, lying between latitudes 00^0 08’30.5’’N (41 236 in UTM 36 N) and 00^0 22’12.5’’ N (15 984) and longitude 34^0 46’08.0’’ E (696 777) and 34 57’ 26.5’’ E (717 761) at an altitude of about 1500 to 1600m above sea level (Kuria *et al.*, 2017).

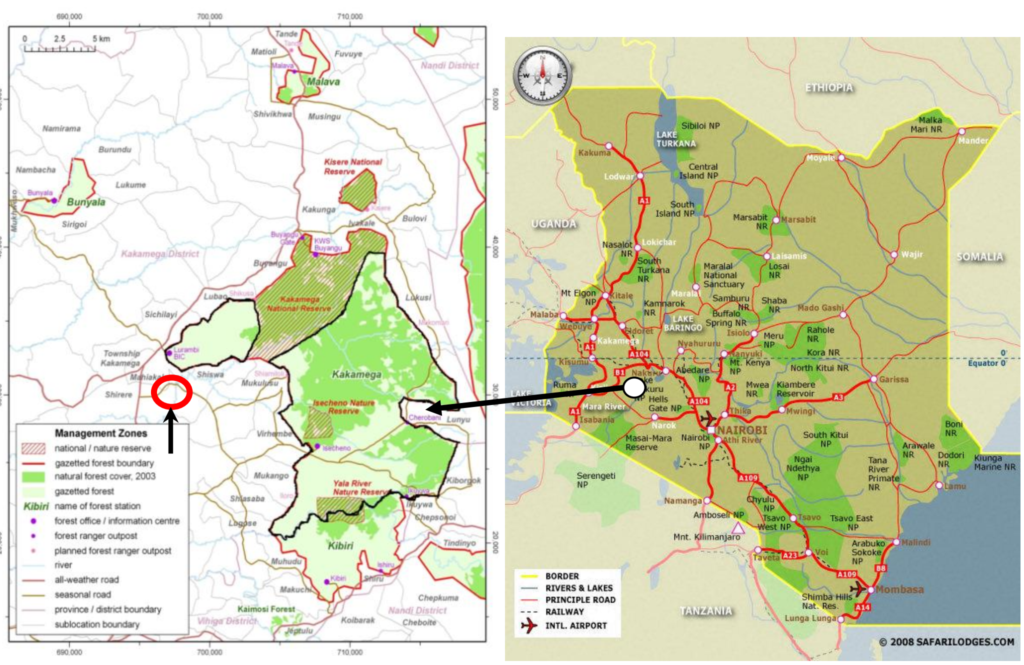

Figure 1: Map of Kenya showing the study area in Kakamega forest. The area marked in black under the jurisdiction of Forest : **Source;** Forest (2015).

This area receives an average of 2080mm of rain per year. Rainfall is bimodal with the heaviest fall in April and May (during the ‘’ long rains’’), with a slightly drier June and a second peak of rain roughly in September to November (the ‘short rains’’). January and

February are the driest months. The temperature ranges between 11^0 C (52F) and 26^0 C (79F)

3.2 Research design

Purposive sampling technique was used in this research. There were six treatments which include different cropping systems; these were maize and beans intercrop, pure maize, pure beans, tea and sugarcane. The sampling from the forest was done as a control experiment. Three sites from each cropping system were randomly identified and three samples from each treatment were collected. The design was efficient to enable comparison of data collected at a different sample sites or groups for both biotic and abiotic aspects of interest without bias since every sample had equal probability of being selected.

3.3 Soil Sampling

Temperature of the soil was recorded using soil thermometer. Soil samples were taken for analysis of soil pH, soil organic matter, nitrogen and phosphorous. During sampling, the soil core was gradually pushed in the soil up to a depth of 20cm below the surface and soil collected. A trowel was used to transfer the sample into clean polythene bags. The polythene bags were then labeled according to the site, treatment, replicate number and depth from which they were retrieved. The soil samples were then transferred to the Department of biological science laboratory at Masinde Muliro University of Science and Technology for soil invertebrate isolation. The remaining soil samples were taken to KALRO Kakamega for analysis of nitrogen, soil pH, phosphorous and soil organic carbon.

3.4 Methods

3.4.1: Determination of soil invertebrate diversity and abundance

According to Bremner 1990 a modified and improvised Berlese Tullgren funnel was used in soil invertebrate extraction. The modified Berlese funnel was made of steel with diameter of 15cm and a wire mesh was fixed at the bottom together with a funnel. The soil samples were placed in the funnel and 40watt bulb was placed 15cm above the soil in the funnel. The setup was then allowed to run for exactly 24 hours per set sample. During this period the organisms were forced to descend down the can so as to seek refuge in the lower levels that are yet to gain heat energy. The lower regions of the soil gained the energy through conduction since the soil holding cans were metallic in nature. The organisms were therefore compelled to move down even further. Eventually, the organisms ended up reaching at the base of the cans which was covered with wire mesh and dropped into the collecting vials (Bano and Roy, 2016).

The trapped organisms were then collected in vials containing 70% ethanol concentration so as to ensure the trapped invertebrates are killed and preserved temporarily. The 70% ethanol was formed by taking 700cm^3 of absolute ethanol and adding 300cm^3 of water to make a liter. By the end of every 24 hours the samples were parked and another set up prepared until all the samples intended to be extracted were exhausted.

Plate 1. Extraction of soil inverterbrate using the Berlese tullgren funnels in the laboratory: **Source**; Author.

The laboratory work was achieved through sorting, followed by mounting and permanent slide preparation. A Carmel brush was used to transfer the catch from the carrying vials onto a watch glass and the vial due to their tiny size, using a dissecting microscope and a tiny sorting pin the invertebrates were the transferred into the storage vials. The specimen were carefully transferred from the rest of the catch and put within the cavity of the slide under a microscope view. Using amounting pin the specimen were then positioned as desired ,either literally, dorsally, transversely, ventrally or longitudinally so as to have a clear view of the anatomical features. Lactic acid was the added as a clearing agent followed by few drops of ethanol as a preservative and put on a slide heater then left to dry for 30 minutes for every set of slides involved in mounting. A cover slip was then smeared with vanish and introduced onto the slide to cover the specimen as it dries even further.

At the end of preparing the permanent slides, they were well labeled and stored to allow identification of taxon levels using a microscope in the later stages. Counting and categorizing them into groups was done with the help of invertebrate expert. Those that were difficult to identify were transferred to National Museum Kenya (NMK) for identification. Identification was achieved using a specialized dichotomous key from (palacio-vargas). The diversity and abundance of the invertebrates was then determined using Shannon diversity index.

3.4.2 Determination of the SOM, Phosphorous, Nitrogen, pH and temperature in the different cropping systems.

Samples collected in polythene bags were processed at a pH of 2 with dilute sulphuric acid and cooled to 4^0C in the refrigerator at the time of processing. Samples for nitrates were analyzed as soon as possible after collection using the UV-vis spectrophotometer (Fiore and O'Brien, 1962). A filtered sample was passed through a column containing granulated copper cadmium in order to reduce nitrate to nitrite. Nitrite (originally present plus reduced nitrate) was calculated by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride to form a strongly colored azo dye that was colorimetrically measured. Separate, rather than combined nitrate-nitrite, values were readily obtained by performing the procedure first with and then without the Cu-Cd reduced stage.

Determination of soil organic matter was done using the Walkley-Black method (Walkley and Black, 1934). The samples of soil were dried and soil organic matter was analyzed. Soil of about 2.0g was weighed and transferred to 500-ml Erlenmeyer flask.10ml of 0.167 M $K_2Cr_2O_7$ was added.

About 20ml of concentrated sulphuric acid was added to the mixture by means of dispenser and swirled gently to mix. Excessive swirling was not done to avoid organic particles adhering on sides of the flask. The mixture was allowed to stand 30 minutes.

The flasks were then placed on an insulation pad during this time to avoid rapid heat loss. About 200ml of water was added using a suitable dispenser, and 0.2g of NaF. Phosphoric acid and NaF were added to complex Fe^{3+} which would interfere with the titration endpoint. Ferrion indicator was added dropwise up to 10 drops. The indicator was added just prior to titration to avoid deactivation by adsorption onto clay surface. Titration was carried out with 0.5M Fe^{2+} to endpoint. The color of the solution at the beginning was yellow-orange, which shifted to turbid gray before the endpoint and then changed sharply to a wine red at the endpoint. A magnetic stirrer was used with an incandescent light to make the endpoint easier to see in the turbid system. Using the above procedure a reagent blank was analyzed without soil. The blank was used to standardize the Fe^{2+} solution daily. The percentage of soil organic matter was then determined.

Extraction of phosphorous was done using Mehlic 3 Double acid extraction (Mehlic, 1984). Mehlic 3 test was used because it is well suited for wide range of soils, both acidic and basic in reaction (Tucker, 1992). Soil of about 2.0g was put into a 50ml Erlenmeyer flask. 20ml of extracting solution was added to each flask and shaken at 200 or more epm for five minutes at a room temperature at 24 to 27^0C. 1cm^3 of charcoal was added to each flask to obtain a colourless filtrate. Filtration of extracts was done again to ensure the extractor is clear. Analyzing of phosphorous was done by colorimetry or inductively coupled plasma emission spectroscopy using a blank and standards prepared in the Mehlich 3 extracting solution.

Determination of pH was done using standard test method for pH measurement (ASTM 1995). To determine soil pH a potentiometer was used which determines the degree of acidity or alkalinity in soils suspended in water and in 0.01 M calcium chloride solution.

Prior to the study of samples, the potentiometer was calibrated with buffer solutions of known pH. The pH measurement was calculated in both the water and the calcium chloride solution since the calcium displaces some of the removable aluminum. Low ion strength counteracts the dilution effect on the exchange balance by taking the salt concentration of the solution closer to that expected in the soil solution. The pH values obtained from the calcium chloride solution measurement were significantly lower than those measured in water due to the release of additional aluminum ions that are hydrolyzed.

Temperature was measured by wooden dowel which was sharpened for easy pushing into the soil. The wooden dowel was pushed into the soil to six inches deep at the sampling site. The dowel was pulled out to leave a deep hole. The thermometer was pushed down in the hole made by the dowel ensuring it reaches the bottom of the hole for accurate reading. The thermometer was left in the soil for about one minute. The reading on the thermometer was taken and recorded for every sampled area.

3.4.3. Determining the relationship between cropping systems, soil characteristics and soil invertebrates

Correlation analysis was done between abundance of soil invertebrates with physicochemical properties (soil organic matter, phosphorus, nitrogen and pH). Correlation was also done between Shannon diversity index, macronutrients and pH. The relationship between pH and macronutrients was also determined.

3.5. Data analysis

Statistical analysis was performed using SAS 9.1 software (SAS Institute Inc.) at $p < 0.05$ confidence level. Data on species diversity was generated using R version 2.10.0 (RDCT, 2009). Kruskal-Wallis test was done to determine differences in abundance of invertebrates in the cropping systems. Determination of soil physicochemical properties (phosphorous, nitrogen, pH, soil organic matter), means were generated using proc means and separated using a student t-test when one-way ANOVA was significant. Spearman's Rank-Order correlation was used to determine the relationship between the physicochemical parameters from the five cropping system and the forest ecosystem with soil invertebrate abundance and diversity.

CHAPTER FOUR

RESULTS

4.0 Introduction

This chapter presents the results for the overall diversity as a measure of both the species richness, and evenness (combined using the Shannon diversity index: H') as well as the abundance of soil invertebrates, macronutrients in the cropping systems and the relationship between soil invertebrate abundance, cropping system and soil characteristics.

4.1 Diversity of soil invertebrates in different cropping systems

Approximately 1215 individual soil invertebrates were collected during the survey belonging to at least 29 insect species. They all belong to the Orders Entomobryomorpha, Symphypleona, Mesostigmata, Trombidiformes, Oribatida, Isoptera, Hymnoptera and Acari.

4.1.1 Seasonal variation in diversity of soil invertebrates based on Shannon diversity index (H')

Highest diversity was recorded in the forest (H'=2.30) followed by the tea farms (H'=1.98) during the dry season, while the lowest diversity of (H'=0.31) was recorded in sugarcane farm (Table 1). During the wet season, the highest diversity was recorded in the forest (H'=2.71) followed by the sugarcane farm (H'=2.31) while the lowest was recorded in the beans farm (H'=1.65). But overall highest diversity of (H'=2.81) was in the forest and the lowest diversity of (H'=1.78) in pure beans farm.

Table 1: The Shannon diversity index (H’) and evenness (E’) of soil invertebrates in different cropping systems around Kakamega Forest

	Diversity (Dry)	Evenness (Dry)	Diversity (wet)	Evenness (Wet)	Overall diversity	Overall evenness
	H'	E'	H'	E'	H'	E'
Beans	1.67	0.932	1.65	0.664	1.78	0.694
Forest	2.3	0.926	2.71	0.957	2.81	0.972
Maize	1.61	0.774	2.26	0.835	2.14	0.772
Maize and beans	1.73	0.889	2.25	0.831	2.29	0.846
Sugarcane	0.31	0.282	2.31	0.833	2.24	0.791
Tea	1.98	0.826	1.86	0.186	2.09	0.792

4.1.2 Composition of soil invertebrates during the wet season

The highest number of taxonomic invertebrate Orders (7) was found in maize farm and the forest while the lowest number of taxonomic Orders of invertebrates (5) was recorded in tea plantation during the wet season (Table 2). The highest number of families of invertebrate (8) was in sugarcane farm and lowest families (6) recorded in tea farm. The highest number of genera/species of invertebrates (17) was found in forest while the lowest (10) was recorded in tea plantation. In the forest ecosystem the most abundant genus was *Friesea* sp. (32) followed, *Isotoma* sp. (29) and *Entomobrya* sp. (22). Moreover pure beans farm exhibited the highest total abundance (211 invertebrates) dominated by *Folsomia quadriculata.* Forest was second with total abundance of(192 invertebrates) dominated by *isotoma sp*. Pure maize ranking third with highest number of invertebrate abundance (176 invertebrates) was dominated by Laelapidae (57 invertebrates) and Caeculidae (36 invertebrates). Sugarcane recorded the lowest abundance (61) but dominated by genus Isotoma (13) and species from Oribatidae (11).

4.1.3 Seasonal variation in composition of soil invertebrates by order and cropping systems

Table 2: Soil invertebrate species abundance in different cropping systems around Kakamega Forest during the wet season.

Cropping system	Order	Family	Genus/species	Total
Maize	Acari		*Euzetes*	1
	Entomobryomorpha	Isotomidae	*Isotoma olivacea*	5
			Folsomia quadriculata	13
			Isotoma sp.	11
		Entomobryidae	*Entomobrya multifasciata*	5
	Mesostigmata	Laelapidae	Laelapidae sp. 1	25
			Laelapidae sp. 2	32
	Oribatida	Oribatidae	Oribatidae sp. 1	12
	Poduromorpha	Neanuridae	*Anurida* sp.	22
			Friesea baltica	5
			Friesea sp.	5
			Hypogastrura sp.	2
			Furculanurida sp.	1
	Symphypleona	Smithuridae	*Sminthurus* sp.	1
	Trombidiformes	Caeculidae	Caeculidae sp. 1	36
			Sub total	**176**
Beans	Acari		*Euzetes*	21
	Entomobryomorpha	Entomobryidae	*Entomobrya multifasciata*	2
			Entomobrya sp. 2	3
		Isotomidae	*Folsomia quadriculata*	110
			Isotoma sp.	4
	Mesostigmata	Laelapidae	Laelapidae sp. 1	4
			Laelapidae sp. 2	9
	Oribatida	Oribatidae	Oribatidae sp. 1	5
	Poduromorpha	Neanuridae	*Anurida* sp.	18
			Friesea baltica	2
		Hypogastruridae	*Hypogastrura*	4
	Trombidiformes	Caeculidae	Caeculidae sp. 1	29
			Sub total	**211**

Table 2: Soil invertebrate species abundance in different cropping systems around Kakamega Forest during the wet season. (Table 2 cont'd).

Cropping systems	**Order**	**Family**	**Genus/species**	**Total**
Maize and Beans intercrop	Acari		*Euzetes*	2
	Entomobryomorpha	Entomobryidae	*Entomobrya multifasciata*	4
			Entomobrya sp. 2	8
			Entomobrya sp.	2
		Isotomidae	*Isotoma olivacea*	13
			Isotoma sp.	20
			Folsomia quadriculata	34
	Mesostigmata	Laelapidae	Laelapidae sp. 2	2
			Laelapidae sp. 1	5
	Oribatida	Oribatidae	Oribatidae sp. 1	12
	Poduromorpha	Neanuridae	*Friesea baltica*	1
			Friesea sp. 3	2
			Anurida sp.	2
		Onychiuridae	Onychiuridae	28
	Trombidiformes	Caeculidae	Caeculidae sp. 1	18
			Sub total	**153**
Tea	Entomobryomorpha	Entomobryidae	*Entomobrya multifasciata*	7
		Isotomidae	*Folsomia quadriculata*	5
			Isotoma sp.	6
	Mesostigmata	Laelapidae	Laelapidae sp. 1	1
			Laelapidae sp. 2	22
	Oribatida	Oribatidae	Oribatidae sp. 1	11
	Poduromorpha	Neanuridae	*Anurida* sp.	38
			Forculanurida sp.	2
			Friesea sp. 2	4
	Trombidiformes	Caeculidae	Caeculidae sp. 1	7
			Sub total	**103**

Table 2: Soil invertebrate species abundance in different cropping systems around Kakamega Forest during the wet season. (table 2 cont'd)

Cropping system	Order	Family	Genus/species	Total
Sugarcane	Entomobryomorpha	Isotomidae	*Folsomia quadriculata*	5
			Isotomidae sp. 1	1
			Isotoma olivacea	2
			Isotoma sp.	10
		Entomobryidae	*Entomobrya multifasciata*	11
			Entomobrya sp. 3	1
			Entomobrya sp. 2	3
	Mesostigmata	Laelapidae	Laelapidae sp. 2	4
			Laelapidae sp. 1	1
	Oribatida	Oribatidae	Oribatidae sp. 1	11
		Euzetidae	*Euzetes* sp.	1
	Poduromorpha	Onychiuridae	Onychiuridae	1
		Neanuridae	*Friesea baltica*	2
			Friesea sp. 2	1
	Isoptera	Termitidae	*Pseudacanthotermes militaris*	7
			Sub total	**61**
Forest	Entomobryomorpha	Isotomidae	*Isotoma* sp.	15
			Isotoma olivacea	14
		Entomobryidae	*Entomobrya* sp.	11
			Entomobrya sp. 2	11
	Mesostigmata	Laelapidae	Laelapidae sp. 1	12
			Laelapidae sp. 2	6
	Oribatida	Oribatidae	Oribatidae sp. 1	14
	Poduromorpha	Neanuridae	*Anurida* sp.	6
			Friesea sp. 2	6
			Friesea sp.	13
			Hypogastrura sp.	13
			Furculanurida sp.	10
			Friesea baltica	10
	Hymnoptera	Formicidae	Hypoponera opacoir	12
	Symphypleona	Dicyrtomidae	*Dicyrtomina ornata*	8
		Smithuridae	*Sminthurus* sp.	14
	Trombidiformes	Caeculidae	Caeculidae sp. 1	6
			Sub total	**192**

During the dry season the highest number of taxonomic Order (7) was found in forest while the least number of Orders (7) was found in sugarcane farm (Table 3). The highest number of families (8) was recorded in forest ecosystem while lowest (3) was recorded in sugarcane plantation. The highest number of genus/species (12) was recorded in forest and lowest (3) was recorded in sugarcane plantation. Maize farm had the highest abundance dominated by Caeculidae sp. (40 invertebrate) and Laelapidae sp. (32 invertebrates). Generally least number of species was collected during the wet season compared to dry season.

Table 3: Soil invertebrate species abundance in different cropping systems around Kakamega Forest during the dry season

Cropping system	Order	Family	Species	Total
Maize	Mesostigmata	Laelapidae	Laelapidae sp. 1	27
			Laelapidae sp. 2	5
	Oribatida	Oribatidae	Oribatidae sp. 1	15
	Poduromorpha	Neanuridae	*Friesea* sp.	1
	Trombidiformes	Caeculidae	Caeculidae sp. 1	40
	Entomobryomorpha	Isotomidae	*Isotoma* sp.	3
			Folsomia quadriculata	18
		Entomobryidae	*Entomobrya* sp.	1
Totals			**Sub total**	**110**
Beans	Entomobryomorpha	Isotomidae	*Folsomia quadriculata*	9
			Isotoma sp.	1
	Mesostigmata	Laelapidae	Laelapidae sp. 1	6
			Laelapidae sp. 2	5
	Symphypleona	Dicyrtomidae	*Dicyrtomina ornata*	6
	Trombidiformes	Caeculidae	Caeculidae sp. 1	8
Total				**35**

Table 3: Soil invertebrate species abundance in different cropping systems around Kakamega forest in western Kenya during the dry season (table 3 cont'd)

Cropping system	Order	Family	Species	Sub total
Maize and Beans	Entomobryomorpha	Isotomidae	*Isotoma* sp.	2
			Folsomia quadriculata	8
		Entomobryidae	*Entomobrya* sp.	3
			Entomobrya sp. 2	1
	Mesostigmata	Laelapidae	Laelapidae sp. 1	6
			Laelapidae sp. 2	2
	Trombidiformes	Caeculidae	Caeculidae sp. 1	2
Total			**Sub total**	**24**
Tea	Entomobryomorpha	Isotomidae	*Isotoma olivacea*	2
			Isotoma sp. 3	1
			Isotoma sp.	13
			Folsomia quadriculata	3
		Entomobryidae	*Entomobrya* sp.	2
	Mesostigmata	Laelapidae	Laelapidae sp. 1	2
			Laelapidae sp. 2	8
	Oribatida	Oribatidae	Oribatidae sp. 1	2
	Poduromorpha	Neanuridae	*Friesea* sp.	1
			Anurida sp.	2
	Trombidiformes	Caeculidae	Caeculidae sp. 1	1
Total			**Sub total**	**37**
Sugarcane	Entomobryomorpha	Isotomidae	*Folsomia quadriculata*	1
	Trombidiformes	Caeculidae	Caeculidae sp. 1	6
	Isoptera	Termitidae	*Pseudacanthotermes militaris*	4
Total			**Sub total**	**11**
Forest	Entomobryomorpha	Isotomidae	*Isotoma* sp.	10
			Isotoma sp. 3	12
		Entomobryidae	*Entomobrya* sp.	5
			Entomobrya sp. 2	12
	Mesostigmata	Laelapidae	Laelapidae sp. 1	6
			Laelapidae sp. 2	8
	Oribatida	Oribatidae	Oribatidae sp. 1	4
	Poduromorpha	Neanuridae	*Anurida* sp.	5
			Friesea sp. 2	7
	Symphypleona	Dicyrtomidae	*Dicyrtomina ornata*	7
	Trombidiformes	Caeculidae	Caeculidae sp. 1	6
	Hymnoptera	Formicidae	Hypoponera opacoir	9
			Sub total	**91**

At least 907 individual soil invertebrates were collected during the wet season which is significantly higher than the 308 individual invertebrates recorded during the dry season. Furthermore, at least 29 species were collected during the wet season which is significantly higher than the 16 invertebrate species collected during the dry season.

A checklist of species abundance by cropping systems and seasons has been provided in table 2 and 3. The species accumulation curve for the species collected during the wet and dry season did not attain asymptote thus the sampling effort has not been expanded (figure 2 and 3)

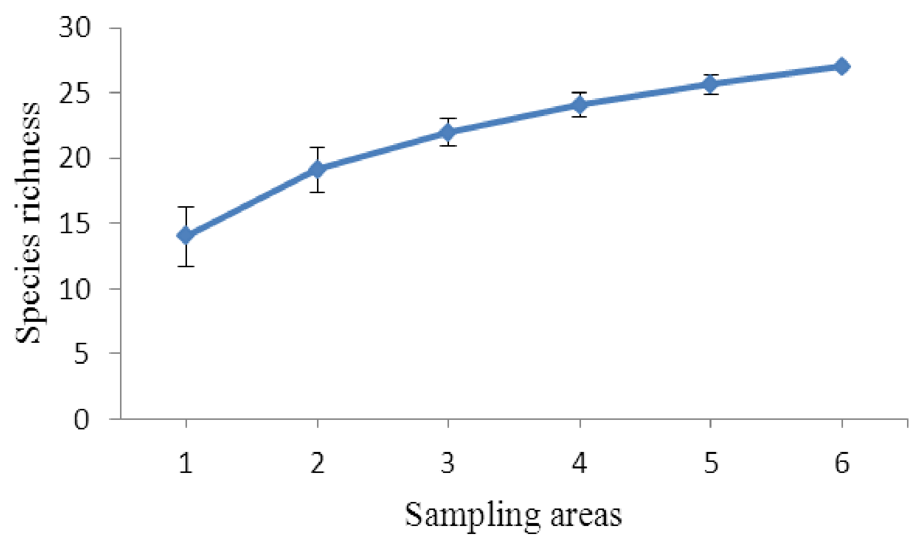

Figure 2: Species accumulation curve during the wet season. Error bars represent standard deviation.

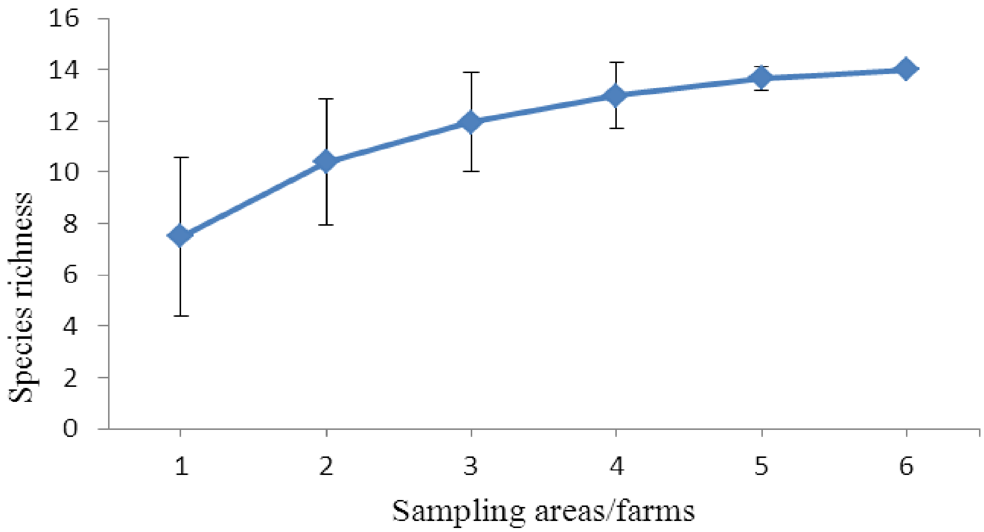

Figure 3: Species accumulation curve during the dry season. Error bars represent standard deviations.

4.1.4 Soil invertebrate abundance and richness in different cropping systems.

In general species abundance and richness was higher in wet season than dry season. In the wet season, the highest abundance was recorded at the bean farm (211) followed by the forest (192). The least abundance was recorded at the sugarcane plantation (72) (Table 4). During the dry season, the highest abundance was recorded at the maize plantation (110) followed by the forest (91) while the least abundance was recorded at the sugarcane plantation (11). Overall, the highest abundance was recorded in maize farm (286) followed by the forest (283) while the least was recorded at the sugar plantation (83). In terms of the species richness the highest was recorded in the forest and sugarcane plantations and the least in tea farm. The highest species richness was recorded in the forest and tea plantations (11 species) in the same season.

Table 4: Species abundance and richness of soil invertebrates during the dry and wet season.

	Dry Season		**Wet Season**		**Overall**	
	Abundance	Richness	Abundance	Richness	Abundance	Richness
Maize	110	8	176	15	286	16
Beans	35	6	211	12	246	13
Maize and Beans	24	7	153	15	177	15
Tea	37	11	103	10	140	14
Sugarcane	11	2	72	16	83	16
Forest	91	11	192	16	283	17
total	**308**	**45**	**907**	**84**	**1215**	**129**

Kruskal-Wallis H test show that the abundance in the cropping systems were statistically significantly different χ^2 (5) = 20.404, p<0.05) (Table 5). The forest and maize farm had the highest abundance with group rank of 40.78 and 35.83 respectively. The intermediate cropping systems were pure beans, beans and maize intercrop and the tea farm whose group ranks were 32.72, 32.28 and 20.33 respectively. The least abundant cropping system was the sugarcane farm with the group rank of 13.06.

Table 5: Differences in abundance of invertebrates in the cropping systems determined by Kruskal-Wallis test.

Cropping systems	Group Rank
Forest	40.78a
Maize	35.83a
Beans	32.72ab
Maize and beans	22.28ab
Tea	20.33ab
Sugarcane	13.06b
Test values; p=0.001, N=54, d.f=5	

Different letters show significant difference between means.

4.2 Micronutrients in different cropping systems

Regarding the six cropping systems, the highest percentage carbon in soil was recorded in forest (3.58%) followed by beans (2.18%) and maize (2.08%) respectively. The least percentage carbon in soil was recorded in the maize and beans intercrop (0.35%) (Figure 4)

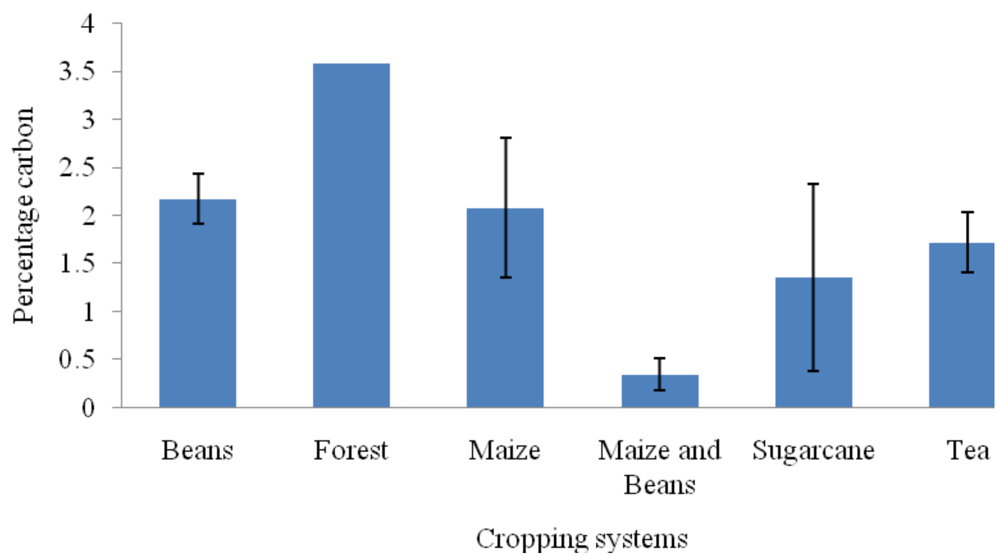

Figure 4: Mean percentage of soil organic carbon in different cropping systems and forest with standard error bars

Phosphorus in the soil was highest in beans farm (2.20%) followed by the tea farm (1.68%) and maize farm (1.05%). On the other hand, the least percentage phosphorus in the soil was recorded in the forest (0.23%) (Figure5).

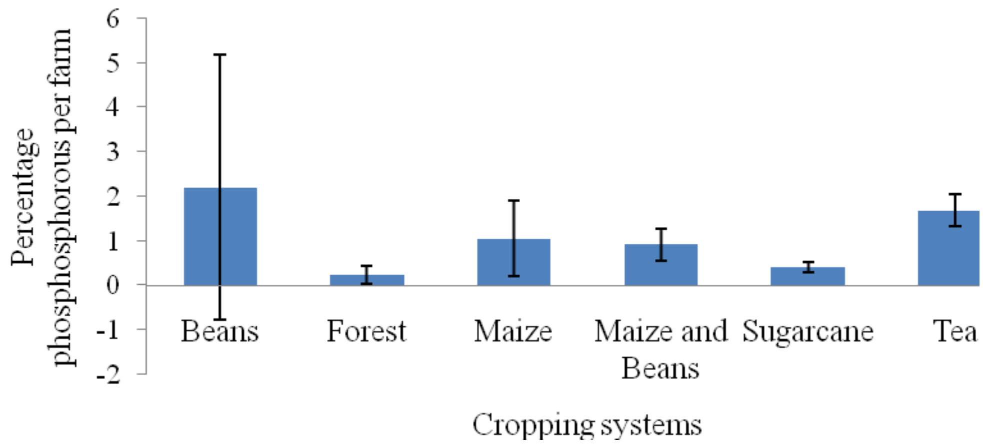

Figure 5: Mean percentage of phosphorus per 100g of soil in the cropping systems and forest with error bars.

Similarly, the percentage nitrogen in the soil varied in the cropping systems and forest. The highest percentage nitrogen was recorded in the maize farm at 0.65% followed by the maize and beans intercrop at 0.59% and tea farm at 0.42%. However, the least percentage was recorded in sugarcane farm with 0.27% levels (Figure 6).

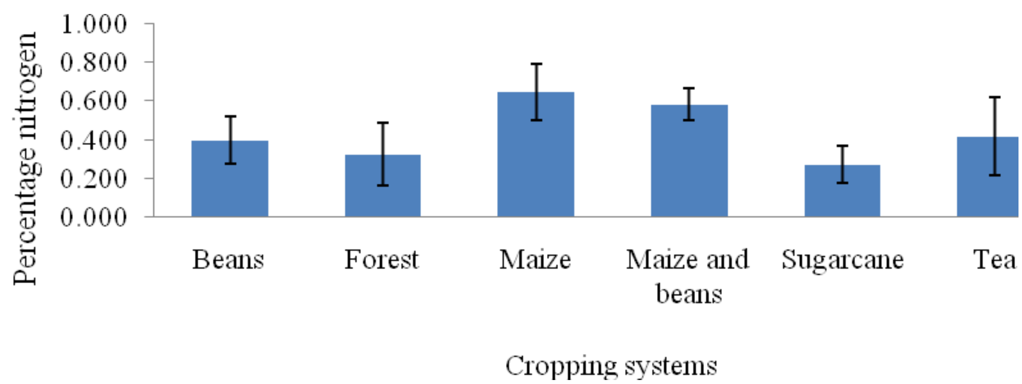

Figure 6: Mean percentage of nitrogen in different cropping systems and forest with error bars.

Analysis revealed a high pH of soil in the sugarcane farm (6.23) followed by the maize farm (5.92) and the forest (5.88). However the least pH in the soil was recorded at the tea farm (4.02) (Figure 7).

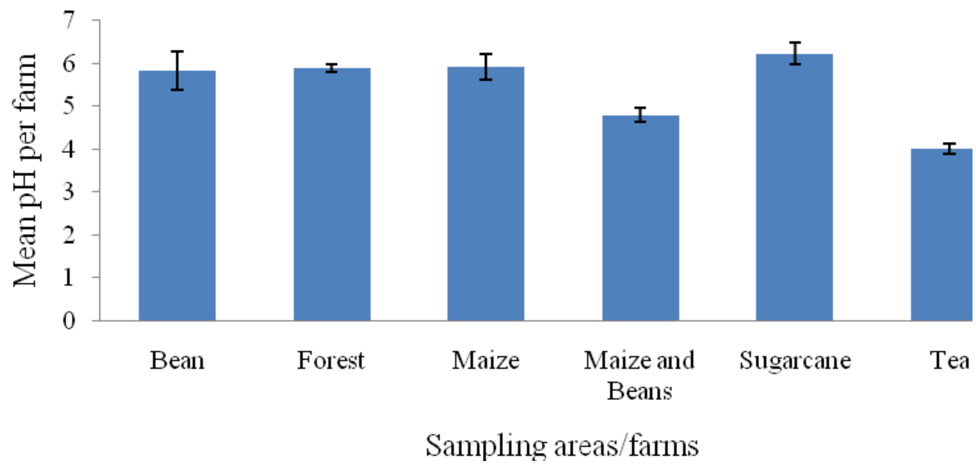

Figure 7: Mean pH of soil in the cropping systems and forest with error bars.

4.3 Relationship of different cropping systems, soil Characteristics and soil invertebrates

In the determination of the relationship of different macro nutrients with soil invertebrates abundance, no correlation was found between phosphorus per 100g of soil and abundance ($r = 0.076$, $p>0.05$), percentage carbon and abundance ($r = 0.63$, $p>0.05$) and percentage nitrogen and abundance ($r = 0.39$, $p>0.05$). Similarly, no correlation was found between Shannon diversity index and percentage of carbon in the soil ($r = 0.42$, $p>0.05$). However, a negative correlation was found between Shannon diversity index with the phosphorous per 100g of soil ($r = -0.87$, $p<0.05$).A detailed analysis of the different soil nutrients in the soil revealed that there was no correlation between the pH and phosphorous per 100g of soil ($r = -0.38$, $p>0.05$), pH and percentage carbon in the soil ($r = 0.39$, $p>0.05$) as well as pH and percentage nitrogen ($r = -0.26$, $p>0.05$).

Cropping systems with pH of 5 experienced greater abundance of soil invertebrates while those with pH of 4 and 6 experienced lower abundance levels (Table 6). Percentage carbon phosphorus and nitrogen varied in different cropping systems.

Table 6: Soil invertebrate diversity, abundance and the physicochemical characteristics.

Cropping Systems	**AI**	**DI (H')**	**Physicochemical factors**				
			T(^{o}C)	**pH±S.D.**	**%N ±S.D.**	**%C±S.D.**	**%P±S.D.**
Maize	286	2.14	22.5	5.92±0.31	0.646±0.14	2.08±0.72	1.05±0.85
Beans	246	1.78	21.5	5.84±0.45	0.398±0.12	2.18±0.25	2.21±2.98
Maize/beans	177	2.29	22.5	4.81±0.17	0.585±0.09	0.35±0.17	0.92±0.36
Tea	140	2.09	23.0	4.02±0.12	0.41±0.20	1.72±0.31	1.68±0.35
Sugarcane	83	2.24	23.0	6.23±0.25	0.272±0.10	1.36±0.97	0.41±0.11
Forest	283	2.81	21.5	5.88±0.09	0.325±0.16	3.58±0.00	0.23±0.19

(AI) Abundance of invertebrates, (DI) Diversity of invertebrates, (T) Average temperature, (%N) Percentage nitrogen in soil, (%C) percentage carbon in soil, (%P) Percentage phosphorous in the soil.

CHAPTER FIVE

DISCUSSION

Overview

This chapter discusses the results of the determination of the diversity of soil invertebrates in different cropping systems, the impact of cropping system on macronutrients and the relationship between soil invertebrate abundance, cropping systems and soil characteristics

5.1 Diversity and abundance of soil invertebrates in different cropping Systems

The forest experienced high diversity of invertebrates compared to the cropping systems, studies done by Ayuke *et al,* (2009) showed the same. It is possible to link the current results of diversity to human induced disturbances. In this regard Ayuke, (2010) observed that undisturbed land tends to have higher diversity than cultivated land. Moreover, disturbance caused by humans tend to reduce diversity of soil invertebrates. Conversely, the forest is less disturbed thus high diversity because the niches of soil invertebrates are not destroyed (Gibson *et al*., 2011). Some soil organisms have been found to be negatively affected by the intensity of agricultural activities (Ponge *et al.,* 2013). The present assertion is supported in part by the findings of Lauga-Reyrel and Deconchat, (1999) and Rosilda *et al.,* (2002), where groups of soil invertebrates responded to changes in soil conditions and land use. Tea farm also had high diversity which may be due to minimal disturbance from human activities Stable ecosystem tend to have high diversity compared to disturbed ecosystems (Gibson *et al*., 2011).

It is possible that the high abundance of arthropods in the forest was occasioned in part by less human disturbance. Maize farm had high abundance of soil mites compared to other farms. This is contrary to what was observed by Maribe *et al.,* (2011) that showed maize farm having low diversity and abundance of mites compared to forest ecosystem possibly due to fewer disturbances in forest. Studies done by Coleman and Crossley (1996) show that mites influence decomposition by grazing on fungi and other soil organisms thus promoting the formation of humus in the soil. Stability of Oribatid mites in all cropping systems may be due to ability of them to change their diets best on food resources that are available. (Maraun *et al*., 2011, Scheu *et al*., 2005). Niche differentiation among different trophic groups may, in part, contribute to the high diversity of soil Oribatid mites and this may be the reason why they are able to appear in all cropping systems and forest (Schneider *et al*., 2004).

There were more collembolan species in forest compared to other farms. Muturi *et al*., (2009) also observed that indigenous forest having high densities of collembolan communities compared to agricultural land. Soil Collembola are present in all habitats but at different densities and diversity as this group of organisms are known to react to changes in land use (Luanga-Reyrel and Deconchat, 1999; Rosilda *et al.,* 2002).

The low abundance of soil invertebrates in sugarcane and tea farms may be due to frequent application of chemicals that are used to kill weeds interfere with their population. Application of herbicides may affect arthropod community dynamics separate from their impact on the plant community and may influence biological control in agro ecosystems (Evans *et al.,* 2010). Burning of harvest remains in sugarcane farm may also have contributed to low abundance of invertebrates because fire kills and destroy habitat of some soil organisms (Srikanth *et al.*, 1997).

The vast majority of species were collected during wet season compared to dry season when the temperatures were a bit high. Results by Robinson *et al.*, (2018) showed that invertebrate species evenness decreased in the warmer sites, leading to an overall decline in Shannon diversity. Factors such as seasons affect distribution of soil invertebrates because of resource availability (Menezes *et al*., 2009; Calvi *et al*., 2010). The wet season had the highest diversity and abundance as observed by Moço *et al*., (2005) that rain contributes to a more favorable environment for biota and stimulates. The results suggest that composition of soil invertebrates among cropping systems might differ given seasonality influences.

By and large human induced disturbance occasioned by activities like tilling the land perhaps interfered with the amount and location of food supply to the invertebrates thus in tilled land the species decreased. Macrofauna species richness and abundance are negatively affected by anthropogenic activities such as deforestation, increased intensity of agriculture and soil disturbance (Okwakol, 2000; Birang *et al*., 2003 and Curry *et al.,* 2002). When land use practices are intensified there is a change compared to the original ecosystem and thus soil organisms have to adapt to the changes which will determine the ultimate community present after the perturbation. If 'health' of soil is maintained well then yield of increases. Hence above-ground and belowground ecosystem is also maintained (Wardle *et al*., 2004).

5.2 Impact of cropping systems on macronutrients.

In the determination of the impact of cropping system on macronutrients, the percentage mean of carbon in the soil was registered the highest in forest (figure 4), also observed by Nogueira *et al*., (2006). It is possible that the percentage carbon was higher in the forest due to accumulation of litter decomposing and high rate of ammonification. In any case some of the soil invertebrates are involved in the decomposition of litter to increase organic matter. According to Blouin *et al.,* (2013) high soil invertebrate abundance and diversity increases organic matter consumption and this may improve soil structure and leads to greater nutrient flux and an improved soil health. Research done by Calegari *et al.,* (2008) showed that there was severe decrease in the amount of organic carbon in soil of land that is continuously cultivated compared to the soil of native forest. On the other hand, the least percentage carbon was registered in maize and beans intercrop and this may be due to much disturbance from humans through cultivation and less accumulation of litter. Low amounts of carbon were observed in cultivated farms which were also observed by Spaccini *et al.,* (2006).

Regarding the percentage of phosphorous in the soil and in/per farms, the highest mean percentage phosphorous in the soil was in beans farm (figure 5). Agricultural lands are said to have high concentration of phosphorus compared to stable ecosystem due to application of fertilizers rich in phosphorus (Gao *et al.,* 2019). Plants with intense and short cycle development such as the corn and beans require high amount of phosphorus in solution and faster adsorbed phosphorus replenishment than perennial crops hence highly supplied through fertilizer leading to accumulations (Lino *et al.,* 2018). In sugarcane farm low phosphorus may be due to increased uptake and accumulation of phosphorus in the plant for growth hence reduces in soil after harvest (Matin *et al*., 1997). The lowest percentage phosphorous was recorded in forest and this may be due to nutrients being utilized hence not replaced on time. According to De Schrijver *et al*., (2012) total phosphorous stocks decreases with forest age.

Highest percentage of nitrogen in the soil was recorded in the maize plantation followed by the maize and beans intercrop and tea plantations (figure 6). Consequently it is possible that the high percentage of nitrogen was recorded in maize farm in part due to the use of nitrogenous fertilizer by farmers. Research done by Fan *et al*., (2020) showed that intercropping maize with legumes increases the uptake of nitrogen by plants compared to maize mono cropping hence in maize farm some nitrogen is retained in soil.

The pH of soils in maize farm, forest and beans was almost similar (figure 7) which possibly could have favored abundance of specific species of soil invertebrate. The pH in tea farm was considerably low, according to Dang, (2005) tea grow well in acidic soil. Unlike other crops such as maize, beans and sugarcane tea can cause acidification of soil hence reduction in pH of soil (Yan *et al*., 2018). Yan *et al.*, (2018) compared the soil pH of tea farm and forest where forest showed high pH than tea farm. This low soil pH may affect the bacteria and fungi in the soil hence affecting the distribution of organisms such as mites and collembolan (Fierer *et al*., 2009).

5.3 Relationship between soil invertebrate abundance cropping systems and soil characteristics.

In this study there was no correlation between the macronutrients and soil invertebrate abundance. This may be due to less number of samples made during the research which did not bring up the correlations Studies done by Zagatto *et al.,* (2017) showed that few significant correlations observed between soil meso-fauna groups and physical-chemical soil attributes. No correlation was observed between carbon, phosphorous and nitrogen with soil invertebrate abundance. However, according to Lavelle, (1997) showed that most of the sampled groups of soil fauna were correlated negatively with carbon/nitrogen ratios and positively with soil nitrogen contents indicating preference of soil fauna for previously decomposed food resources.

There was no correlation between pH and nitrogen contrary to what was observed by Chakraborty, (2016) showing correlation between pH and nitrogen because increased use of nitrogenous fertilizer may lower pH of the soil. Nitrogen enriched directly to the soil increases soil acidification hence change in pH of the soil (Chen *et al.,* 2019). There was no relationship between phosphorus and pH contrary to results observed by Curtin *et al*., (2001) showed that an increase in pH caused decrease in soluble phosphorus. Soil pH of 6 to 7.5 is ideal for availability of phosphorus for plant use, very high and low pH can cause fixation by aluminium, iron or calcium (Jensen, 2010). No correlation was found between pH and soil organic carbon unlike what was observed by Curtin *et al.,* (1998) which showed a relationship between soil ph and soil organic carbon. Soil ph increases solubility of soil organic matter by increasing dissociation of acid functional groups (Andersson *et al.,* 2000). Dissolved soil organic matter increases with pH and consequently carbon and nitrogen (Curtin *et al.,* 1998).

CHAPTER SIX

6.1. Conclusion.

- The study demonstrates that the maize and beans intercrop had the highest diversity and abundance of soil invertebrates followed by pure maize. Diversity and abundance of soil invertebrates was higher in the wet season than during the dry season. Stable ecosystems exhibit higher diversity of species.

- The highest percent phosphorous, nitrogen and carbon was recorded in pure beans, pure maize and pure beans respectively. The lowest phosphorous, nitrogen and carbon was recorded in forest, sugarcane and maize and' beans intercrop respectively.

- The soil nutrients level influenced the soil invertebrate diversity and abundance but this was not statistically significant.

6.2. Recommendations

- Farmers should be encouraged to plant maize and beans intercrop which enhances high diversity and abundance of soil invertebrates. Farmers should employ agricultural activities that have less effect on the diversity of soil invertebrates hence conservation of the soil invertebrates.

- Secondly, given that forests had high carbon content presumably because of high litter content that contribute to organic matter, the present study observes that farmers can as well be encouraged to employ decomposed organic manure in cropping systems. Sugarcane farmers should use fertilizers rich in phosphates since sugarcane farm recorded low phosphate levels.

- In order to enhance the relationship between soil invertebrate diversity, abundance and nutrient levels it is recommended farmers to practice intercropping.

6.3. Suggestion for further research

- There are some issues this study did not address but are important can form basis of further studies. Diversity and abundance of both micro invertebrate and macro invertebrate should be looked at and how they interact.
- Other physicochemical properties should be included in the study such as the micronutrients and other climatic factors like humidity, moisture content e.t.c which can affect distribution of soil invertebrate.
- Sampling should be done over long period of time to enable one achieve appropriate relationship between soil organism and physicochemical characteristics.

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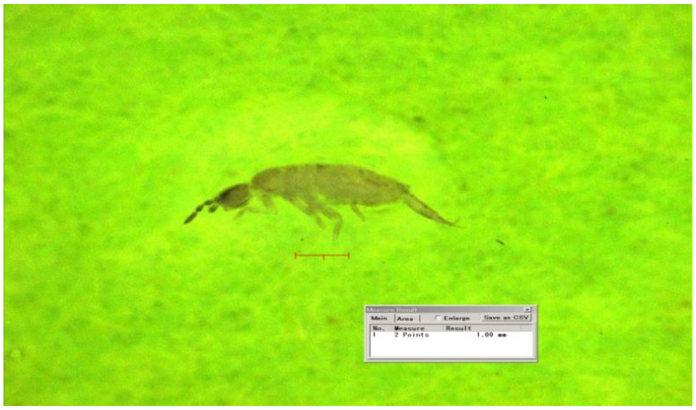
APPENDICES

Appendix 1: Some of the soil invertebrates collected in the cropping systems.



Isotoma olivaceas

Entomobrya multifasciata

Folsomia quadriculata

Appendix II: Coordinates of cropping systems and forest.

cropping systems	**Latitude**	**Longitude**
Maize farm	$0^0$17’23.1”	$34^0$46’33.9”
Bean farm	$0^0$17’03.7”	$34^0$47’27.6”
Tea farm	$0^0$17’44.7”	$34^0$48’23.8”
Maize and bean farm	$0^0$17’44.7”	$34^0$47’51.2”
Sugarcane farm	$0^0$17’29.9”	$34^0$47’24.0”
Forest ecosystem	$0^0$17’32.4”	$34^0$46’29.0”