THE INFLUENCE OF SOIL FERTILITY MANAGEMENT PRACTICES ON DIVERSITY AND ABUNDANCE OF SOIL FAUNA IN THE CENTRAL HIGHLANDS OF KENYA

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ANIMAL ECOLOGY) OF KENYATTA UNIVERSITY.

BY

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DECLARATION

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To the **Almighty**, for providing all I ever needed to achieve this work and to **my mother and siblings** for their longest serving friendships.

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ABSTRACT

The need for an increase in crop (particularly food) production to match the demand from an ever-increasing human population has led to intensive agriculture. This is usually associated with a high level of ecological disturbance. Soil fauna seem to play a key role in determining soil quality via mineralisation and the farmers already use presence of macrofauna as fertility indices yet their balance is likely to be upset by such disturbances. It is necessary to study their distribution in common farm management practices associated with intensive agriculture to determine which practices can be useful in increasing soil fertility and productivity sustainably. Presently, over 73% of the smallholder farmers in Kiambu District, Central Kenya are using crop manure, animal wastes and inorganic fertilizers to increase their farms' fertility and subsequent productivity. Disparity in these organic amendment and soil erosion control practices has resulted in a scenario whereby patches of productive/fertile and less-productive/degraded soils have developed and are conspicuously identifiable by majority of the farmers. This study was to find out if the organic resource management practices which farmers adopt in response to soil fertility decline, enhance the biodiversity and activity of soil fauna, some of which may serve as indicators of soil quality. Six small-scale farms were selected from members of Karura Catchment Committee in Kikuyu Division of Kiambu District. A series of 20 x 20 x 20cm soil monoliths were dug, macrofauna hand-sorted, identified and counted. In addition, some key microfauna/microorganisms (Bacteria, Fungi and

Actinomyecetes) and mesofaunal groups (nematodes) were studied. The latter was done by plate dilution technique and the sieving/filtration respectively. Sampling was done as from May to December 2000. Results obtained pointed towards the fact that the farms that had no soil erosion control or soil fertility control (termed unproductive by farmers) were less species rich but more species-even (S= 38 and J=1.35323). Farms with both soil erosion control and organic amendments as a soil fertility control (termed productive by farmers) had a higher species richness of S=47 and less evenness of J=0.61614. The third category I had added as 'moderately productive' (had soil fertility control in terms of organic amendments but no soil erosion control) had the least number of species (27) and a 'moderate' richness and evenness. The ratio of parasitic nematodes to non-parasitic nematodes was highest in the non-productive farms even though they had the least overall total count. Distribution of various microfauna groups differed in each farm with the lowest overall count being in the non-productive patches. Fungi density was highest in the degraded farms depicting a more acidic nature of the soils. Overall, these results pointed towards the fact the practice involving organic amendments incorporation and a soil erosion control involving agro forestry led to increase high faunal species, abundance and activity, rendering the farms more productive.

CHAPTER 1

1.0. INTRODUCTION AND LITERATURE REVIEW

1.1. INTRODUCTION

1.1.1. FARMING PRACTICES IN KIAMBU DISTRICT

Kiambu District has a long history of agricultural activity. In the nineteenth century, the Bantu inhabitants (mainly the Agikuyu) practiced shifting cultivation with the major aim of producing food. The practice was at a small-scale level (Bernard, 1972). At the turn of the 20th century, the British colonialists took the area as part of the prestigious 'white highlands'. These were commonly used for cash crop production mainly coffee, tea and pyrethrum. The land was subjected to intensive cultivation with plantation farming and large-scale animal husbandry. In addition, there was now an intensive application of agrochemicals (fertilizers, pesticides, herbicides, etc.) and increased mechanization, which were formerly absent. With the attainment of independence in 1964, various changes occurred, among them, the reacquisition of farming lands by black Kenyans. This was either through land purchase or by resettlement schemes. However, the farming activities did not quite revert to the former plantation farming and large-scale animal husbandry rather, mixed enterprise agriculture was practiced. (Helleiner, 1968; Oloya, 1969; Bernard, 1972; Richard, 1974, Woomer *et al.* 1999).

Today, the main cash crops grown in this district are coffee and tea with plantations occupying a total of 47,200 ha. Most farmers are small holders (Gitau *et al.* 1994) with a total of 94,800 ha of land under such ownership. Various crops are also grown for domestic use, in small scale mixed farms (Jaetzold and Schmidt, 1983). These include maize, beans, Irish potatoes, fruits and vegetables. Sweet potatoes, bananas and arrowroots are mainly grown for subsistence (Wachira, 1996). In addition, horticulture and floriculture are practiced in the more humid and cooler parts of the district (Jaetzold and Schmidt, 1983).

Dairy farming is a common practice with a high tendency towards zero grazing of improved breeds (Woomer, *et al.* 1998). According to a 1997 unpublished report by ILRI/KARI/MALM, the dairy animal population in the district was estimated at 240,000 head with an average of 5 heads per homestead. Poultry, sheep, rabbit, goat and bee keeping are common in the lower parts of the district. Livestock is usually raised under confinement, allowing more land to be used for production of commercial crops (mainly vegetables, tea, coffee, and pyrethrum) and to facilitate the recovery of manure (Woomer, *et al.* 1998). According to Jaetzold and Schmidt (1983), the area can be divided into four agroecological zones. The Upper Highland zones (UHO-2) have forestry, sheep and cattle keeping, and growing of pyrethrum as the main land use. The Upper midland zones (UM1-5) include coffee, sunflower and maize, and livestock/sorghum zones. Lower midland zones (LM4-5) have livestock keeping and millet farming only. Finally, the Lower highland zones (LH1-5) have such

activities as tea/dairy farming, wheat farming, maize-pyrethrum farming and ranching.

Intensive cultivation in Kiambu District, like in most other agricultural areas coupled with the ever-increasing population pressure, has led to massive deforestation for more agricultural land, usually with little opportunity for fallowing. Studies conducted in the temperate semi-arid regions have shown that such activities have a major bearing on the diversity and activities of soil organisms (Rasmussen and Collins, 1991) and subsequently, the soil fertility.

1.1.2. FERTILITY AND PRODUCTIVITY OF KIAMBU FARMLANDS

Kiambu District has a high potential agricultural production with a land surface of 218,800 ha of which 142,000 ha is arable (Gitau *et al.* 1994; Maarse, 1995; Ombui *et al.* 1997). The rest of the land ranges from low medium potential to rangeland, around Ndeiya and Longonot.

Farmers here are aware of patches of poor soils in their farms and are therefore practicing diverse integrated nutrient management strategies to enhance their productivity (Murage, 1998). Over 73% of these farmers use crop residues, animal wastes and inorganic fertilizers. These are usually applied on patches with

crops having high market value (Murage, 1998). Contour plowing and agroforestry are the common soil erosion control practices (Gitau *et al.* 1994).

Apart from the gradual decline in productivity, farmers have observed that the less-productive soil patches have less soil macrofauna (Murage *et al.* 2000). The situation in these farms could be explained by the suggestion given by Lavelle and Pashanasi (1989), that the reduction in diversity and population sizes of the soil fauna species could in part reduce the ability of agricultural systems to withstand unexpected periods of stress. Results from soil fertility studies done earlier at KARI-Kabete stations indicate that these very soils have a potential to be extremely productive (Kapkiyai *et al.* 1997).

1.2: LITERATURE REVIEW

1.2.1. THE ROLE OF SOIL FAUNA IN LITTER DECOMPOSITION AND SOIL FERTILITY ENHANCEMENT

Soil fauna enhance the bio-degradation and humification of organic residues by comminuting organic residues and increasing their surface area for microbial activity and interactions, by producing enzymes that break down complex biomolecules into simple compounds and by polymerizing compounds to form humus. In addition, they improve the environment for general microbial

growth (Schinner, 1995; Tian, 1997, Ayuke, 2000). Swift, (1997) has summarized the role of these populations and biological processes as follows:

1. Symbionts such as rhizobia and myccorhiza increase the efficiency of nutrient acquisition by plants.

2. A wide range of fungi, bacteria, and animals participate in the process of decomposition, mineralisation and nutrient mobilization and therefore influence the efficiency of nutrient cycles.

3. Soil organisms mediate both the synthesis and decomposition of soil organic matter (SOM) and therefore influence cation exchange capacity; the soil Nitrogen, Sulphur, and Phosphorus reserve; soil acidity and toxicity; and soil water-holding capacity.

4. The burrowing and particle transport activities of soil fauna, and soil particle aggregation by fungi and bacteria, influence soil structure and soil water regimes.

These roles are achieved by an almost elaborate division of the populations into trophic groups consisting of herbivores, detritivores, predators and omnivores (Wilson-Rummenie *et al.* 1999). Under natural conditions, soil fauna and microorganisms form an integrated system for decomposition of organic residues (Wardle and Lavelle, 1997). However, with environmental disturbance, such as conversion of natural systems to agricultural systems and the

elevation of atmospheric carbon dioxide, the integrated system is hampered with (Swift, 1996).

In most terrestrial ecosystems, the majority of net primary production enters the decomposition sub-system of plant litter. Plant litter provides habitats in which organisms interact in various ways, contributing not only to the effective decomposition, but also their survival (Price, 1988). The biodiversity here ranges from bacteria, fungi and protozoa, to invertebrate animals (Lee, 1985; Hawksworth and Mound, 1991). The latter group constitutes earthworms, termites and litter feeding arthropods. Each group tends to act independently to bring about a combined effect with the rest. Brown, (1993) referred to the resulting dependency as Metabiosis.

For purposes of this study, soil fauna have been divided into macro- meso- and micro- fauna. These groups are often taxonomic but sometimes species with similar biologies are grouped together for purposes of integration (Hendrix *et al.* 1986; Coleman *et al.* 1992,). These classifications can be according to body length (Wallwork, 1970) or body width (Swift *et al.* 1979).

1.2.2. SOIL MACROFAUNA

1.2.2.1. The role of earthworms

Earthworms are usually common in any soil samples and are known to contribute to plant litter decomposition and nutrient release through ingestion and mixing of the same in the soil (Tian, 1997). Their casting activities also promote nutrient recycling in the soil (Lee, 1985), apart from affecting soil structure and aeration. Earthworms have some enzymes capable of decomposing chitin and oligosaccharides. Their gut milieu may promote activities of cellulase and mannanase (Hauser, 1993) and the growth of fungi that are useful in decomposition (Kang, 1994). They are also involved in the mobilization of soil phosphorus (Zhang *et al.* 1998). Bonche (1977) grouped earthworms into three different ecological types:

- Epigaeic species - these dwell in surface litter.
- Endogaeic species - are active in mineral soil layers
- Anecic species - these move vertically between deeper soil layers and the soil surface

Some earthworm species seem to be intermediate between these categories and do not fit into any group very well. 'Misfits' include some species inhabiting decaying logs. It is because of earthworms' high abundance, biomass and activity

CHAPTER 2

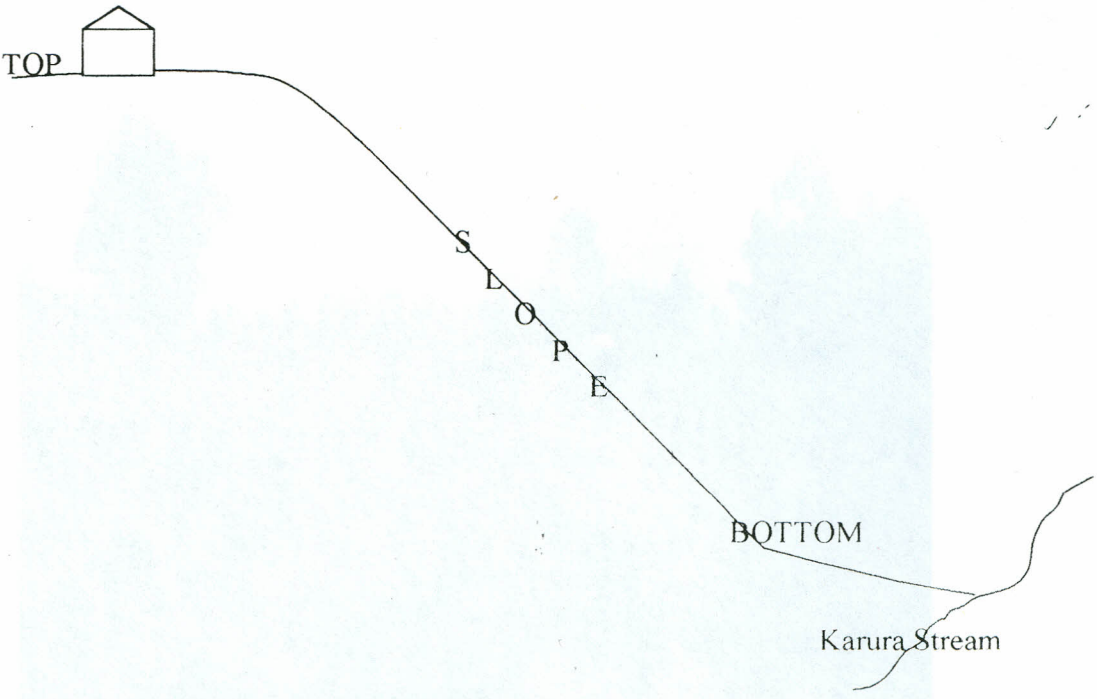
2. MATERIALS AND METHODS

2.1. DESCRIPTION OF STUDY AREA

The studies were carried out in Kiambu District of Central Province, Kenya. Priority was assigned to farms located on the Kikuyu Red Clay or other humic Nitisols. The district lies between 0° and 25° S and 36° and 37° E. It is at 1350m to 2400m height above sea level and occupies a total of 228 000 km^2 (Survey of Kenya, 1992). The soil is a Humic Nitisol rich in most plant nutrients except N and P due to volcanic influence and has been referred to as ' Kikuyu Red Clay'. It has bimodal rainfall pattern with long rains between March and May and short rains between October and December. The mean annual rainfall is 1100 mm and temperatures range between 10^0C and 25^0C, depending on the location and altitude.

As mentioned earlier (section 1.1) the district has four agro ecological zones. Kikuyu Division where the study farms are situated, has some patches of the UM to the extreme left (5 & 6). The rest of it has LH (3,4 & 5). Therefore, the agricultural practices include; marginal coffee, wheat, maize, pyrethrum and livestock (See appendix 1). The selected farms all lie along the Karura streams and are thin strips of land having part of the top slope/plateau, the V-slope of the valleys and the rich valley bottom of the streams (Figure 2.1).

Figure 2.1: Sketch illustrating the general catena of the sampled farms.



The plateau (top) is used for homestead, zero grazing of cattle, sheep pens, and chicken rearing. Just near the sloping area, a fodder crop (Nappier grass) is grown. The sloping area is planted with some nappier, maize, beans, potatoes and bananas while the valley bottom is used for planting vegetables especially during the dry season for selling to the neighboring towns. The average size of each farm is 2.3 hectares. Farmers identified four of the farms as either productive (2) (Plate 2.1) or unproductive (2) (Plate 2.2) while the other two farms I have added and termed 'moderately productive'(Plate 2.3).

Plate 2.1: Picture showing a productive farm that has both soil erosion control (as bench terraces and agroforestry) and a regular addition of cow dung and crop residues.

Plate 2.2: Picture showing an unproductive farm that has neither a soil erosion control measure nor addition of organic amendments in terms of cow dung and crop residues. The foreground shows vegetables growing in the valley bottom.

Plate 3.3: Picture showing the top part of a moderately productive farm with addition of cow dung manure but no soil erosion control practice.

2.2 SAMPLING METHODS

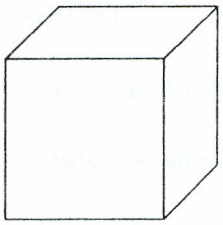
2.2.1 General methods

Soil monoliths of size 20 x 20 x 20 cm (Figure 2.2) were dug at the three main soil management practices; (i) those with both the soil fertility control measure and bench terracing with agroforestry as a soil erosion control measure (S.E & S.F) and which farmers called productive, (ii) moderately productive farms with manure addition as a soil fertility control measure (S.F) and (iii) those with non of these practices (NONE) termed unproductive by farmers. Therefore, each practice had two representative farms. The sampling was done in a random stratified way with slope position as strata, to ensure that it was as representative of the whole farm as possible. Sampling was done every fortnight and at each visit, ten samples were taken from each farm as from 8 AM to 12 Noon. This was done from May to December 2000.

2.2.2. Sampling for macrofauna

Litter enclosed by the monoliths and the dug out soils were placed on white plastic trays and macrofauna hand sorted from it. 70% Alcohol was used to preserve the retrieved macrofauna in Mc Cartney specimen bottles for subsequent studies, as is the conventional practice (Anderson and Ingram, 1994). The preserved macrofauna were identified at the Department of Zoology, Kenyatta University upto famil. A record was kept of the number of individuals of each level.

Figure 2.2. Illustration showing a soil monolith before it is dismantled for handsortng of macrofauna.



2.2.3. Sampling for mesofauna/nematodes

A. Field sampling

After sorting the soil samples in section 2.2.2, they were each mixed thoroughly then two handfuls of each composite sample scooped into a small polythene bag. These were then labeled to include the slope level and farm type e.g. Top-S.F or Bottom-NONE and carried to the Plant Pathology Laboratory at the University of Nairobi, for further analysis. Since the interest was in nematodes that are associated with plant roots, this was done twice during the planting season; at two weeks after planting and then during the harvesting period.

B. Laboratory procedure

A nematode suspension was made using the sieving and filtration method (ARC, 1997). A 200 ml fresh soil sample from the two handfuls mentioned in (A) above was placed in a 10-liter bucket and covered with water to half the bucket. Soil lumps were gently broken by rubbing them in between fingers while still

immersed in the water. The resulting mixture was poured through a 2 mm aperture sieve into a second bucket. All the buckets used here were the same size. The residues in the first sieve were discarded.

The contents of the second bucket was stirred and allowed to settle for 10 seconds and then poured through a 250 microns sieve into the first bucket leaving behind heavy particles to which five liters of water was added and the process repeated. The sieve was rinsed over basin 1, the residues back-washed into a 1-litre plastic jar and the pan contents decanted into a 500 ml beaker. Basin 2 was cleared and the process repeated using a 90 microns, 63 microns, 45 microns aperture sieves and residues collected as described above. The contents of the beaker were allowed to settle for two hours after which the supernatant liquid was quickly decanted off. The remnant was poured onto a double layer of paper towels placed inside a circular sieve that was already placed in a plastic plate. This setup was then covered by another plastic plate and left undisturbed for the next 24 hours. Nematodes move through the paper towel holes into the collecting water in the plates while soil particles remain on the paper towels.

After this period of time, the suspension was carefully concentrated by passing it through a 45 microns sieve and one ml of it poured into a nematode counter before observation under a compound microscope. The total number of nematodes was recorded. Using presence or absence of a stylet as a morphological indicator, a further record of whether each nematode was plant parasitic or non-parasitic noted. For each of the soil samples (e.g. Top-S.E/S.F),

counting was done for three different one ml suspensions and an average calculated of total numbers and proportions of parasitic and non-parasitic nematode. Nematode numbers were averaged over the two sampling occasions.

2.2.4. Laboratory preparation for microfauna/microorganisms

The soil samples fresh from the fields as described in section 3.2.3 (A) were refrigerated for two days at 10-15°C awaiting further analysis. After this, they were subjected to the soil dilution plate method (Ingham, 1994; Parkinson, 1994; Schinner *et al.* 1995) as follows: Ten grams of soil were dispensed in 90 ml water blanks and three to four glass beads added to the beaker. A water blank refers to sterilized water (by autoclaving) contained in a 250 ml beaker. By placing the beaker on its stands a mechanical shaker was used for five minutes to break up all of the soil particles and obtain a uniform suspension. From this initial suspension (its dilution was 1:10 or 10^{-1}) of each sample a dilution series was made using 2-ml blowout pipettes of known accuracy and 18 ml water blanks in test tubes as the diluents. The resulting suspension/diluent was shaken vigorously but carefully for five minutes by hitting the test-tube gently on the palm of the hands. It was allowed to settle and labeled appropriately (10^{-2}) then the process repeated for a further four diluents. Therefore each sample was diluted from a 10^{-1} upto 10^{-6} factor progressively as shown in table 2.1.

Table 2.1: The dilution factors prepared for laboratory microbe analyses.

Containers	Amount of soil suspension	Amount of sterile water	Resultant dilution
Beaker	10 g soil	90 ml	10^{-1}
Test tube 1	2 ml	18 ml	10^{-2}
Test tube 2	2 ml	18 ml	10^{-3}
Test tube 3	2 ml	18 ml	10^{-4}
Test tube 4	2 ml	18 ml	10^{-5}
Test tube 5	2 ml	18 ml	10^{-6}

Aliquots (0.1ml) of chosen dilutions as shown in table 2.2 were dispensed/inoculated onto a series of sterile plastic petri dishes. Use of these dilutions is a standard practice, since they are the most appropriate for colony growth in such experiments.

Warm (40°C) fungal, actinomyecetes and bacteria media were poured to half fill the sterile petri dishes and 0.1ml diluents pipetted into them as described above. These media were already prepared using standard methods and procedures and their temperatures were maintained by keeping them in a 40°C water bath. Each petri dish was swirled gently to mix its contents immediately to avoid its quick solidifying. For each medium type, an extra half-filled petri dish was spared for control. Into these no aliquot was added, so that each soil sample had a total of 21 petri dishes (i.e the above eighteen plus three controls).

Table 2.2: The number of plates inoculated per dilution for each microbial group.

Microbial group /Dilution factor	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}
Fungal	2	2	2	0	0	0
Actinomyecetes	0	0	0	2	2	2
Bacterial	0	0	0	2	2	2

The plates were left to stand for about 20-30 minutes so that the agar solidified completely. They were then inverted upside down and incubated in a dark incubator at a temperature of 30°C for seven days. The colonies that developed after these days were counted and recorded for each dilution factor that gave between 30-300 colonies as is the conventional practice (Ingham, 1994; Parkinson, 1994; Schinner *et al.* 1995). Any factor that gave less than 30 or more than 300 was not considered. Presence or absence of microbial colony growth in the controls after the incubation period was to be used as an indicator of septic or aseptic conditions of the procedure, respectively.

All through this process the working conditions maintenance of an aseptic environment was attempted by wiping the working surface with 70% alcohol at the start and lighting a Bunsen burner to keep the surrounding air free from other microbes. Whenever any container was opened, its top was first passed near the

flame before pouring contents into or out of it. Microbial population per gram of dry soil was determined as shown below:

$$\text{Population } g^{-1} = \frac{\text{No. of colonies x dilution factor}}{\text{Mass of soil}}$$

2.3. DATA ANALYSES

2.3.1. Macrofauna

The effect of land management practices on macrofaunal diversity and abundance at the different types of farms/land management systems were tested using the following indices: Simpson - Yule diversity (D), the Shannon-Wiener (H') indices, and species Evenness (J') as stipulated by Krebs (1989). Shannon-Weiner diversity index, expressed as;

$$\text{Simpson - Yule diversity, } D = 1/\sum pi^2.$$

Where p is the proportion of species (family in this case) i in the community.

$$\text{Shannon-Wiener, } H' = \sum pi \ (\log pi.)$$

Where p is the proportion of species (family in this case) i in the community.

$$\text{Evenness, } J = H' / \log S.$$

Where S is the number of species (families in my case) found in an area.

Using information from the available literature (Gillot, 1995; Chinery, 1997) the macrofauna were grouped into various trophic groups based on their feeding habits. The percentage abundance and family richness (total number of species

represented) of each group was then calculated and represented graphically.

3.3.2.Mesofauna (Nematodes)

Ratio (R) of non-parasitic/free-living to plant parasitic nematodes was calculated to compare their density as influenced by the different practices and slopes. R<1 means that there are less free-living nematodes than parasitic ones and R>1 means that there are more free-living nematodes than plant parasitic ones. All nematode data on abundance in each farm type and slope level were transformed into $log_{10}(x+1)$ and subjected to ANOVA (PROC GLM, SAS Institute, 1985). Where ANOVA showed significant F values, a Tukey's test was used to separate the means.

2.3.3.Microfauna/microorganisms

Mean microbial density for each group and practice was calculated and then transformed into $log_{10}(x+1)$. ANOVA was then performed to ascertain the observed mean differences and make comparisons between microbial groups and between practices. Where there was a significant F value, Tukey's test was carried out to separate the means.

CHAPTER 3

3. RESULTS AND DISCUSSIONS

3.1. RESULTS

3.1.1.Macrofauna

Total count of sampled macrofauna was highest in the productive farms (1796) followed by the unproductive farms (1124) and finally the moderately productive farms (546). They belonged to twenty orders and over 50 families (Table 3.1.) According to the diversity indices, the farms referred to as productive (under soil erosion and soil fertility control/incorporation of organic amendments), had more families caught (47) than the unproductive farms (38), which had none of these practices. However unproductive farms were more rich (H'=2.14 and D=6.96) than productive farms (H'=1.04139 and D=7.42), as shown in Table 3.2. Unproductive farms also had a higher evenness (J=1.35) than the productive ones (J=0.52). The moderately productive (had soil fertility control in terms of organic amendments) had the least number of families (27). They also had 'intermediate' richness and evenness but their D value was higher than that of the other two farm types.

Herbivores were the most abundant in the unproductive patches (47%), followed by detritivores (30%), omnivores (14%) and carnivores (9%) (Figure 3.1). In the productive farms, omnivores took the lead (40%), followed by detritivores (29%), herbivores (25%) and carnivores (6%). Omnivores were the majority again in the moderately productive farms (39%), followed closely by

detritivores (32%), then herbivores (16%) and finally carnivores (13%). See figure 3.1.

When family richness was considered in terms of trophic groups, unproductive farms had herbivore families number as highest (17), followed by carnivores (12), omnivores (5) and detritivores (4) (Figure 3.2). A similar trend was observed in the productive farms with 20 herbivore, 13 carnivore, 8 omnivore and 6 detritivore families. Moderately productive farms had 10 families of carnivores, 7 of herbivores, 5 of omnivores and 5 of detritivores.

3.1.2. Mesofauna (Nematodes)

The ratio (R) of free-living nematodes to plant parasitic ones was lowest in the un-productive farms (0.25) followed by the productive (0.43) and the moderately productive farms (0.7) (Table 3.3.). Total abundance of nematodes was significantly lower (Tukey's test, $p<0.05$) in the unproductive farms than in the productive and moderately productive farms (Table 3.3). However, the productive and moderately productive farms were not significantly different ($p>0.05$). The valley bottom had significantly lower ($p<0.05$) nematode numbers than the plateau-like top and the valley bottom (Appendix 2a Table 3.4) while the plateau-like top and the valley bottom were not significantly different ($p>0.05$). On the other hand, there were no significant differences ($p>0.05$) in density of non-parasitic nematodes across the slopes and farms/practices (Appendix 3.1c).

Similarly, there was no significant difference ($p>0.05$) in density of parasitic nematodes across the slopes and farms (Appendix 3.1. b).

3.1.3. Microfauna/microorganisms

All the control plates demonstrated no microbial growth suggesting that the whole laboratory procedure was done aseptically. Mean density of the three microbial groups between and within farms is shown in Table 3.5. Actinomycete colony counts were significantly higher ($p<0.05$) in the moderately productive farms than in the unproductive farms while there was no significant difference ($p>0.05$) between the moderately productive and the productive farms. Bacteria density seemed not to be influenced by practice since there was no significant difference across the farms ($p>0.05$). Fungi colony counts were significantly higher in the unproductive farms than the productive ones. On the other hand, there was no significant difference between the moderately productive and the unproductive farms and the moderately productive and the productive farms.

Table 3.1. List of soil macrofauna within various trophic groups: herbivores, detritivores, carnivores and omnivores.

Order	Families	Common Names
	HERBIVORES	
Coleoptera	Curculionidae	Snout Beetle
	Meloidea	Blister beetle
	Tenebridae	Mealworm
Isopoda	Porcellionidae	Woodlice
Diptera	Agromyzidae	Leaf miner
Hemiptera	Miridae	Mirid bug
	Aphididae	Aphid
	Lygaeidae	Back bug
	Tingidae	Lace bug & true bug
	Cicadellidae	Plant hopper
	Fulgoroides	Plant hoper
Isoptera	Termitidae	Termite
	Kalotermitidae	Termite
Lepidoptera	Pieridae	Yellow butterfly
	Gelechiidae	Moth
	Nymphalidae	Milk butterfly
Orthoptera	Gryllidae	Field cricket
	Acrididae	Grasshoper
Phasmida	Phasmatoidea	Stick insect
Heteroptera	Pentatomidae	Stink bug
	DETRITIVORES	
Blattodea	Ectobiidae	Cockroach
Isoptera	Porcellionidae	Woodlice
Coleoptera	Scarabidae	Dung beetle
	Anthricidae	Ant-like beetle
Oligochaeta	Megascolisidae	Earthworms
Diplopoda	*	Milipedes
	CARNIVORES	
	Carabidae	Ground beetle
	Coccinelidae	Ladybird
	Eucneomidae	Click beetles
	Cantharidae	Black sucker
Diptera	Tipulinidae	Midge

Table 3.1. Continued.

Gastropoda	Mesogastropoda	Land snail
Neuroptera	Myrmellionidae	Antlion
Odonata	Libelludiae	Dragonfly
Hemiptera	Reduviidae	Assassin bug
Heteroptera	Pentatomidae	Stink bug
Aranaea	*	Spiders
Chelicerata	*	Scorpion
Chilopoda	*	Centipedes
Hymenoptera	Chalcididae	Wasps
	OMNIVORES	
Isoptera	Rhinotermitidae	Termites
	Hodotermitidae	Termites
Coleoptera	Dermestidae	Skin and carpet beetle
	Staphylinidae	Rove beetle
Blattodea	Octobiidae	Cockroach
Hymenoptera	Formicidae	Brown Ants

* Not identified.

Table 3.2: Macrofaunal diversity indices for the various farms/practices

S=total number of families caught.

FARM TYPE	H'	J	D	S
Productive	0.87	0.52	7.42	47
Moderately productive.	1.01	0.71	9.97	27
Unproductive	2.14	1.35	6.97	38

Figure 3.1: The percentage abundance of different macrofauna trophic groups captured in the different practices.

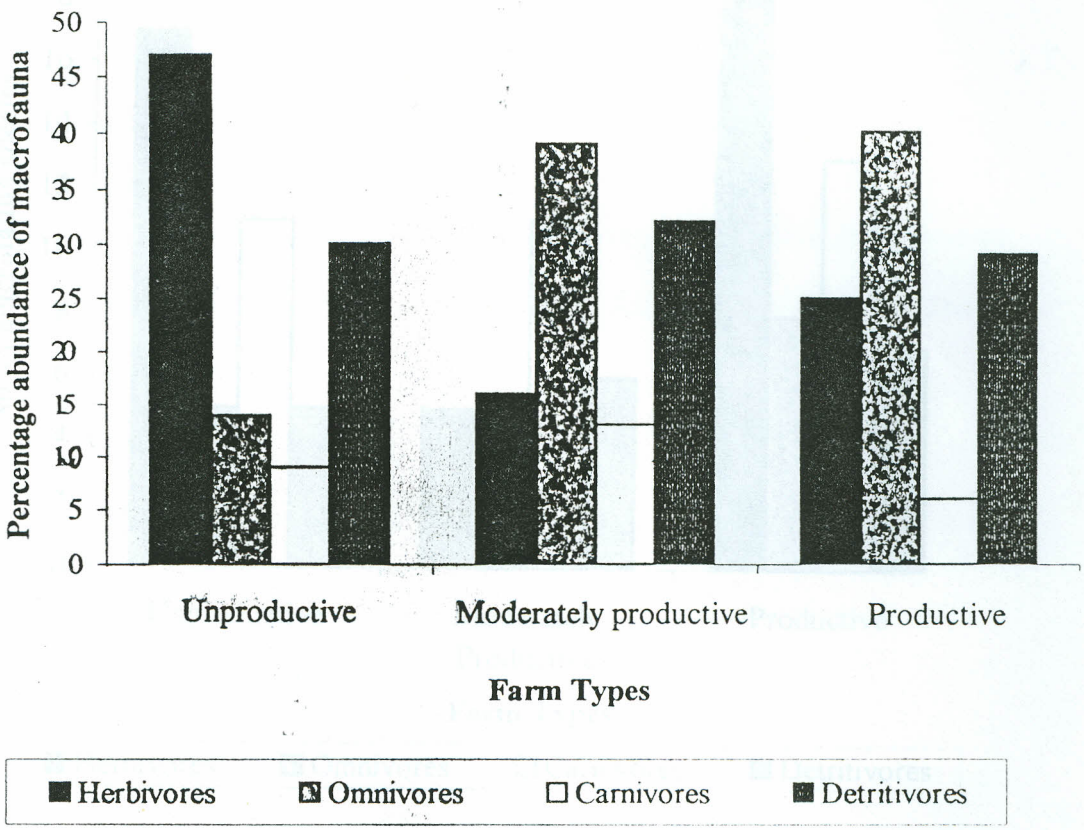


Figure 3.2. The number of species of different macrofauna trophic groups captured in the different practices.

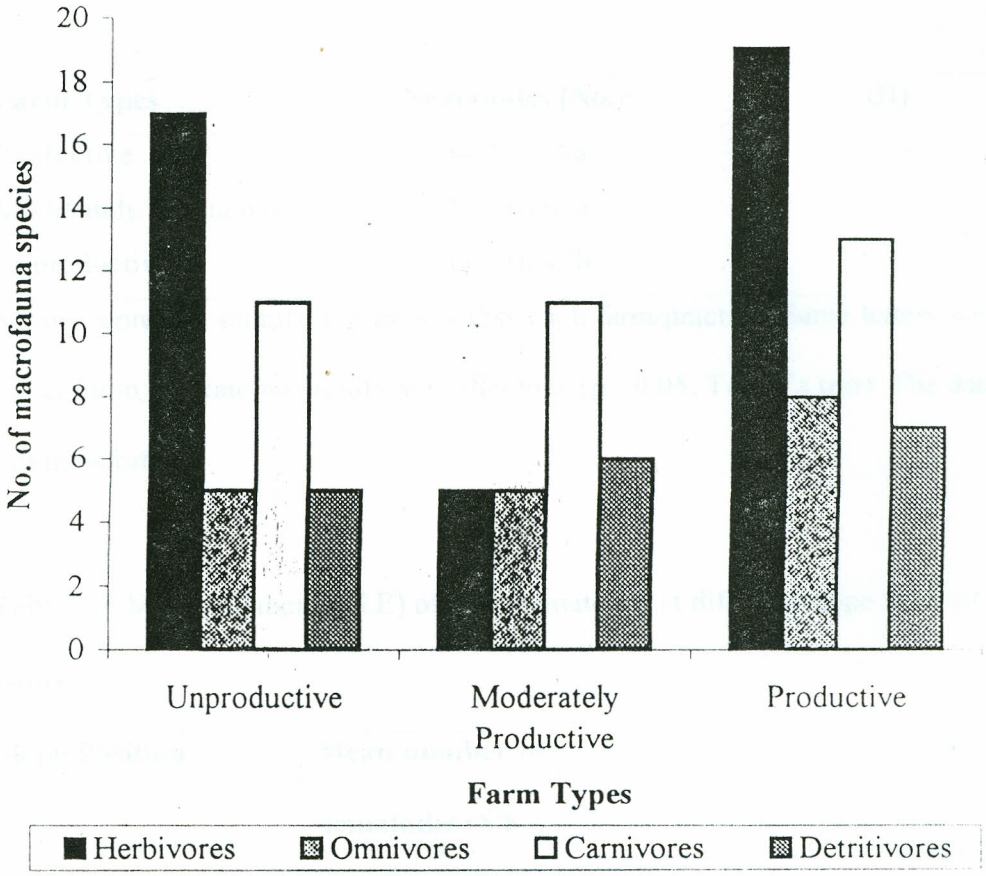


Table 3.3: Mean (± S.E) number of total nematodes per practice and ratio (R) of parasitic to non-parasitic nematodes.

Farm Types	**Nematodes (No.)**	**(R)**
Productive	34.7±6.26**a**	0.43
Moderately Productive	21.1±6.62**a**	0.70
Unproductive	11.3±6.47**b**	0.25

Means represent sample averages across each farm/practice. Same letters within the column indicate no significant difference (p= 0.05, Tukey's test). The data is not transformed

Table 3.4 Mean number (± S.E) of total nematodes at different slope level of the farms.

Slope Position	**Mean number of nematodes±S.E**
Top (plateau area)	12 ± 3.69**b**
Middle (Steep area)	12 ± 2.43**b**
Bottom (River bed)	9 ± 2.48**a**

Same letters within the column indicate no significant difference (p= 0.05, Tukey's test).

Table 3.5 Density of microfauna/microorganisms per gram of soil in the different farms/practices, the means procedure (data not transformed).

Microbe	Farm type	Mean (±Std Error)
Actinomyecetes	Productive	762,500(±228,781)**ab**
	Moderately productive	6,697,000 (±3,728,433)**a**
	Unproductive	371,000(±100,174)**b**
Bacteria	Productive	721,428(±206,691)
	Moderately Productive	2,166,117(±956760)
	Unproductive	684,818(±281,604)
Fungi	Productive	535(±298)**b**
	Moderately productive	1474(±609)**ab**
	Unproductive	3934±(1836)**a**

Similar letters within the column indicate no significant difference (p=0.05, Tukey's test).

3.2. DISCUSSION

3.2.1. Macro fauna

There was a higher total macro fauna abundance in the productive farms probably due to the availability of large supplies of substrate in the form of organic matter. The organic matter also acts as a refuge from predation and makes the temperatures in the soil less extreme (Wilson-Rumenie, *et al.* 1999). In a study on the character of composition and distribution of soil fauna under some tropical forests in China, Yang *et al.* (1998) obtained a positive relation between numbers of soil fauna and litter fall. Similarly, Rodriguez *et al*, (1998) observed that areas of land covered by cow dung had higher macro fauna numbers than the controls that had none. Tongway and Ludwig (1996) and Mara and Edmonds (1998) also associated high organic content with an increase in macro fauna numbers. Although the productive farms in this study were richer than the unproductive ones, the latter were more diverse. The macro fauna in unproductive farms were likely to be more exposed to the action of predators since there is no incorporation of organic matter to hide in and this, according to Ricklefs (1990) leads to an enhanced diversity. Although this study showed that soil fertility had an influence on diversity, Ayuke (2000) and Silva *et al.* (1997) found that the densities of soil fauna were greatly low under unfertilized systems but the diversity was not influenced. I presume that the length of time for which the fauna is exposed to whatever treatment may determine whether the diversity will have changed or not.

The farms I studied had a history of about ten years under their current practices which is ample time for fauna populations to stabilize.

Apart from the disparity in organic amendment practices, the productive farms all had soil erosion control practices in form of bench terracing and agroforestry. This I presume could have been an additional factor in determining the abundance and diversity of macro fauna. In an experiment using arthropods as bio-indicators in agroecosystems, Paoletti *et al.* (1999) obtained results suggesting that a mosaic rural landscape including woodlots and cropland is essential for creating an ecologically favorable agricultural environment. Similarly, Mara and Edmonds (1998) while studying soil invertebrate densities found out that both the density and richness of Acari and Coleoptera were significantly higher on forested sites than on clear-cut sites. This, they suggested could be due in part to the disparities in moisture content and temperature fluctuations between the two sites. Soil erosion control practices also aid in reducing habitat loss that occurs with erosion. Overall, the productive farms in this study ended up having a more mosaic setting with more trees than the unproductive farms and thus the higher species richness. Tongway and Ludwig, (1996) also used the laying of piles of branches on degraded soil patches to rehabilitate them and found that apart from an overall increase in their productivity potential, the soil fauna populations increased and soil temperatures were moderated. The moderately productive farms behaved 'moderately' except for having the lowest richness of 27. These farms had organic amendments for their soils but no soil erosion control and

therefore, in terms of number of practices, they only had one advantage over the unproductive and one disadvantage below the productive. They were more diverse than the productive patches probably because the litter providing habitats for hiding was less here since there was no agroforestry to supplement the manure in terms of leaf fall.

This study supports the findings of Wilson-Rumenie *et al.* (1999) that soils with high levels of litter have more detritivore populations than herbivore populations. Herbivores, which are mostly plant pests, were highest in the unproductive farms probably because plants were the principal food source. The situation was different in the moderately productive and productive farms. In both cases, detritivores, which are instrumental in breaking down organic matter and releasing nutrients for plant uptake, were more than herbivores. This is because of the addition of organic matter, which is their main food source. Like in any food chain, carnivores were the least individuals in all the three farm categories.

3.2.2. Nematodes

The ratio of free living to parasitic nematodes was lowest in soils with no organic amendments and no soil erosion control. Tebrugge *et al.* (1995) found that an improvement in soil management practices was associated with reduction in soil-borne pathogens, improvement in yield and abundance of soil fauna among other benefits. Since some soil borne diseases are caused by soil-dwelling parasitic nematodes, there is a higher chance of plants growing in the farms lacking both practices to be infected by these diseases, than those in either farms

with solo organic matter additions or those with both organic matter amendment and soil erosion control. This was the case in Brazil where Blancaneaux *et al.* (1993) found that the application of green manures helped to minimize the utilization of pesticides for soil borne diseases. While studying the interaction between soil nematodes with five earthworm species and dead worm tissue, their results showed that enhancement of microbivore (free-living) nematodes resulted in a simultaneous inhibition of plant parasitic nematodes by earthworm participation in the decomposition process. Microbivore nematodes are usually enhanced where decomposition is also enhanced thus, the addition of cow dung and crop residues in the present study, increased their abundance. By suppressing plant parasitic nematodes, the diseases they cause are also reduced resulting in increased crop yields, a factor which could well explain the fertility/productivity status of the farms we studied. Ibewiro *et al.* (2000) also obtained results that showed a clear ability of plant parasitic nematodes to reduce biomass yield of maize by 10% and nitrogen accumulation by a legume (Lablab) to only 69% of that accumulated by the same plants grown in un inoculated soils.

Nematode overall density varied significantly with soil management practice probably because these practices determined the type and quality of substrate. Ayuke, (2000) reported that fauna density is largely determined by the organic content of the substrate/soil while Anderson, (1984) suggested that the richest and largest soil nematode communities tend to be where there is plenty of organic matter. It is also evident in my study that the gradient of land affected

nematode activity since the lowest numbers were in the valley, followed by the slope and then the plateau-like top. This I presume is due to the difference in moisture contents at each slope position. The valley bottom is wet during the dry season due to irrigation and is virtually waterlogged during the rains. The top of the slope (plateau) and the steep areas are drier between rains. Soil nematodes being aerobic tend to prefer moist soils that are not waterlogged (Perry and Wright, 1998) since the later usually have their airspaces taken up by water.

From the management practice point of view the bench terraces occurring in the productive farms that tend to reduce drastic sloping of the land also seem to favor nematode activity and occurrences. The largest populations were found in such farms although this was not significantly different from the moderately productive farms. This could be because soil erosion that naturally results in habitat (soil) loss and exposure to dehydration is reduced.

3.2.3 Microfauna/microorganisms

The major disparities in overall density of the various groups of microorganisms can be attributed to estimation by laboratory cultural methods, which is limited and difficult because a substantial fraction of their population escapes isolation (Stolp, 1988; Schinner, 1995). However, it has been used as a method for estimating total populations of fungi, bacteria and actinomyecetes as a criterion of microbial activity in any soil at a particular time (Garrette, 1963; Schinner *et al.* 1995).

The moderately productive farms had the highest overall microbial density. This finding agrees with that of Seemen *et al.* (1998) who studied forest soils in Russia. Not only were microorganisms more numerous in the fertilized soils they studied but also more favorable from the viewpoint of improving soil fertility. The soil erosion control by agroforestry and bench terraces in my study did not appear to significantly increase the density of microorganisms as I had expected, basing on the assumption that leaf litter would be responsible for such an increase. Thus, the moderately productive patch still had a much higher microbial density though it only had organic matter addition and no soil erosion control practice.

The higher mean density of fungi in the unproductive farms could have been due to acidity associated with poor soil conditions and which in turn stimulate an increase in fungal growth (Vargas and Hungria, 1997; Schinner, 1995). Ahl *et al.* (1999) observed similar results in Germany where the microbial decomposer community changed towards increase in fungi as the soil fertility conditions deteriorated. In fact a latter soil analysis showed that these farms had an acidic pH of 3.6 as compared to 5.4 in the productive farms and 5.8 in the moderately productive ones. I would therefore attribute this 'bloom' to the fact that this microbial group is favored by low pH while the other two are not. In contrast, Beare, *et al.* 1997a reported increased fungi in soils with large deposits of humus. However, in my study the soils in the unproductive farms were highly eroded and therefore exposed to agents of weathering (including biological ones)

and these could have influenced the results. Indeed a few saprophytic fungi have been reported to play a role in weathering of mineral soils (Mehta *et al.* 1979 Sharma, 1989, Read, 1990 Beare *et al.* 1997b) and they could have constituted the bulk of samples from the unproductive patch whose top soils are so eroded that the usually covered parent material is exposed to further erosion.

Measurements of pH are important criteria for explaining the capability of soils to support the presence and action of different microbial groups (Paul and Clark, 1990). This is because different microbial groups have different pH preferences. Soils in the moderately productive farms were more basic than those of productive farms and thus the significantly higher density of actinomycetes. This microbial group and bacteria thrive well in basic conditions and at pH below 5 (Arai, 1976; Paul and Clark, 1989) they may cease to grow (Sinha and Sirvasta, 1990). This also explains why they were of the lowest density in the more acidic soils of the unproductive farms and in fact some of these could well be individuals which had been dormant but were stimulated to grow by the optimum conditions offered in the microenvironments of the laboratory culture procedure.

When food is available for the microorganisms, they occur in large numbers and contribute more to mineralization. This releases nutrients for plant uptake thus improving the soil fertility status and enhancing plant health. Results by Zhang *et al.* (1998) showed that an increase in the soil biota population was matched by an increase in phosphorus supply to plants. This can explain the fact that the farms with organic matter incorporation were termed more productive

than the ones with none in terms of crop yield, by the farmers. This was also the case in some Chinese poplar mixed stands where Sun *et al.* (1998) observed that the productivities of the mixed stands were closely and positively correlated with the soil microorganisms. On the contrary, Milic *et al.* (1998) showed that the number of soil microorganisms did not have a significant effect on yield of some sugar beet varieties though yield quality was affected by some groups of microorganisms.

In addition to increased and improved microbial activity in decomposition, the increased acidity of the unproductive farms could have also led to its poor status. This is especially so because with increase in acidity, dissolution of nutrients such as phosphorus and calcium increases (Paul and Clark 1989). This makes them be leached to the lower soil horizons during rainy seasons, rendering them out of the reach of plant roots and yet phosphorus is (together with nitrogen) inherently deficient in this soil type on which all the farm types studied are located.

CHAPTER 4

4.0. GENERAL CONCLUSIONS AND RECOMMENDATIONS

4.1. CONCLUSIONS

The productive farms had the most macrofauna family richness, second highest family diversity and second highest family evenness as compared to the other two farm types. They also had the most count of individuals captured during the sampling period. Of these macrofauna, detritivores were of a higher percentage than herbivores due to their involvement in the decomposition of cow dung and leaf litter from agroforestry. These farms had a higher ratio of freeliving nematodes to plant parasitic ones than the unproductive farm meaning that there is a lower probability here of having incidences of nematode related plant diseases. There was no significant difference between total microorganism density between these farms and the unproductive ones although they had significantly lower fungi density and their actinomycetes density almost doubled that of the unproductive ones. This means that they are less acidic than their unproductive counterparts.

The unproductive farm had the second highest family richness, highest family evenness and highest family diversity values. They had the second highest total macrofauna counts. Of these macrofauna, herbivores which are mostly plant pests, were of a higher percentage than detritivores due to absence of additional organic matter in the form of cow dung and leaf litter from agroforestry, as was the case in the productive farms. Therefore the most available food was the crops grown. These farms had a lower ratio of free-living nematodes to plant parasitic

ones than the productive farms meaning that there is a higher probability here of having incidences of nematode related plant diseases. Although there was no significant difference between total microorganism density in these farms and that in the productive ones, they had significantly higher fungi density and their actinomycetes density was almost half that of the unproductive ones. This may be because they are more acidic than their productive counterparts.

The additional category (moderately productive farms) did not behave as intermediate between the above two in all cases. In terms of macro fauna, they were more family diverse and family even than the productive farms. However, they had the lowest total macrofauna count and family richness. Of these, detritivores were of a higher percentage than herbivores due to their involvement in the decomposition of cow dung. On the other hand, these farms had the highest ratio of freeliving nematodes to plant parasitic ones overall, meaning that they had the lowest probability of having nematode related plant diseases thus higher productivity. Such a soil is likely to be considered more fertile by the farmers. They also had the highest total microorganism density and actinomycetes density over the other two farm types.

Overall however, my findings support Lee and Pankhurst (1992), Radford *et al.* (1995) and Schill *et al.* (2000) suggestions that management practices that favor the biodiversity of soil communities can greatly increase crop yield. This is because of their effects on soil animal populations, which in turn increase the available nutrients for plant uptake (Palma *et al.* 1997). Schinner,

(1995) and Sun *et al.* (1998) also concluded that soil microorganisms respond to soil management practices and since these determine their metabolism they indirectly determine the yield of plants. This is because the latter depend on soil microorganisms to avail nutrients to them through metabolisation. Senapati, 1992 also found that addition of organic matter to soils encourages fauna-fauna interactions which favor agricultural ecology e.g. increase of earthworm populations, suppress plant parasitic nematodes while at the same time favoring the increase of free–living (microbivore) nematodes. Under the prevailing conditions of study, results showed that soil erosion control coupled with organic amendments is overall better than either practice alone. The practice involving soil erosion control measures and organic matter additions had high populations of soil macrofauna and free living nematodes and this could explain their higher productivity as compared to the unproductive ones which had less of both groups.

Finally, I found that farmers' perception of productive versus unproductive farms actually matches the status of soil fauna and so their use of macro fauna as indices of soil fertility is justified. My addition however, was not truly intermediate between the two extremes identified by farmers. This can be accounted for by the on-farm nature of my studies and therefore a high chance of differences resulting from farmer-to-farmer differences in handling any particular practice, particularly the frequency and amount of cow dung addition in the productive and moderately productive farms.

4.2. RECOMMENDATIONS

1.A long-term research with the aim of ascertaining the sole effect of each practice/treatment should be done to ascertain these results.

- The failure of two rainy seasons during my time and any other present spatial effects could have influenced my results, since populations of soil fauna are known to stabilize after five to seven years.
- In undertaking such a research, it should be manipulative rather than on-farm, so that treatments can be easily and freely laid out. Such components as amount of organic matter additions can also be desirably measured/controlled.

2. A research aimed at identifying key indicator organisms (eg. a chosen species or guild) representative of more ecologically based land management should be carried out. These species or guilds can be used as indices of land deterioration in future and as directives when designing suitable land management practices.

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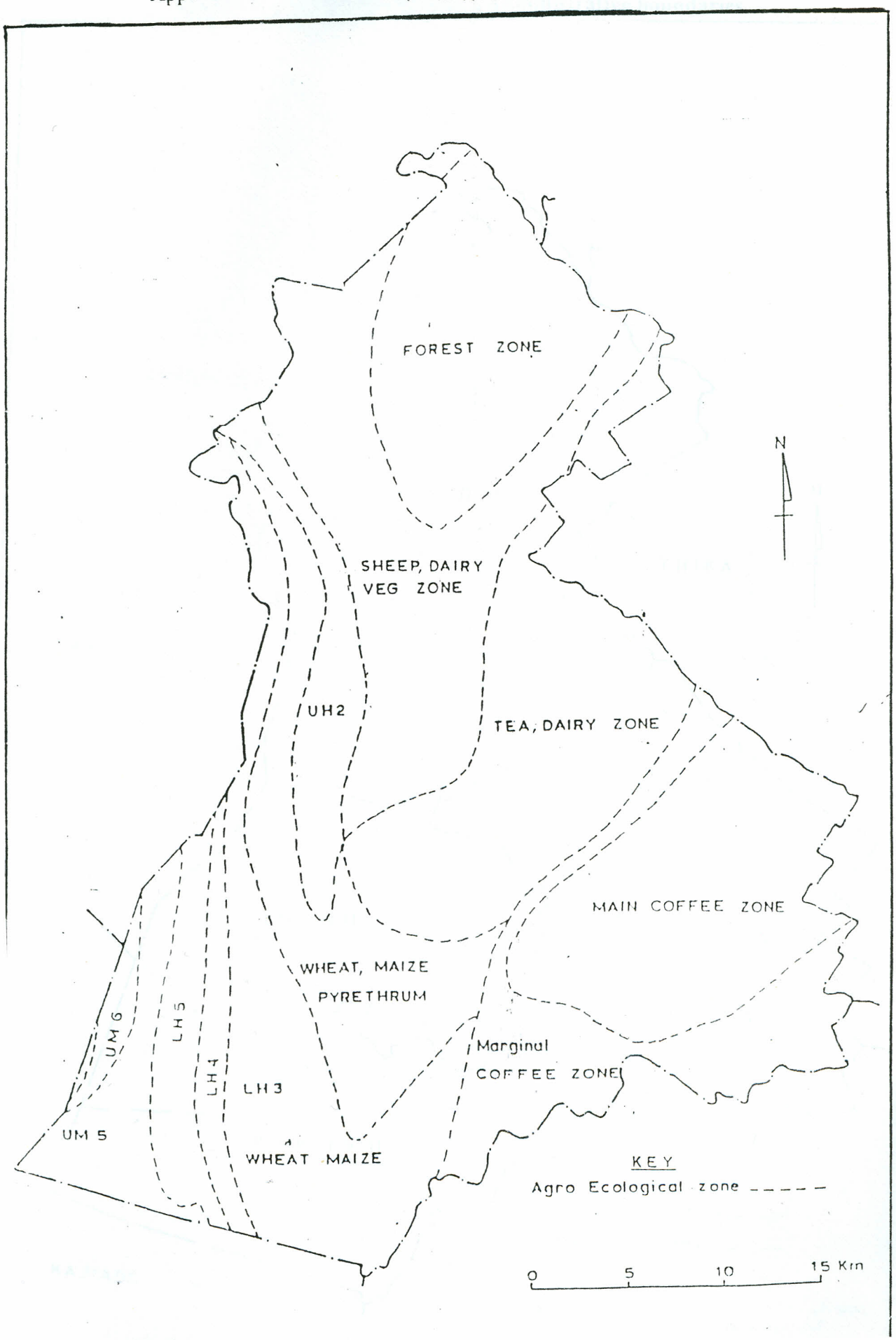
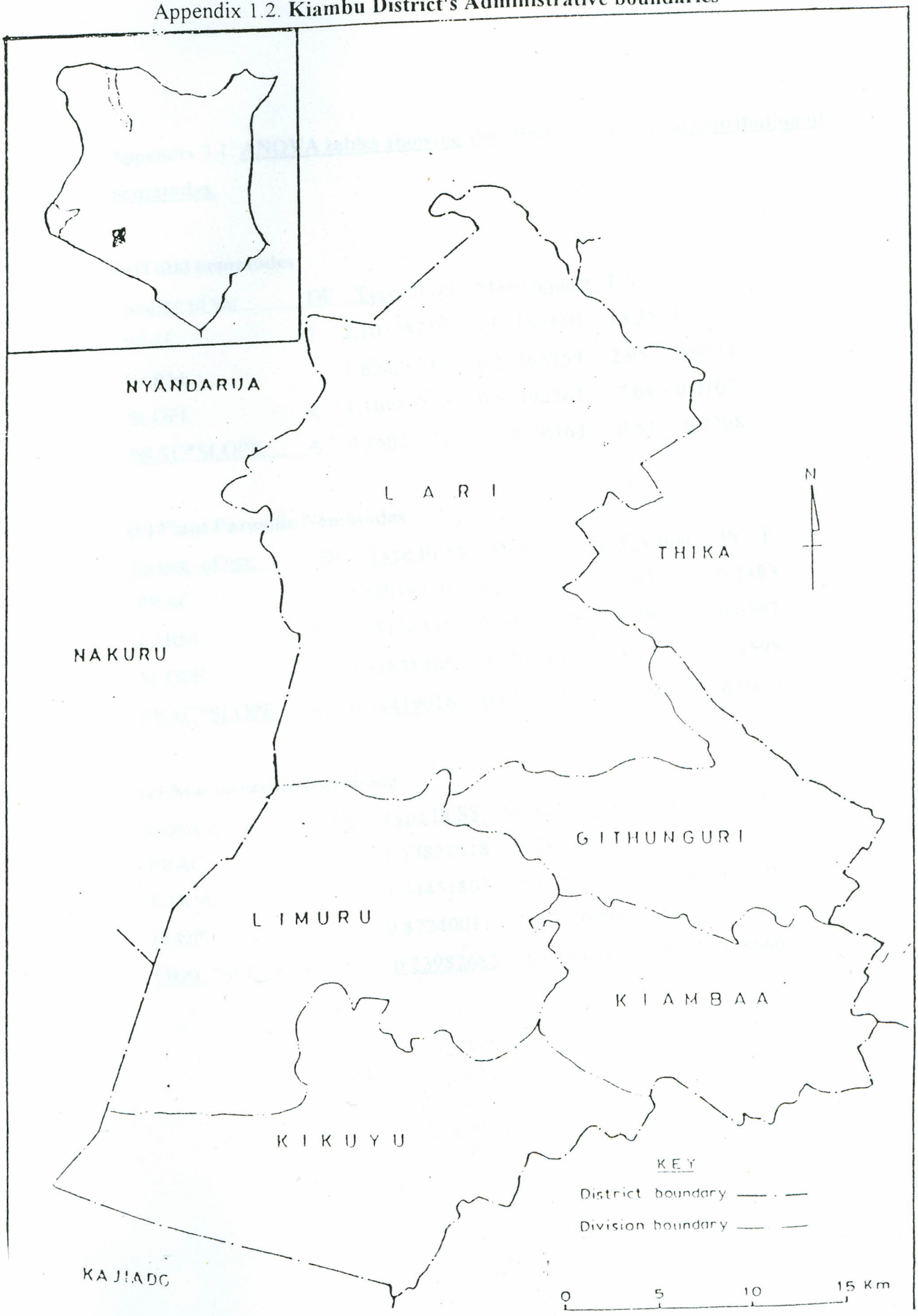
Appendix 1.1. **Kiambu District's Ecological Zones**



Appendix 1.2. **Kiambu District's Administrative boundaries**



Appendix 3.1: **ANOVA tables showing the effect of practice on distribution of nematodes.**

(a)Total nematodes

Source of var.	DF	Type III SS	Mean Square	F Value	Pr > F
PRAC	2	2.10378259	1.05189130	13.35	0.0011
FARM	7	1.62426314	0.23203759	2.95	0.0534
SLOPE	2	1.10986525	0.55493262	7.04	0.0107
PRAC*SLOPE	4	0.16024656	0.04006164	0.51	0.7308

(b) Plant Parasitic Nematodes

Source of var.	DF	Type III SS	Mean Square	F Value	Pr > F
PRAC	2	0.82019210	0.41009605	3.03	0.2483
FARM	7	0.75114395	0.10730628	0.79	0.6597
SLOPE	2	0.31828405	0.15914203	1.17	0.4598
PRAC*SLOPE	4	0.04419016	0.01104754	0.08	0.9803

(c) Non-parasitic/free-living

Source of var.	DF	Type III SS	Mean Square	F Value	Pr > F
PRAC	2	1.57821118	0.78910559	12.71	0.0730
FARM	7	1.34451803	0.19207400	3.09	0.2660
SLOPE	2	0.87240011	0.43620005	7.02	0.1246
PRAC*SLOPE	4	0.23982682	0.05995671	0.97	0.5660

Appendix 3.2: **ANOVA tables showing the effect of practice on microbial density and disribution**

(a) Total

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Practice	2	3.1138623	1.5569312	2.91	0.0585
Microbial group	2	325.7036626	162.85183	304.65	<.0001
Farm	21	7.8258641	0.3726602	0.70	0.8281
Practice*Microbe	4	8.9592161	2.2398040	4.19	0.0034

(b) Actinomyecetes

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Practice	2	3.84467217	1.92233609	5.14	0.0139
Farms	15	5.43192976	0.36212865	0.97	0.5126

(c) Bacteria

Source of var	DF	Sum of Type III SS	Mean Square	F Value	Pr > F
Practice	2	1.12203682	0.56101841	3.00	0.0697
Farms	16	5.57784231	0.34861514	1.86	0.0846

(c) Fungi

Sourceof Var	DF	Type III SS	Mean Square	F Value	Pr > F
Practice	2	7.15286295	3.57643147	3.69	0.0355
Farm	21	10.45216754	0.49772226	0.51	0.9447