SOIL INVERTEBRATE MACROFAUNA: POPULATION DYNAMICS AND THEIR ROLE IN LITTER DECOMPOSITION WITHIN A HEDGEROW INTERCROPPING IN EMBU, KENYA

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DECLARATIONS

DECLARATION BY CANDIDATE

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DEDICATION

Dedicated to Jonathan Chege and my family for their support and encouragement during this study.

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ABSTRACT

Crop yields in Embu, Kenya, as in much of the developing world, are poor due to declining soil fertility caused by continuous cropping with few inputs. In low-input systems, soil biota regulates the transformation of organically bound nutrients into plant-available forms thereby enhancing food productivity. Management practice engaged may influence the nature of fauna population composition and structure and could lead to elimination/reduction of key groups and/or species of soil fauna and in some cases low abundances or biomass.

A study was conducted during the long- and the short -rains of the year 2000 on-station at Embu in an ongoing experiment within hedgerows. The experiment had ten treatments replicated three times in randomized complete block design within hedgerows. The main experiment quantified the abundance of soil invertebrate macrofauna at three soil depths (0 – 10, 10 – 20 and 20 – 30 cm) and established their relationship to soil chemical and physical properties within seasons. The macrofauna populations were monitored in soil monoliths of 25 cm × 25 cm × 30 cm. Soil cores and soil samples for physical and chemical analyses respectively, were taken from 5 different locations at 0 – 30 cm depth within each plot at the start and at the end of each season.

Simultaneously an experiment was conducted to investigate the role of soil macrofauna in litter decomposition and the relationship between litter quality and rate of decomposition. Two types of polyvinyl chloride litterbags

with mesh size 7 and 1mm were used. The 7 mm mesh size allowed macrofauna to enter while the 1 mm excluded the macrofauna. Two types of litter: *Calliandra calothyrsus* Meissner and *Leucaena leucocephala* Lam de Wit were placed in the litterbags in duplicate in selected treatments of the Embu trials, and were sampled for chemical concentrations at 1, 2, 4, 8, and 16 weeks.

Results from the study indicated that the composition and structure of soil invertebrate macrofauna varied with soil depths. Most faunal groups thrived well in the lower soil depths (20-30 cm) than topsoil (0-10 cm) layer/depths in hedgerows during the dry spell as opposed to during the wet conditions when the trend was reversed. Termites were the most abundant of the fauna observed. More fauna were recorded during the dry spell than when the conditions were moist. Hedgerow agroecosystem treatments that involved organic inputs offered a desirable niche for the macrofauna as opposed to those that entailed addition of inorganic fertilizer *C. calothyrsus* litter supported higher macrofaunal population than that of *L. leucocephala*.

The macrofauna abundance, biomass and diversity were correlated to soil nitrogen, phosphorus, potassium, pH and compactness, but at varied levels. Soil invertebrate macrofauna enhanced the rate of decomposition of both litter types. *Leucaena leucocephala* decomposed and released nutrients faster than *C. calothyrsus* and the former had lower lignin and/or polyphenols to nitrogen ratio than the latter. The study endorses the potential of soil invertebrate macrofauna as biological indicator organisms of ecosystem status.

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ABBREVIATIONS AND ACRONYMS

ANAFE	African Network for Agroforestry Education
CIAT	International Centre for Tropical Agriculture
FAO	Food and Agriculture Organization of the United Nations
ICIPE	International Centre for Insect Physiology and Ecology
ICRAF	International Centre for Research in Agroforestry
TSBF	Tropical Soil Biology and Fertility Programme

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the problem

Production of adequate food to meet the needs of an ever-increasing population is a major challenge for most developing countries and in particular those of tropical Africa (Borlaug, 2000). Increasing population pressures and widespread food deficits in sub-Saharan Africa, and Kenya in particular, have compelled national programmes and international donors to place a high priority on increased agricultural productivity and alleviation of poverty among the small-scale farmers. Despite this, few new technical packages capable of increasing net returns without deteriorating the environment have been developed (ICRAF, 1997a). A balanced approach that addresses both human needs and environmental concerns is thus required (Pierce, 1990; Woomer *et al.*, 1994; ICRAF, 1997b). Therefore, farmers should have access to increase their incomes and feed the population at the lowest possible cost while conserving the agricultural resource base. Thus, agroforestry technologies have been proposed as some of the feasible approaches that might assist farmers to achieve this (ICRAF, 1997a; Mugendi, 1997).

Most of the developing nations rely on agricultural exports and are dependent on imports from developed nations. Continued degradation of the agricultural resource base will, therefore lead to lack of economic growth and increased rural-urban migration. This socio-cultural disruption may, in turn, promote political instabilities at national and regional levels.

Developing countries such as Kenya must not only exploit their soils and trees for economic growth, but they must also protect the essential productivity of these ecosystems for the benefit of future generations. This should be done keeping in mind that technological developments in temperate zones may not be applicable or appropriate in the tropics and that relatively little data and information are available regarding tropical soil biology (Brown *et al.,* 1995).

Soils are highly constraining environments, colonized by organisms that respond in complementary ways to the overall quality of resources and the nature of their environments (Lavelle *et al.*, 1993). Soil fauna may affect soil function in a variety of ways. Thus soil fauna could be used as indicators of nutrient status of soil in a given site (Vanlauwe *et al.,* 1996, Rao *et al.*, 1998). The focus on food production should therefore, be widened to include the problem of how best to conserve natural resources and biodiversity while achieving optimum sustainable yields.

1.2 Statement of the problem

The present situation in central highlands of Kenya is closely related to that of western Kenya where most households are only able to produce enough food to feed themselves for a few months and are forced to buy more from the market during the remaining months or endure hunger periods (Sanchez *et al.,* 1997).

With high and ever increasing human population on the same piece of land in central highlands of Kenya, more food must be produced. However, this has been hindered by poor crop yields resulting from declining soil fertility due to continuous

cropping and non-application of fertilizers by most farmers due to liberalization of trade and introduction of structural adjustment programmes (SAPs). The SAPs have forced fertilizer costs to increase to unaffordable levels to most small-scale farmers.

In Embu, farmers have live fences around their farms and grow hedges on contours, but rarely use the biomass from these for soil fertility improvement. Several studies have shown that tree residues can be used as a source of nutrients to crops (Niang *et al.,* 1996; Palm, 1996; ICRAF, 1997a).

Soil invertebrates are the major determinants of soil processes in tropical ecosystems (Lavelle *et al.*, 1994a and b). Whereas pest management is an integral part of crop production, the potential for manipulating the beneficial soil animals has rarely been considered in designing management practices (Lavelle *et al.*, 1994b). Practices that eliminate beneficial soil faunal communities are unlikely to contribute to the sustainable production in the long term, especially in low-input systems based on organic residues.

The diversity and role of soil fauna have been largely ignored by traditional and conventional agriculturists due to limited knowledge on their impact on crop yields (ICIPE, 1997). In recent years, many well documented articles and reports (Lavelle *et al.*, 1997) have established the importance and urgency of improving knowledge and management practice for tropical soils. There's relatively little data and information available regarding tropical soil biology. Technological developments in temperate zones may not be applicable or appropriate in the tropics (Swift *et al.,* 1998).

This study investigated the population dynamics of soil invertebrate macrofauna and their role in litter decomposition within a hedgerow intercropping. The study will form a basis for the understanding and improving soil fertility thereby addressing the aforementioned concerns.

1.3 Research objectives

The overall objective of the study was to investigate population trends of soil invertebrate macrofauna and their role in litter decomposition within agroecosystems.

Specifically, the study aimed at:

i. Quantifying the abundance, biomass and diversity of soil invertebrate macrofauna at three soil depths.

ii. Quantifying macrofauna population in relation to soil chemical and physical properties and seasons.

iii. Investigating the role of soil macrofauna on the rate of litter decomposition.

iv. Comparing the rate of litter decomposition of *Calliandra calothyrsus* Meissner and *Leucaena leucocephala* Lam de Wit.

1.4 The research hypotheses

i. Soil invertebrate macrofaunal communities vary in abundance, biomass and diversity with soil depth.

ii. Abundance, biomass and diversity of soil macrofauna are dependent on seasons and soil chemical and physical properties.

iii. Soil invertebrate macrofauna enhance the rate of plant litter decomposition.

iv. The rate of litter decomposition is related to tree species hence resource quality.

1.5 Significance of the study

The outcome of this study is anticipated to form a basis for the understanding and improving soil fertility using readily available resources especially for the resource poor farmers thereby addressing food security in Embu, Kenya where food production has become the most critical factor of development.

Moreover the study will provide experimental evidence on the significance of the soil invertebrate macrofauna on the functioning of an agroecosystem. The study will also give an account of abundance and diversity of soil invertebrate macrofauna within a hedgerow intercropping in high potential zone. The study will contribute a great deal towards filling the knowledge gap on the role the soil macrofauna play in maintenance of soil fertility.

1.6 The research rationale

Crop yields in Embu, Kenya are poor due to declining soil fertility prompted by continuous cropping and application of fertilizers in non-sufficient quantities by farmers. Agroforestry technologies have been demonstrated to increase crop yields (Niang *et al.*, 1996; ICRAF, 1997a) and are economically attractive to farmers (Sanchez *et al.*, 1997). According to O'Neil *et al.* (1992), organic farming is inexpensive and ensures steady, sustainable crop production. Although yields may be lower than those resulting from high input agriculture, they can be maintained indefinitely.

According to Bruyn (1997), soil degradation in the tropics is related to drastic decline in activity and diversity of soil fauna among other aspects. The challenge in the future will therefore be to shift the emphasis of soil fauna research towards understanding their function in soil processes essential to ecosystem functioning. The soil biota including soil microbial biomass and soil fauna provide the means and regulate the transformation of organically bound nutrients into plant-available forms through mineralization (Lavelle *et al.*, 1994a; Vanlauwe *et al.,* 1996; Tian *et al.*, 1997).

The process of litter decomposition is critical for maintaining the functioning of natural and managed ecosystems. This process occurs with partial involvement of soil invertebrates in the terrestrial ecosystems. Mugendi (1997) pointed out that studies on how litter quality affects decomposition in agroforestry systems are scanty.

The abundance of soil macrofauna can be used to indicate the biological health of the soil (Doube, 1997) and the improvements in biological management of soil fertility are possible only upon understanding the processes involved. Little research has been done on this aspect thus a need to undertake a study on the same; and with this sort of experimental evidence, scientists can indicate to the farmer the state of the soil resource based on the composition and/or structure of soil faunal species.

1.7 Definition of terms

The definition of major terminologies used in the study is as outlined below. The first four terminologies were derived from the Concise Oxford Dictionary (1995).

i. Abundance: This is the profusion, total number or the amount of organisms in a given area.

ii. Biomass: The weight or the heaviness of organisms in a given area.

iii. Diversity: Entails the variety or the different kind of the organisms.

iv. Fauna population: Includes the abundance, biomass and diversity of fauna.

v. Macrofauna: Includes animals longer than 4 mm (or wider than 2 mm), which are easily located by the naked eye. They are active on the soil surface, but may move or live in the soil. Examples are earthworms, termites, beetles, ants, millipedes, centipedes, etc (Anderson and Ingram, 1993).

1.8 Assumptions and actuality

This study was confined in an experimental site and was conducted for two seasons and therefore, the sample size and the length of the study was subject to these, respectively. Microfauna and mesofauna contribute to litter decomposition and may influence the performance of the macrofauna. Nematodes and microfloral of varied species may influence soil properties hence the abundance of soil macrofauna. Litterbags may influence the performance of the macrofauna in litter decomposition. Whereas great care prevailed during the study the above mentioned concerns were assumed to be constant for this particular study. Results were thus interpreted in light of these stipulated limitations and assumptions.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil Fauna

Soil is a habitat for a vast, complex and interactive community of soil organisms whose activities largely determine its chemical and physical properties. Soil macrofauna consists of invertebrates measuring between 2 mm and 10 mm in length, and are a highly diverse group with a large number of arthropods, oligochetes and gasteropods (Swift *et al.*, 1979). Other forms of soil biota include the microfauna (invertebrates of less than 0.2 mm in size) and mesofauna (invertebrates greater than 0.2 mm but less than 2 mm).

According to Gonzalez and Seastedt (2000), higher density of litter fauna and taxonomic diversity thrive in wet condition as opposed to dry environments. They also found out that taxonomic diversity was positively correlated with plant litter decomposition across any site.

Rigorous experimentation on the relationships between soil species richness and the regulation or resilience of nutrient cycles under global change remains a high priority (Swift *et al.*, 1998). According to Swift *et al.* (1998), there seems to be fewer data from which to judge the significance of changes in diversity within functional groups.

2.2 Fauna and Land-use

Research to identify appropriate means of sustaining tropical soil productivity has intensified during the last two decades and some promising technologies have been proposed. The importance of biological processes for soil fertility conservation is known, but there is little understanding of these processes in tropical cropping systems (Sanginga *et al.*, 1992), hence a need to explore this field.

Earthworms and litter arthropods populations rapidly disappear following disturbances of the soil, and are often not replaced by adaptable exotic species. Some groups of termites resist pedoturbation better and as a result, their relative proportions increase (Woomer *et al.*, 1994). Conversion from arable farming to forestry in Munchen, Germany, increased the abundance of faunal groups whereas mineral fertilization showed no effect on the faunal groups that were investigated (Grassi *et al.*, 1992), thus the type of land use affects the population trends of these soil animals.

A survey carried out to investigate arthropods associated with plant species grown in an agroforestry system in the Machakos area of Kenya revealed that pruned trees supported a richer arthropod fauna than the unpruned (Opondo-Mbai, 1995). This was due to the increase in the organic inputs into the soil that provided nutrition to the arthropod fauna. According to Keplin and Broll (1997) and Kimbatsa (1998), changes in soil macrofauna population correlate with the type of vegetation and land use. Moreover, a study on soil macrofaunal communities made along a secondary plant succession following sheep grazing abandonment in some chalk grasslands of upper-Normandy, France, showed that endogeic species dominated

under herbaceous vegetation while epigeic species were more important in woody plots (Dutoit *et al.*, 1996). Therefore these studies reveal that land use has a significant role in determining faunal populations in terms of abundance and diversity in a given site.

2.3 Faunal population and soil conditions

A survey of earthworms in Western Gojam, Ethiopia by Fentaw (1991) indicated that several genera of worms are distributed throughout the country whenever there is moisture. Report by Reddy *et al.* (1996) on the effects of soil management treatments on population densities of soil microarthropod and earthworms, and earthworm biomass depicted significantly higher densities during the crop (wet) than fallow (dry) periods. Invertebrate community of a number of soil types studied in dry savannas of Southwest Ethiopia during the dry and the wet season showed a gradual decrease of soil biota in the dry season as opposed to the wet season (Rybalov, 1990). The formation of agrocoenoses causes local changes in arthropod groups and the minimum number of soil fauna is typical of near-bank areas in the Kara Canal Zone, Asia (Sabirova, 1995) thus soil biota, to a large extent, may be used as an indicator of moisture status of a soil in a given environment.

Soil collembolans population correlated positively with soil moisture and temperature under four agroforestry tree species applied as mulch (Badejo *et al.*, 1998). Therefore, use of prunings of agroforestry tree species as mulch in agroecosystems would encourage the growth of collembolan populations and enhance their role in decomposition process hence nutrients release.

2.4 Faunal litter decomposition and season

A study on decomposition characteristics and potential rates of litter production of tropical grass and legume species in Columbia showed that rates of litter decomposition decreased and litter half-lives increased during the onset of the dry season (Thomas and Asakawa, 1993).

Decomposition- and nitrogen-release patterns of biomass from three agroforestry multipurpose trees (*C. calothyrsus, Cordia africana* Lam and *Grevillea robusta* A. Cunn. ex R.Br) investigated in four contrasting environments (microregions) in the Kenyan highlands established that decomposition pattern can be described as a function of biomass quality, climate, and soil conditions during cropping season (Mugendi and Nair, 1997). Studies done in northern Arizona strongly suggests that decomposition is limited by moisture in a given ecosystem (Murphy *et al.,* 1998). Hence litter decomposition could be having some correlation to season and therefore a need to investigate the same in an agroforestry setting.

2.5 Litter decomposition and resource quality.

The rate of decomposition of *Cassia siamea* Lamarck prunings in an alley cropping system investigated using litter bags in the semiarid area of the Machakos District, Kenya, during the short rains and the long rains gave an indication that faunal decomposition have some relation to the resource quality (Mugendi *et al.*, 1994). The nature of the organic material and the processes to which they had been subjected could be reflected by their rate of decomposition (Janseen, 1996).

According to Mafongoya *et al.* (1998), the potential of the organic inputs from agroforestry species to supply nutrients depends on their resource quality. Nutrient release pattern from organic materials could in part, be determined by their chemical composition, or quality and consequently litter quality have a strong influence on decomposition (Palm, 1995; Perez and Diaz, 1997). The overall challenge is, therefore, to develop ways of managing organic matter decomposition to optimize short-and long-term release of nutrients and to maintain soil organic matter thereby replenishing soil fertility. According to Cadisch *et al.* (1998), nutrients recovery especially nitrogen from plant litter are governed by the residue quality. Moreover, litter of high quality is required for increased soil organic matter turnover and improved crop production in tropical agroecosystems (Seneviratne, 2000).

Soil fauna are important regulators of decomposition and their activity influence distribution of organic matter in the soil profile and physical structure (Lavelle *et al.*, 1998). According to Yamoah *et al.* (1995), the supply of high quality organic material through agroforestry and related cropping systems, would improve the fertility of the soil and crop yield.

2.6 Litterbag studies on faunal decomposition

Studies using buried litterbags indicated that decomposition was rapid during the high-rainfall period (Puri *et al.*, 1992). Further studies using litterbag experiment carried out by Vanlauwe *et al.* (1997) established that decomposition and nitrogen

release patterns of *L. leucocephala* and *Senna spectabilis* DC. pruning residues were different but significant correlations were found between the decomposition rates.

Litterbag studies in the field showed that decomposition was correlated with the activity of soil fauna (Tian, 1992 and Tian *et al.*, 1997). A litter bag technique used to study the decomposition and nutrient release from *L. leucocephala* and *Leucaena pallida* Benth prunings and cattle manure in a hedgerow intercropping trial conducted in the Ethiopian highlands, showed that, their decomposition patterns varied (Lupwayi and Haque, 1999).

The challenges for soil biologists in the tropics are therefore, to develop greater understanding of ways in which soil organisms function in agricultural ecosystems and to learn how to manipulate those functions to improve the productivity and sustainability of the system (Swift *et al.*, 1998). Quantifying soil macrofauna and assessing their role in litter decomposition is, therefore, important in determining the biological health and fertility of the soil.

According to Hector *et al.* (2000), decomposition of plant litter is a key process for the flow of energy and nutrients in ecosystems that may be sensitive to the loss of biodiversity and that plant diversity could affect litter decomposition through changes in litter species composition. Therefore, it is worthwhile noting that, decomposition processes are complex and are mediated by the integrated activities of biotic (soil fauna, micro-organisms), abiotic, and resource quality. They, in turn influence the rate of decomposition and nutrient release. There is therefore need to investigate these aspects in an agroforestry set-up. Based on the above

reports, there is a need to establish how soil invertebrate macrofauna influence soil properties in agroecosystems.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Experimental site

The study was conducted at the National Agroforestry Research Project (NAFRP) site at the Kenya Agricultural Research Institute (KARI) Regional Research Centre, Embu district in the Eastern province of Kenya. The centre is in the central highlands of Kenya on the southeastern slopes of Mt. Kenya at 0° 30'S, 37° 30'E and an altitude of 1480 m. The average maximum temperature is 25°C; the minimum is 14°C while the long-term monthly temperature is 19.5°C. The area receives a total annual rainfall of between 1200 and 1500 mm in two distinct seasons: long rains (March to June) average 650 mm and the short rains (mid October to December) average 450 mm. The soils are mainly Humic Nitisols (FAO, 1989) derived from basic volcanic rocks (Jaetzold and Schmidt, 1982). They are deep, well weathered with friable clay texture with moderate to high inherent fertility.

3.2. Experimental treatments

Calliandra calothyrsus and *L. leucocephala* hedgerows were planted in April 1992 while the application of experimental treatments started in the long rain season of March 1993. The two hedgerow species had been identified as two of the most appropriate species for soil fertility management (Heinemann *et al.*, 1990). There

were ten treatments replicated three times in randomized complete block design. Treatments are detailed in Figure 1.

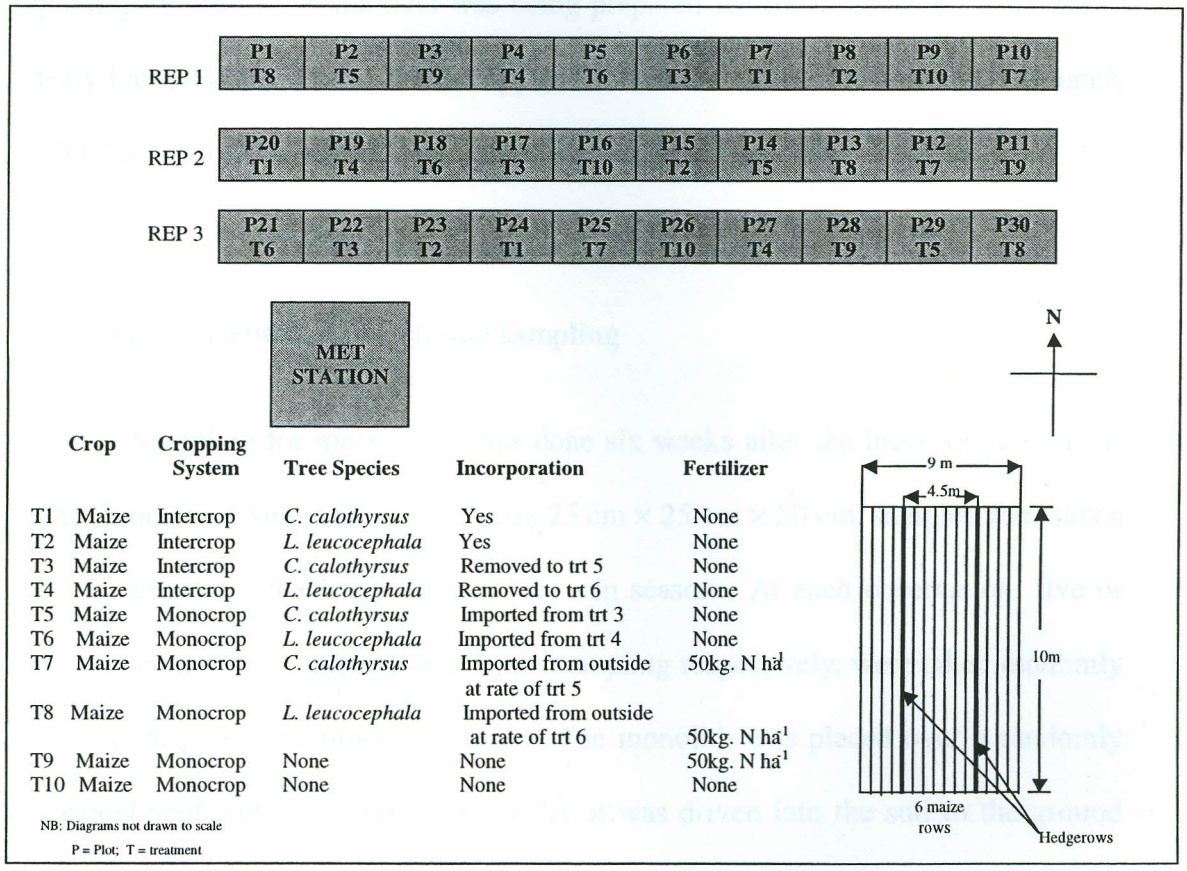


Figure 1: Field and plot layout, and experimental treatments within hedgerows at the National Agroforestry Research Project (NAFRP) site in Embu, Kenya.

3.3 Management of tree hedges and pruning incorporation

Calliandra calothyrsus and *L. leucocephala* tree hedges were lopped at a height of 50-cm using sharp knives two days before maize was planted. Leafy biomass and succulent stems were separated from hardened stems that were used for

firewood. The leafy biomass were weighed, chopped into smaller pieces (5 to 10 cm) and spread evenly on the ground over the plot area. They were then incorporated in the soil using hand hoes in the plots that were designed to receive pruning (Figure 1) as the land was being prepared for maize planting. The rate of leafy biomass of each tree species applied to different treatments was approximately 2 $Mgha^{-1}season^{-1}$ on dry weight basis.

3.4 Soil Invertebrate Macrofauna sampling

Sampling for macrofauna was done six weeks after the incorporation of the litter biomass. Using a monolith of size 25 cm × 25 cm × 30 cm, samples were taken in two seasons - the long and the short rain seasons. At each observation, five or three samples for abundance and depths sampling respectively, were taken randomly from each plot three times per season. The monolith was placed over a randomly selected spot and using a metallic mallet, it was driven into the soil to the ground level. The soil from the monolith was removed by hand depthwise at 0-30 cm for fauna abundance sampling and at 0-10 cm, 10-20 cm and 20-30 cm for specific depths sampling into plastic buckets. The soil from each depth was placed in different plastic trays (20 cm × 30 cm) and gently sorted out to locate the organisms. The organisms were separated into major taxonomic groups, and then collected in glass and plastic bottles using a pooter. After sorting, soil was returned to the sampling sites to minimize site degradation. In the laboratory, counting and recording was done. Number and biomass of different category of organisms were

expressed per square metre. After counting, the soil fauna were preserved in 75% alcohol for subsequent identification at the Department of Entomology, National Museums of Kenya, Nairobi. To assess the diversity among the different treatments and depths, Shannon and Wiener diversity index (Krebs, 1985) was used. This index was calculated using the following equation:

$$H' = -\Sigma (p_i \ln p_i)$$

Where H' is the Shannon index and p_i is the proportion of individuals found in the i^{th} species, estimated as n_i/N, where n_i is the number of individuals of the i^{th} species and N the total number of individuals within the sample.

3.5 Soil chemical analyses

Soil samples were taken using 2-inch (5.08 cm) diameter auger randomly from five different locations at one depth interval (0-30 cm) before and after both faunal sampling decomposition study. One composite sample was prepared per plot for all the three blocks. From the composite sample 200 g of soil was packed into a polythene bag and kept in a refrigerator at 4^0C. After all the plots were sampled, the samples were put in cooler boxes filled with ice and transported to the laboratory where they were refrigerated before analysis was done. Extraction and determination of nitrogen, phosphorus and potassium as well as the soil pH were done using methods outlined in the ICRAF laboratory manual (ICRAF, 2000).

3.5.1 Determination of soil nitrogen and phosphorus

Analysis for total nutrient content requires complete breakdown or oxidation of organic matter. A portion of soil sample was ground to pass through a 0.5 mm mesh from which 0.4 g was taken and digested by wet oxidation based on a Kjeldahl method with sulphuric acid; the samples were then analysed calorimetrically at 655nm and 880nm for total nitrogen and phosphorus concentration, respectively, in the soils.

Calculations

1. Nitrogen

N concentration in soil (%):

$$= \frac{[(SNCONC - SNBLNK)\ SNVOL] \times 0.0001}{SNSOLWT}$$

Where SNCONC = N concentration in soil digest (mg/l)
SNBLNK = N concentration in blank digest (mg/l)
SNVOL = Total volume of diluted digest (ml)
SNSOLWT = Soil sample weight (g)

2. Phosphorus

P concentration in soil (%):

$$\frac{[(SPCONC - SPBLNK)\ SNVOL] \times 0.0001}{SNSOLWT}$$

Where SPCONC = P concentration in soil digest (mg/l)
SPBLNK = P concentration in blank digest

3.5.2 Determination of soil potassium

Soil samples were taken by means of a 2.5 ml soil -scooper and analysed using modified Olsen extractant; the concentration of K was determined using a flame photometer:

Calculations

1. Exchangeable K

The values read from the instrument were in me/100 ml of soil. The mean blank readings were subtracted from the sample readings to obtain net concentration values.

a) Exchangeable K (soil volume basis):

$$EXK100M = EXKCONC - EXKBLNK$$

Where EXK100M = exchangeable K (me/100 ml soil)
EXKCONC = Concentration of K in sample (instrument reading for sample, in me/100 ml soil)
EXKBLNK = Concentration of K in blank (instrument reading for blank, in me/100 ml soil)

3.5.3 Determination of soil pH

This was done using the method detailed in the ICRAF laboratory manual (1995); this standard method uses a soil: water ratio of 1:2.5. 10ml of soil was scooped into 60ml bottles to which 25ml distilled water was added and stirred for 10 minutes on a 33-place stirrer and left to stand for 20 minutes before stirring again for

2 minutes and allowing the soil to settle for 30 seconds. The pH was determined by use of a pH-meter.

3.6 Soil physical properties analyses

3.6.1 Bulk density

Double cylinder method was used for bulk density determination. Soil samples were collected from 5 locations within each plot at the start and at the end of each sampling. The core sampler was driven into the soil to a depth of 30 cm. The sampler was then carefully removed so as not to disturb the soil. The soil extruding beyond each end of the sampler was trimmed with a knife before placing it into empty cans. The samples had their fresh weight determined and then taken to the laboratory where they were put in an oven and dried to constant weight at 105°C. The samples were later cooled and weighed. Weight of empty sample holders was also taken. Bulk density was determined using the formula shown below (Klute, 1986).

$$\text{Bulk density (g/cm}^3\text{)} = \text{M (ds)/V}$$

Where: M (ds) = Mass of dry sample (g) and V = Volume of dry soil sample (cm^3)

Total porosity was calculated from the bulk density and the particle density (assumed to be 2.65g/cm^3 for most mineral soils) as:

Total porosity (%) = {1 - (bulk density/particle density)} × 100 (Anderson and Ingram, 1993).

3.6.2 Soil water determination

Using core ring sleeves, soil samples were collected from 5 locations up to a depth of 30 cm within each plot at the start and at the end of the experiment to determine soil water. A labelled 50-ml beaker was weighed and its weight recorded. Subsamples of soil were added to the beaker to about one-third capacity. The beaker with soil was weighed immediately and its weight recorded. The soil was oven dried at 105°C for 24 hours. The beaker with dry soil was weighed and its weight recorded. Gravimetric soil water content was determined using methods outlined in the ICRAF laboratory manual (ICRAF, 2000).

3.6.3 Surface compactness.

A hand penetrometer was used to measure surface compactness. Depending on the expected resistance, either of the two cones (0.25 or 0.50 cm^2) and one of the three springs (5, 10 or 15 kgf) was fitted onto the penetrometer. For soils with an expected low resistance (less cohesive soils) the largest cone (0.50 cm^2) and the weakest spring (5 kgf) were used and vice versa. The movable ring was slid to zero. Using one hand the cone was pushed with a constant speed of about 2 cm^2 per second through the layer under investigation up to a maximum of 10 cm deep. Three locations within each plot for the three replications were measured and their mean taken at the start and at the end of the experiment. The movable ring showed the maximum compression of the spring. The location, the cone diameter and the spring used were recorded. Cone resistance (kgf/cm^2) gave a measure of the soil surface compactness (Laryea *et al.*, 1997).

3.7 Decomposition and nutrients release of incorporated litter

The experiment on litter decomposition was conducted within a hedgerow intercrop to investigate the role of soil macrofauna in litter decomposition and the relationship between resource quality and the rate of decomposition.

Two types of plastic (polyvinyl chloride) bags with mesh size 1 mm and 7 mm having dimension of 30 × 20 and 33 cm × 30 cm, respectively, with an envelope configuration were used. The 1 mm and 7 mm were used to exclude and include the soil invertebrate macrofauna, respectively. The sides of the litterbags were bent to retain the shape of shallow box like container to prevent compression of the enclosed litter and also to allow or exclude free access to most macrofauna groups. One hundred grams (fresh weight) of *L. leucocephala* or *C. calothyrsus* was placed into the bags and the open edges of the bags then sealed with nylon thread and the litter spread evenly within the bags. Ninety (90) bags of each mesh size were buried in a completely randomized design (CRD) and horizontally in the soil at a depth of 15 cm with the subtreatments replicated twice. This was to allow retrieval of two litterbags (one of 1mm and another of 7mm) per each plot at 1, 2, 4, 8 and 16 weeks after incorporating. The retrieved litter was analysed for dry matter and nutrients loss within the plots whose treatments involved litter incorporation (treatments 1, 2, 5, 6, 7, and 8). Throughout the period of the experiment, the experimental area was kept free of weed by hand weeding.

3.7.1 Dry matter loss analyses of *Calliandra calothyrsus* and *Leucaena leucocephala*

At each sampling, the soil attached to the litterbag was carefully removed and the litter was put in polythene bags and taken to the laboratory where soil and organic debris were sorted out by hand from the decomposing plant materials. Samples were then cleaned and oven dried at 65°C to a constant weight for dry weight determination (Anderson and Ingram, 1993). The dry weights were expressed as percentage of the initial sample weight at time zero.

Decomposition rate constants (k) were estimated using Wieder and Lang (1982) first order exponential equation:

$$L_R/L_I = e^{-kt}$$

Where: L_R = litter remaining after a given time.

L_I = initial litter weight at time zero.

t = time interval of sampling L_R expressed in weeks.

k = rate constant (decomposition rate constant per week).

e = base of natural logarithm.

The k values were estimated using a non-linear module in the EXCEL spreadsheet. This exponential model was considered to be close to the biological reality where the decomposition rate of fresh litter is rapid when hydrosoluble compounds are leached, but subsequently decrease over time.

3.7.2 Nutrient release of *Calliandra calothyrsus* and *Leucaena leucocephala*

The oven-dry samples of fresh plant samples taken at the onset (time zero) and during the experiment were ground in a Wiley mill (Cyclotec 1093 sample mill) to pass through a 0.5 mm sieve. Sub-samples of the ground litter were analyzed for total nitrogen, phosphorus, potassium, calcium, and magnesium (ICRAF, 2000), lignin content (Rowland and Roberts, 1994) and polyphenols (Anderson and Ingram, 1993). One gram of ground plant samples was ashed in a muffle furnace at 500^0C for 4h to correct for soil contamination when the samples were buried in the soil.

The ashed samples were reweighed and percentage ash content determined as shown below:

% Ash = [(crucible + unashed sample) - (crucible + ashed sample)] /[(crucible + unashed sample) - (crucible weight)] × 100

The nutrient values were corrected on the basis of ash-free weight:

Ash free weight per g of material = 1 - 0.01 × % ash.

% Corrected value for nutrient (N, P, K, Ca, and Mg) = 0.01 × % nutrient (N, P, K, Ca, and Mg)

Decomposition and nutrient release (N, P, K, Ca, and Mg) over time was calculated following the formula by Giashudin *et al.,* (1993):

% of nutrient released = 100 - (% of original nutrient remaining).

Where: % of original nutrient remaining = (% nutrient remaining at time t)/ (% nutrient at time zero) × % of original weight remaining

% of dry weight remaining = (DWt)/(Dwi) × 100

Where: DWt = oven dry weight at time t and Dwi = initial oven dry weight.

3.8 Impact of litter decomposition on maize grain yield

During the long rain season of the year 2000 there was a crop failure due to drought and therefore only the short rain season yields data were used for the study. The maize crop was harvested at maturity (five months after sowing). The maize cobs harvested were placed into labeled paper bags and taken to the laboratory for oven drying at 65°C to constant weights. Grains were then separated from the cores and their dry weights recorded and yield ($kgha^{-1}$) determined.

3.9 Data analyses

Data collected from the field was edited and coded in Microsoft Excel. In case of low values and therefore the need to avoid skewness, logarithmic transformation was done. The transformed data was subjected to analyses of variance (ANOVA) using Genstat for Windows program release 4.2, 5th edition. Standard error of difference of means (SED) was used to separate treatment means at 95% confidence interval. Correlation analyses were done as deemed necessary. Conclusion and generalization were then deduced.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Population of soil invertebrate macrofauna

The macrofauna observed during the period of study were identified up to the group/order/species levels. It was, however, not possible to identify some as they were still in their juvenile stage. Different macrofauna groups were observed in varying numbers during the study period as shown in Table 1. The hedgerow site recorded nine distinct groups of macrofauna. As opposed to other groups of fauna sampled, coleoptera recorded three distinct families and species, and this was in excess of the other eight groups of macrofauna observed. Although hymenoptera recorded one family, like coleoptera, it also registered three distinct species. Aranae and isoptera recorded one family and species each. Myriapoda, acarina, chilopoda, diptera and lepidoptera groups were not identified to their respective families and/or species as they were still in their juvenile stage of development. These observations could have been because the region offered a wide range of habitat for diverse faunal groups and hence a rich ecosystem. The hedgerow agroecosystem could have offered the coleoptera a better niche over the other groups observed hence the assortment of families and/or species for this particular group. Literature search revealed no explanation towards the preference (or lack of it for the rest of the groups) of coleoptera for the hedgerow agroecosystem.

Table 1: Macrofauna groups observed within hedgerows in Embu, Kenya.

Group/Order	**Family/Subfamily**	**Genera/Species**
1. Myriapoda (Millipedes)	NI*	NI*
2. Coleoptera (Beetles)	1. Scarabidae/aphodina 2. Staphylinidae. 3. Carabidae.	1. *Aphodius ividus* L. (chaffer grub). 2. *Philanthus* sp. (dark tiny beetles). 3. *Hyparpulus ornatus* Per.
3. Hymenoptera (Ants)	Formicidae/Myrmacinae	1. *Bothroponera* sp. (big dark ants) 2. *Euponera* sp. (brownish and small). 3. *Anoma* sp. (red ants).
4. Acarina (Mites)	NI*	NI*
5. Chilopoda (centipedes)	NI*	NI*
6. Aranae (Spiders)	Agriopidae	*Araneus dradematus* L.
7. Isoptera (Termites)	Termitinae/Macrotermitinae.	*Microtermes pusillas* Wasmann (tiny termites)
8. Diptera (Flies)	NI*	NI*
9. Lepidoptera (Moths)	NI*	NI*

* = Not identified

4.1.1 Abundance, biomass and diversity of soil invertebrate macrofauna

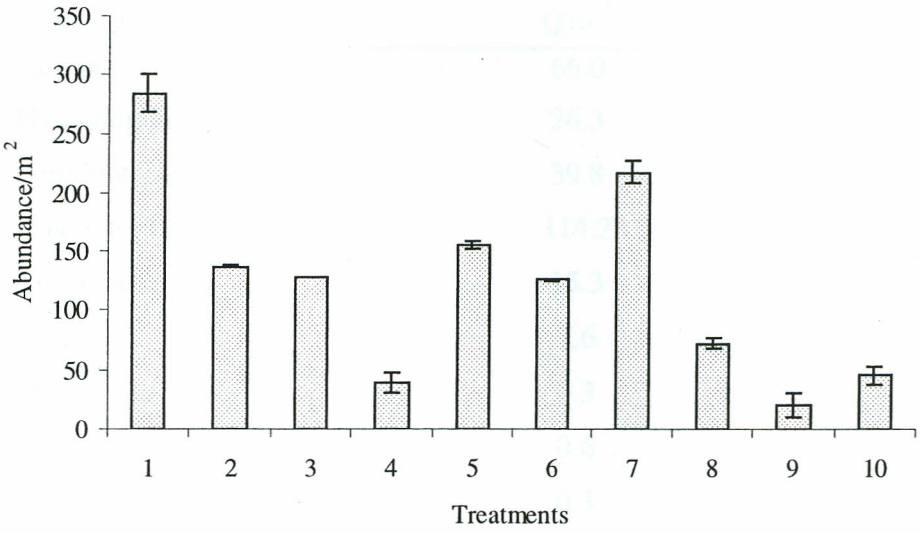
Relatively higher numbers of fauna were observed within the hedgerows agroecosystem (Table 2). Isoptera (termites) were the most abundant contributing 77.2% of the macrofauna observed followed by hymenoptera, lepidoptera, coleoptera, chilopoda, aranae, myriapoda, acarina and diptera in that order. These taxa could be seen to utilize the benefits accrued from combining trees with crops than with trees or crops alone. Moreover, disturbance to a site could also have given rise to the observed site preferences.

Table 2: Average macrofaunal abundance observed within hedgerows in Embu, Kenya

Faunal group	Abundance (m^{-2})	(%)
Isoptera	946	77.2
Hymenoptera	161	13.1
Lepidoptera	48	3.9
Coleoptera	38	3.1
Chilopoda	13	1.1
Aranae	7	0.6
Myriapoda	6	0.5
Acarina	3	0.2
Diptera	3	0.2
SED	0.020	0.018

The presence of high number of termites could also imply that termites were better able to withstand disturbed conditions as well as diminishing food resources resulting from such disturbances. It could also have been that the termites being ecosystem engineers influenced the access of litter to other faunal groups hence their abundance over the rest. Termites may as such be able to survive a wide range of conditions. This corroborates with the work done by Christopher (1994) that showed that the influence of termites is not confined to certain litter qualities, and that they control the accessibility of litter to other decomposers to an extent that exceeds their influence by direct consumption.

Macrofauna abundance varied significantly ($p<0.05$) across treatments with higher numbers of fauna being recorded for treatments with *C. calothyrsus* than with *L. leucocephala* over the sampling period (Figure 2) within the hedgerows. Treatments involving *C. calothyrsus*, biomass incorporation without fertilizer (Treatment 1) recorded highest numbers of fauna. This could have been due to the long-term residual effect (decomposes and releases nutrients slowly over time) of *C. calothyrsus* than *L. leucocephala*, this, coupled with integration of biomass with inorganic fertilizer, further enhanced macrofaunal abundance. Treatments involving addition of inorganic fertilizer without organic input (Treatment 9) registered the lowest number of macrofauna. It could be that the inorganic fertilizer had injurious effects on soil macrofauna and/or that the macrofauna had preference for nutrition from organic source over the inorganic fertilizer.



(Bars = standard errors)

Figure 2: Macrofauna abundance within hedgerows during the long and the short rain seasons in Embu, Kenya.

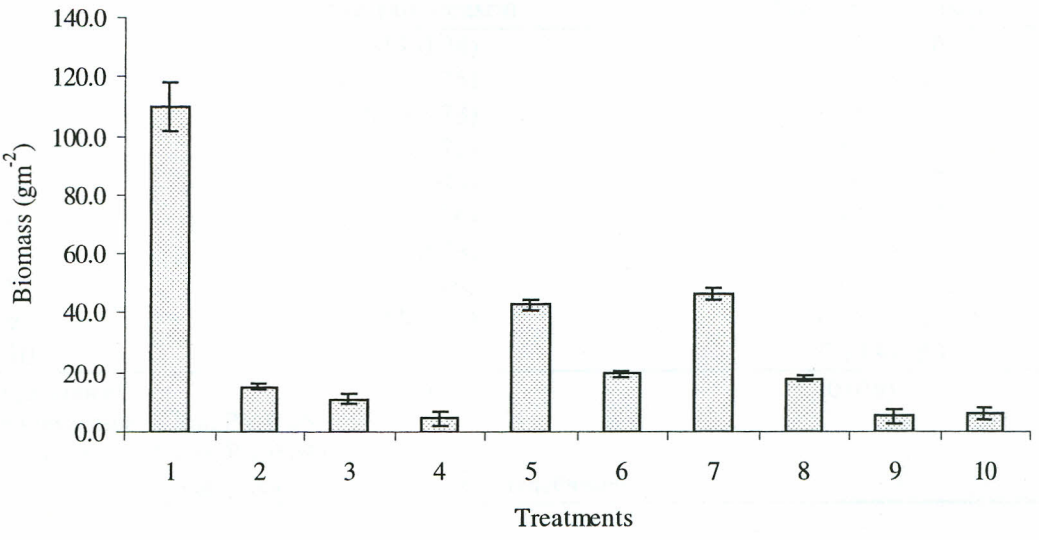
Average macrofaunal biomass of the soil invertebrates recorded within the hedgerows varied significantly with the coleopterans contributing the greatest biomass followed by isoptera and lepidoptera (Table 3). The dipterans formed the minority in terms of the biomass. Therefore, coleopterans could have been deriving better nutrition from within the hedgerows than the dipterans hence their higher biomass.

Table 3: Average macrofaunal biomass observed within hedgerows in Embu, Kenya.

Faunal group	Biomass (gm^{-2})	Biomass (%)
Isoptera	66.0	23.6
Hymenoptera	26.3	9.4
Lepidoptera	39.8	14.2
Coleoptera	114.2	40.9
Chilopoda	15.3	5.5
Aranae	7.6	2.7
Myriapoda	9.3	3.3
Acarina	0.6	0.2
Diptera	0.3	0.1
SED	0.010	0.008

Average biomass significantly varied ($p < 0.05$) across the treatments (Figure 3) with the greatest biomass being recorded with treatments involving *C. calothyrsus*, biomass incorporation without fertilizer application (Treatment 1). In most cases, more biomass was recorded for treatments with *C. calothyrsus* than with *L. leucocephala*. This could have been due to the long-term residue effect of *C. calothyrsus* as opposed to that of *L. leucocephala* thereby providing food to the organisms for an extended duration. Addition of inorganic fertilizer depicted a decrease on the faunal population. This could have been because the macrofauna had preference for organic nutrition from *C. calothyrsus* and *L. leucocephala* than from inorganic sources. The inorganic fertilizer could have had a deleterious effect on the macrofauna. This observation is in assentment to studies conducted by Matson

et al. (1997) that established that fertilizers have injurious environmental effects to adjacent, and even distant ecosystems.



(Bars = standard errors)

Figure 3: Macrofauna biomass within hedgerows during the long and the short rain seasons in Embu, Kenya.

Macrofauna diversity as indicated by the Shannon-Wiener index was significantly different ($p<0.05$) across treatments for the two seasons within the hedgerows (Table 4) with treatments involving *C. calothyrsus* (Treatments 1, 3, 5 and 7) recording the highest diversity. Macrofauna diversity within the hedgerows was greater in long rain season than in short rain season as depicted in Table 4. This

gave an indication that the long rain season, although dry, could have offered a wide niche range for the macrofauna than the short rain season that was basically wet.

Table 4: Shannon-Wiener indices within hedgerow agroecosystem in Embu, Kenya.

Treatment	Shannon-Wiener Indices	
	Long rain season	Short rain season
1	0.043(0.74)	0.071(0.76)
2	0.064(0.75)	0.119(0.76)
3	0.037(0.73)	0.061(0.75)
4	0.000(0.71)	0.090(0.77)
5	0.055(0.74)	0.093(0.77)
6	0.085(0.76)	0.095(0.77)
7	0.034(0.73)	0.037(0.73)
8	0.076(0.76)	0.087(0.77)
9	0.032(0.73)	0.087(0.77)
10	0.013(0.72)	0.133(0.80)
SED (treatment)	(0.020)	(0.019)

Long rain season: F test: P = 0.05
Short rain season: F test: P = 0.047
Values in parentheses are square root $\{\sqrt{(x + 0.5)}\}$ transformed.

Relatively higher diversity was recorded during the wet period (short rain season) than during the dry spell (long rain season). The results correspond to research findings by Gonzalez and Seastedt (2000) that higher density of litter fauna and taxonomic diversity thrive in wet condition as opposed to dry environments.

Overall, biomass gave a better indication of site than both the abundance and diversity. Biomass depicted a significant difference across the treatments as previously depicted in Figure 3.

4.1.2 Population of soil invertebrate macrofauna at varied soil depths

Macrofauna abundance and biomass for specific groups were varied ($p < 0.05$) at different soil depths across the two seasons as shown in Tables 5 and 6, respectively. Termites were observed in all depths for both seasons whereas the moth caterpillars were confined in the 0-10 cm depth and were only present during the short rain season.

Significant differences were observed ($p<0.05$) among the different macrofauna groups in terms of abundance, biomass and diversity across treatments during the sampling periods. Termite and ants were both observed during the two sampling periods. Overall, termites were observed in higher numbers and biomass for all the treatments in both seasons. The long rain season recorded the highest number and biomass of fauna as opposed to short rain season. These findings are in agreement to those that have been reported by Hulugalle *et al.* (1997).

Table 5: Macrofauna abundance at different soil depths within hedgerows in Embu, Kenya.

Depth (cm)	Termite		Ant		Beetle	Centipede	Millipede	Spider	Mite	Fly	Caterpillar
	LR	SR	LR	SR	LR	LR	LR	LR	LR	LR	SR
0 - 10	245	110	41	7	6	3	2	3	1	1	42
10 - 20	135	19	40	0	11	4	1	2	1	1	6
20 - 30	236	1	22	1	21	6	3	2	1	1	0

Abundance = counts/m^2
LR and SR = long and the short rain seasons respectively
SED: LR = 0.016, $P < 0.001$; SR = 0.018, $P < 0.001$

Table 6: Macrofauna biomass at different soil depths within hedgerows in Embu, Kenya.

Depth (cm)	Termite		Ant		Beetle	Centipede	Millipede	Spider	Mite	Fly	Caterpillar
	LR	SR	LR	SR	LR	LR	LR	LR	LR	LR	SR
0 - 10	14.7	11.5	6.1	0.8	23.9	2.2	3.8	3.7	0.2	0.1	34.9
10 - 20	11.3	2.1	4.7	0.1	43.1	5.6	1.7	2.3	0.2	0.1	4.9
20 - 30	16.3	0.0	4.6	0.1	47.2	7.5	3.8	1.6	0.2	0.1	0.2

Biomass = (1×10^{-2}) gm^{-2}
LR and SR = = long and the short rain seasons respectively
SED: LR = 0.022, $P < 0.001$; SR = 0.018, $P < 0.001$

The relatively great biomass of termites recorded in all the treatment in both seasons implies that they were better able to withstand periods of harsh environmental conditions as well as diminishing food resources. This gave an indication that termites were able to survive a wide range of conditions. Results of this study corroborate with experiments conducted in the central highlands of Kenya which showed that soil faunal composition, abundance and biomass were dominated by termites which accounted for more than 90% of the faunal observed (Dangerfield, 1997).

Macrofauna diversity as indicated by the Shannon-Wiener index at varying soil depths was significantly different over the two seasons within hedgerows as depicted in Table 7. During the long rain season the diversity was higher in the 20-30 cm depth and lower in the 0-10 cm depth within the hedgerows. In the short rain season the upper 0-10 cm depth recorded the highest diversity while the 20-30 cm depth recorded the lowest.

Table 7: Shannon-Wiener indices at different soil depths within hedgerows in Embu, Kenya.

	Shannon-Wiener indices	
Depth (cm)	Long rain season	Short rain season
0 - 10	0.014(0.72)	0.111(0.78)
10'-20	0.036(0.73)	0.105(0.78)
20 - 30	0.082(0.76)	0.055(0.74)
SED (depth)	(0.008)	(0.005)

Long rain season: F test: $p < 0.001$; Short rain season: F test: $p < 0.001$.
Values in parentheses are square root $\{\sqrt{(x + 0.5)}\}$ transformed.

Higher diversity recorded in the 20-30 cm depth during the long rain season could have resulted from macrofauna movements in search of food that was rather scarce during the same season, as it was dry. Indigent food resources within the hedgerows could also have necessitated such an observation. Higher diversity in the 0-10 cm depth during the short rain season could have been due to very moist and cold condition resulting from rainfall experienced during the same season and since the lower depth (20-30) offered a cold site the macrofauna could have preferred such a depth. Studies have shown that the amount of organic matter available, moisture, temperature, pH level and soil chemical properties limit size of faunal population (Radford *et al.*, 1995; Lavelle, 1995 and 1997; Swift *et al.*, 1998; Decaens *et al.*, 1999a; Yeates *et al.,* 2000; Norgrove and Hauser, 2000)

Overall, the population of the invertebrate macrofauna within the hedgerow intercropping was high. Faunal abundance, biomass and diversity were significantly varied across treatments with and without organics. More faunal abundance, biomass and high diversity were observed with treatments involving organic inputs (Treatments 1, 2, 5, 6, 7, and 8) than those without (Treatments 3, 4, 9, and 10). The above observations could have been due to the nature of organic matter, management practice, moisture and temperature hence the nature of faunal composition and structure. This observation agrees with studies done by Yeates *et al.* (2000) and Lavelle *et al.* (1998), which showed that variation in organic matter, management practice and soil chemical properties causes distinct alterations to faunal structure.

The faunal structure observed could have been due to the nature of the organic matter, the food resources present and the physical status of the soil. The quality and quantity of litter, which were different, could have influenced the soil conditions and consequently dynamics of the fauna across the treatments. Furthermore, the drier conditions at the soil surface that prevailed during the long rain season (Appendix 1) could have created an environment beyond tolerance limits of most soil fauna groups, consequently decreasing their diversity. Tian *et al.* (1997) found that in harsh environments, only those fauna groups that are buffered from climatic extremes by building nest (e.g. termites) or those groups living in deeper soil layers are not immediately affected but may eventually suffer from the reduction in food resources. Several studies have shown that the amount and quality of organic matter available, moisture, temperature, and soil properties and the structure of the vegetation limit size of faunal population (Lavelle, 1995 and 1997; Norgrove and Hauser, 2000; Cortet and Poinsot, 2000).

The low abundance, biomass and diversity of the soil fauna observed at varying depths in the unfertilized control typically represent the status of soil fauna in the arable fields of resource poor farmers in Embu, Kenya. Poor crop yields may be as result of declining soil fertility that is due to continuous cropping and application of insufficient external inputs by most farmers. Continuous cropping that is highly practiced by most farmers in Embu may decrease plant richness and consequently reduce the diversity of food resources to the soil fauna hence their variation with different management

practices. Studies have shown that such changes in the land use systems lead to reduced abundance, biomass and diversity of soil fauna communities (Dangerfield, 1997).

4.2 Relationship between soil invertebrate macrofauna with soil physicochemical properties

Soil physical properties that were considered during the period of study included bulk density, total porosity, gravimetric soil moisture and soil compactness. Chemical properties of soil that were considered during the period of the study included: Soil nitrogen, phosphorus, potassium and pH. Only those soil physicochemical properties that were significantly different ($P < 0.05$) across the various treatments were compared against macrofaunal abundance, biomass and diversity. The correlation between abundance, biomass and diversity was highly significant ($p < 0.05$) as depicted in Table 9.

4.2.1 Variation of soil invertebrate macrofauna with soil physical properties

Soil compactness was significantly different across treatments as well as between seasons (Table 8). Bulk density (1.01g/cm^3), total porosity (61.9%) and gravimetric soil moisture (16.17% and 40.05% in long rain and the short rain seasons, respectively) were not significantly different across all the management practices studied.

Table 8: Soil compactness within hedgerow agroecosystem in Embu, Kenya.

Treatment	LR ($kgfcm^{-2}$)	SR ($kgfcm^{-2}$)
1	4.3	6.2
2	6.0	8.1
3	3.9	6.0
4	6.9	16.8
5	4.3	5.6
6	3.3	5.6
7	5.9	11.1
8	7.9	12.2
9	6.5	12.1
10	4.1	8.4
SED	1.18	1.14
F Test	**0.002	***<0.001

Key: LR = Long rain season; SR = Short rain season
** = Highly significant at p = 0.05; *** = Very highly significant at p = 0.05

Soil was more compact in short rain season than long rain season in treatments with *L. leucocephala* than those with *C. calothyrsus*. Highest compactness was registered with *L. leucocephala* without biomass incorporation or fertilizer application (Treatment 4). In most cases, treatments that involved litter biomass incorporation without fertilizer application (Treatments 1, 2, 5 and 6) had minimal soil compactness whereas those that involved inorganic fertilizer application (Treatments 7, 8, and 9) had maximum level of compactness. This could have been because the organic matter incorporated provided ready food to the faunal community that subsequently moderated the soil conditions by way of increasing aeration hence penetrability. There was a significant ($P < 0.05$) negative correlation of the soil macrofauna abundance with surface compactness. The trend of

macrofauna biomass depicted a positive correlation, which was rather insignificant while diversity depicted a significant negative correlation with soil compactness (Table 9)

Greater soil compactness in short rain season than in the long rain season could have been due to soil disturbance necessitated by weeds removal and tendering of crops as opposed to the long rain season where the crop failed hence no weeding or other soil disturbing activities. The quality of the organic input to the soil and the nature of land use and/or management could have influenced soil compactness and consequently faunal abundance. These findings are in agreement to those of Lavelle (1992 and 1995) that the type of organic input and frequency of the management practices employed determines the nature of soil physical properties.

Different macrofaunal groups might have devised survival strategies to fit with the varying soil compactness thereby creating an increase in biomass that was rather insignificant but a significant decrease in abundance and diversity. Therefore, soil compactness seems to impact positively on the macrofaunal biomass but negatively on abundance and diversity. Though increased compactness is not necessarily a good soil physical attribute, it looks like it enhanced soil macrofauna biomass and hence may be a better measure of soil biological status than abundance and diversity. A significant portion of the increase of biomass may have originated from an improved access to soil nutrients and organic resources especially in the short rain season.

Table 9: Correlation coefficient matrix of soil macrofauna population and soil physicochemical properties within hedgerows in Embu, Kenya.

	Abundance	Biomass	Diversity	Compactness	N	P	K	pH
Abundance	1							
Biomass	0.89**	1						
Diversity	0.96**	0.75**	1					
Compactness	-0.51*	0.37	-0.59*	1				
N	0.31	0.52*	0.10	0.07	1			
P	-0.17	-0.27	-0. 10	-0.16	0.02	1		
K	0.44	0. 27	0.46	-0.33	0.21	-0.30	1	
pH	-0.09	0.04	-0.06	-0.06	-0.28	-0.69**	0.04	1

* Significant at $P < 0.05$; ** highly significant at $P < 0.05$

Due to failure of the rains in the long rain season, there was neither weeding nor cultivation that was done and therefore minimal soil disturbance as opposed to the short rain season where rainfall was received in time. The type of management practices employed may have influenced soil physical properties. Cultivation in the short rain season may have interfered with the structure of the soil thereby compacting it and in turn this could have influenced the survival of most fauna. Abundance of the fauna was thus lower in the short rain season than the long rain season, but may be, due to favorable abiotic conditions the diversity of the fauna was higher in the short rain season as opposed the long rain season. These findings support those of Lavelle *et al.* (1997) and Norgrove and Hauser (2000) that soil fauna community numbers correlate with changes in land management and degradation of ecosystem/land. Both will lead to depletion of soil macrofaunal communities.

4.2.2 Variation of soil invertebrate macrofauna with soil chemical properties

Soil chemical nutrients particularly nitrogen and phosphorus are critical to the farming community of Embu, and are the most limiting especially in the farms of the small-scale farmers who cannot afford inorganic fertilizers (FURP, 1987). These elements determine the productivity of a given farm or soil. The soil chemical nutrients that were compared against macrofaunal population observed during the study period include nitrogen, phosphorus, potassium and the soil pH.

The relationship between faunal abundance, biomass and diversity with the soil chemical nutrients was varied (Table 9). The trend of faunal abundance and diversity was positively correlated to that of mineralizable nitrogen but the relationship was insignificant at $p< 0.05$. Macrofaunal biomass had a significant positive correlation with mineralizable nitrogen. Faunal biomass may thus be seen as better measures of soil nitrogen level than abundance and diversity. A similar observation was made with the soil potassium although the relationship was not significant. Faunal population increased with increasing mineralizable nitrogen and/or potassium levels. Nitrogen and/or potassium may thus be seen as important nutrients for fauna and might have enhanced their population.

Macrofaunal abundance, biomass and diversity were negatively correlated to extractable inorganic phosphorus and the correlation was not significant (Table 9). Phosphorus concentration in the soil could be of less importance than nitrogen and/or potassium and consequently did not enhance their abundance, biomass and diversity. There was a decrease in macrofauna abundance, biomass and diversity with increasing phosphorus levels. Faunal population may as a result, not be a measure of soil phosphorus levels.

The macrofaunal abundance and diversity depicted an insignificant negative correlation with the soil pH. Nevertheless, macrofaunal biomass depicted an insignificant positive correlation (Table 9). The macrofauna thrived relatively well in pH ranges of between 5.5 and 5.8. Increase in pH caused a reduction in faunal abundance and diversity. Soil pH could therefore

have impacted on faunal populations and a slight change on the same may alter macrofaunal composition and structure. Research done elsewhere concurs with the findings of this study that the size of faunal population is limited by the soil pH and chemical and/or physical properties of the soil as revealed by Conn and Dighton (2000), Decaens *et al.* (1999b), Sabirova (1995) and FURP (1987).

On average, abundance, biomass and diversity of macrofauna were positively correlated to the soil nitrogen and potassium and negatively with Phosphorus. The soil macrofauna abundance and diversity were negatively correlated to pH but positive with biomass. Therefore, macrofaunal population and structure could be used as an indicator of soil nutrient status and pH.

A significant portion of the increase of fauna could be associated with improved access to soil nutrients and/or organic resources rich in nitrogen and/or potassium. The findings of the study depicted that soil macrofauna could respond differently to varying soil nitrogen, phosphorus and potassium levels. Faunal communities may have adjusted to nutrient concentrations by either increasing or decreasing their selectivity thus variations in their composition and structure. Research done elsewhere concurs with the findings of this study that the size of faunal population is limited by the quantity and quality of organic matter available, pH and chemical and/or physical properties of the soil (Fentaw, 1991; Sabirova, 1995; Lavelle, 1997; Conn and Dighton, 2000; Decaens *et al.*, 1999a; Norgrove and Hauser, 2000; Kandji *et al.*, 2001).

4.3 Influence of soil invertebrate macrofauna on litter decomposition

Decomposition and nutrient release of the litter biomass are the key processes by which nutrients locked up in plant parts eventually become available to crops. The processes are regulated by variables such as the quality of the litter, climate, soil properties and decomposer communities (Upadhyay and Singh, 1989). Therefore, understanding the influence of these variables on biomass decomposition and nutrient release is a vital step to better management of organic inputs that are applied in different agroecosystems (Mafongoya *et al.,* 1997).

Nutrient analyses of the litter used in the decomposition study depicted that *C. calothyrsus* and *L. leucocephala* varied in nutrient content as shown in Table 10 and therefore, they could be varied in terms of nutritional value hence resource quality. A t-test indicated that nutrient concentrations of the two species were significantly different ($p < 0.05$).

Table 10: Average chemical composition of *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows in Embu, Kenya.

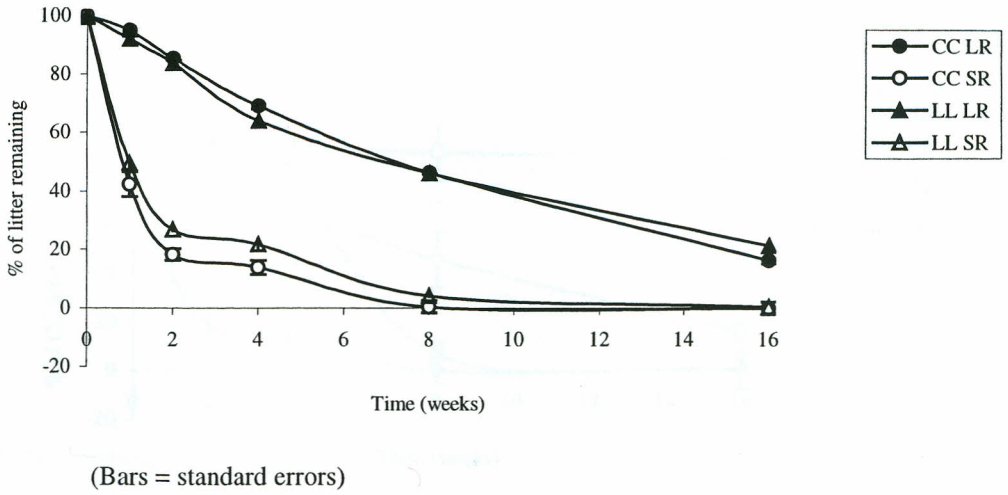
Material	%N	%P	%K	%Ca	%Mg	%Lignin	%Polyphenol
CC	2.8	0.1	0.6	1.2	0.4	13.4	11.2
LL	2.8	0.1	1.9	1.3	0.3	9.5	8.1
SED	0.02	0.01	0.06	0.04	0.01	0.10	0.11

In Figure 4, it is evident that *L. leucocephala* decomposed at a faster rate than *C. calothyrsus* in the long rain season unlike in the short rain season where *C. calothyrsus* decomposed at a faster rate than *L. leucocephala*. The pattern of litter decomposition was gradual in long rain season and drastic in short rain season. This could have been due to differences moisture and temperatures experienced and therefore varied faunal population within treatments involving the two tree species. These findings agree with the observations made by Mugendi *et al.* (1994) in Machakos district of Kenya, during the short rains and the long rains, which gave an indication that faunal decomposition, could be having some relation to climatic conditions and resource quality.

The varied rate of decomposition of *L. leucocephala* and *C. calothyrsus* could have been due to the varied litter substrate quality with the former being of higher quality than the latter as it had lower ratios of lignin and/or polyphenols to nitrogen. The findings support report by Bubb *et al.* (1998) which indicated that litter-mass loss is strongly correlated with litter quality indicators such as nitrogen, phosphorus, carbon to nitrogen ratio, lignin and polyphenolics.

The rate of decomposition of *L. leucocephala* and *C. calothyrsus* was faster in the short rain season than in the long rain season. This could have been due to the presence of fully established crop (the crop cover could have offered a favorable microclimate) that might have increased the decomposition of the residues of the prunings. This corroborates to findings by Vanlauwe *et*

al. (1997) that crop cover may increase decomposition and nitrogen release of the residues.



(Bars = standard errors)

Figure 4: *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) decomposition within hedgerows in Embu, Kenya.

The litter enclosed in 7-mm litterbags decomposed at a faster rate than that in the 1-mm litterbags and the rates were higher in short rain season than in long rain season for both *C. calothyrsus* and *L. leucocephala* as depicted in Figures 5 and 6, respectively. These variations in decomposition could have been due to varied effects of the different size classes of decomposers giving an indication that the presence of soil invertebrate macrofauna could have promoted the rate of litter decomposition. The long rain season was dry due to drought, and although the faunal biomass and abundance were high during this specific season, the diversity was low as opposed to the short rain season where higher diversity of organisms was recorded. Therefore, higher faunal

population and biomass could have enhanced decomposition in long rain season. These results corroborate to the findings reported by Rusek (1998), Insam *et al.* (1996), Gupta and Oli (1998) and Beck, (2000) that fauna play an important role in plant litter decomposition processes.

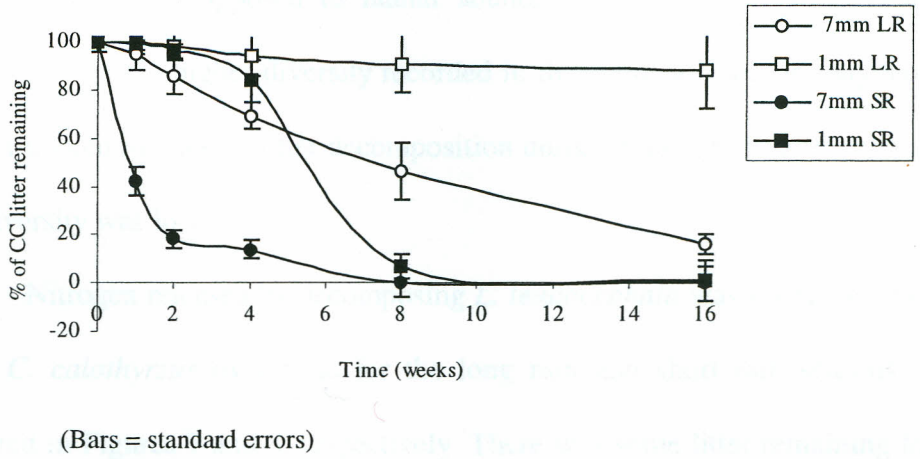


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Figure 5: The influence of litterbag mesh size on *Calliandra calothyrsus* (CC) decomposition within hedgerows in Embu, Kenya.

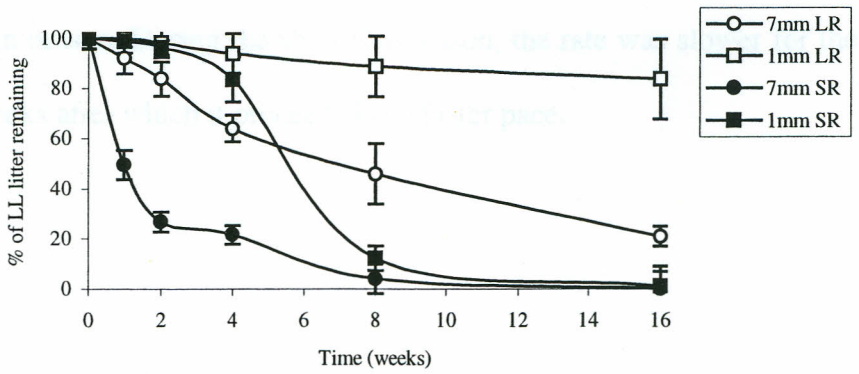

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Figure 6: The influence of litter-bag mesh size on *Leucaena leucocephala* (LL) decomposition within hedgerows in Embu, Kenya.

The community composition in terms of diversity coupled with moist conditions may have played a great role in enhancing the rate of decomposition in the short rain season as opposed to the long rain season. Therefore, both the biotic and the abiotic factors could have influenced litter decomposition, though, decomposition may have been influenced more by the faunal diversity as opposed to faunal abundance. Different feeding habits resulting from the higher diversity recorded in the short rain season may have also promoted the rate of litter decomposition unlike in long rain season where the diversity was low.

Nitrogen released by decomposing *L. leucocephala* was faster than that from *C. calothyrsus* over time for the long rain and short rain seasons as depicted in Figures 7 and 8, respectively. There was some litter remaining for both the species even after the 16th week for the long rain season whereas all the litter had decomposed by the 8th week in the short rain season. The rate of litter decomposition was relatively slow within the first four weeks of the long rain season. During the short rain season, the rate was slower for the first two weeks after which it proceeded at a faster pace.

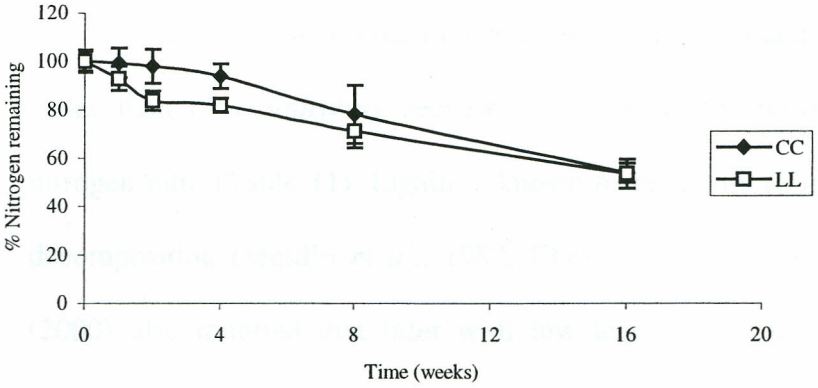

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Figure 7: Nitrogen release pattern of decomposing *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows during the long rain season in Embu, Kenya.

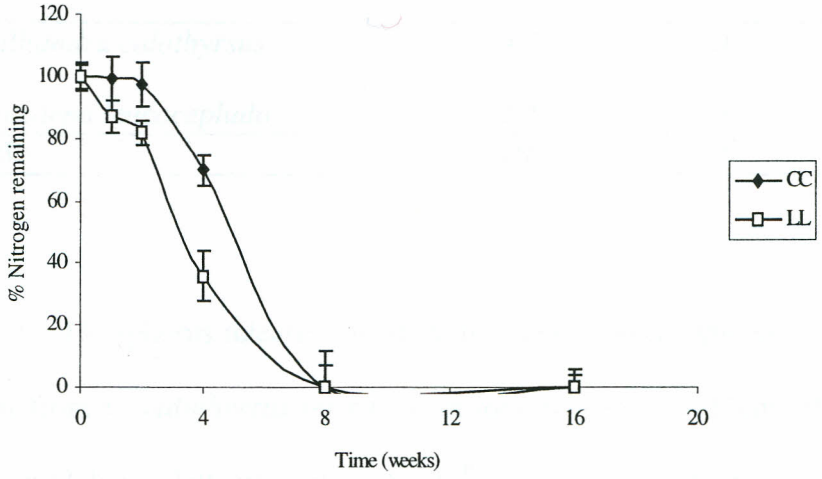

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Figure 8: Nitrogen release pattern of decomposing *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows during the short rain season in Embu, Kenya.

Leucaena leucocephala could have decomposed and released nitrogen faster than *C. calothyrsus* because of lower lignin and/or polyphenols to nitrogen ratio (Table 11). Lignin is known to be highly resistant to microbial decomposition (Melillo *et al.*, 1982; Chesson, 1997). Thomas and Prescott (2000) also reported that litter with low levels of lignin releases nitrogen faster. According to Vityakon *et al.* (2000), polyphenols exhibit a significant influence on nitrogen release from litter biomass.

Table 11: Lignin (Lig) and/or polyphenols (Pp) to nitrogen (N) ratios of *Calliandra calothyrsus* and *Leucaena leucocephala* within hedgerows in Embu, Kenya.

Plant Material	Lig/N	Pp/N	(Lig +Pp)/N
Calliandra calothyrsus	4.8	4.0	8.9
Leucaena leucocephala	3.4	2.9	6.3
SED	0.02	0.06	0.01

Phosphorus release from decomposing *L. leucocephala* was faster than that from *C. calothyrsus* over time in long rain season (Figure 9) with some material being left even after the 16th week. In the short rain season both species released phosphorus at relatively the same rate with all the material having decomposed by the 8th week (Figure 10). These observations could have been due to variations in moisture and temperature.

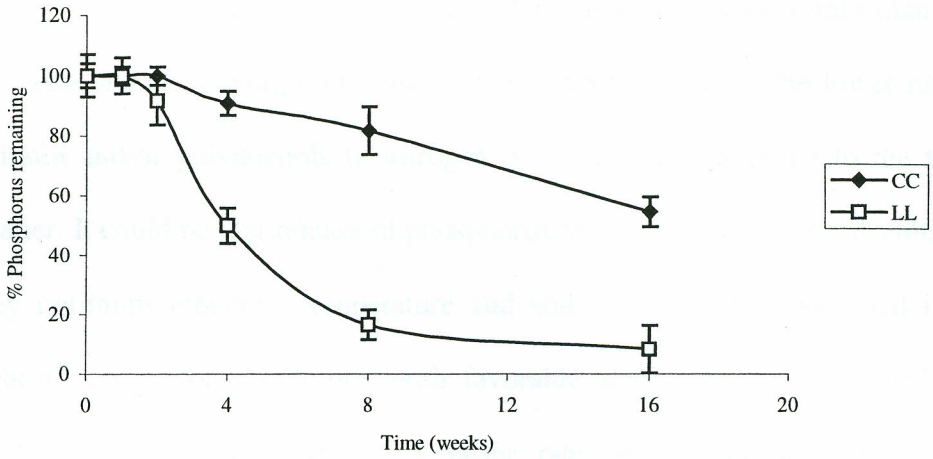

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Figure 9: Phosphorus release pattern of decomposing *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows during the long rain season in Embu, Kenya.

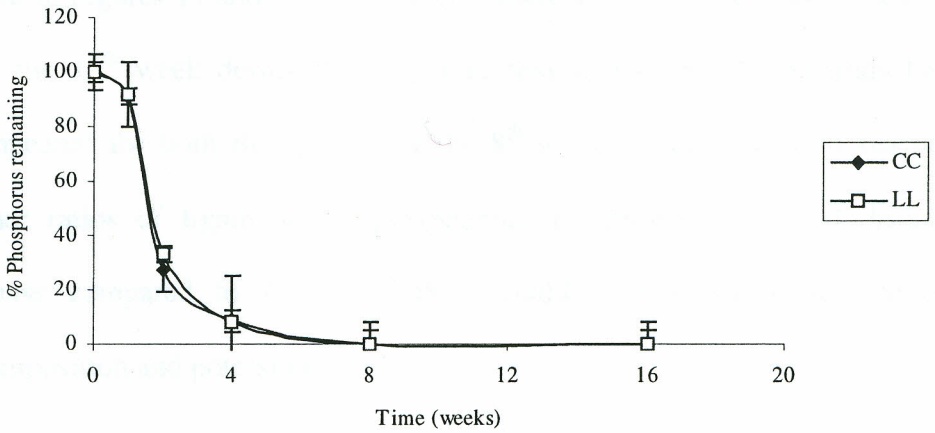

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Figure 10: Phosphorus release pattern of decomposing *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows during the short rain season in Embu, Kenya.

The faster rate of phosphorus release from *L. leucocephala* than from *C. calothyrsus* in long rain season could have been due to the lower ratio of lignin and/or polyphenols to nitrogen of the former compared to the to the latter. It could be that release of phosphorus from *C. calothyrsus* was enhanced by optimum moisture, temperature and soil condition that prevailed in the short rain season. Therefore, with favorable abiotic factors, *C. calothyrsus* would release phosphorus at a faster rate. Rates and patterns of litter decomposition are described as a function of litter quality, climatic and soil conditions (Thomas and Asakawa, 1993; Mugendi and Nair, 1997)

Potassium release from decomposing *L. leucocephala* was faster than that from *C. calothyrsus* over time in long rain and short rain seasons as shown in Figures 11 and 12, respectively. There was some material remaining after the 16th week during the long rain season whereas all materials had disappeared for both the species by the 8th week of the short rain season. Higher ratios of lignin and/or polyphenols to nitrogen in *C. calothyrsus* biomass compared to *L. leucocephala* could explain the slow rate of decomposition and potassium release.

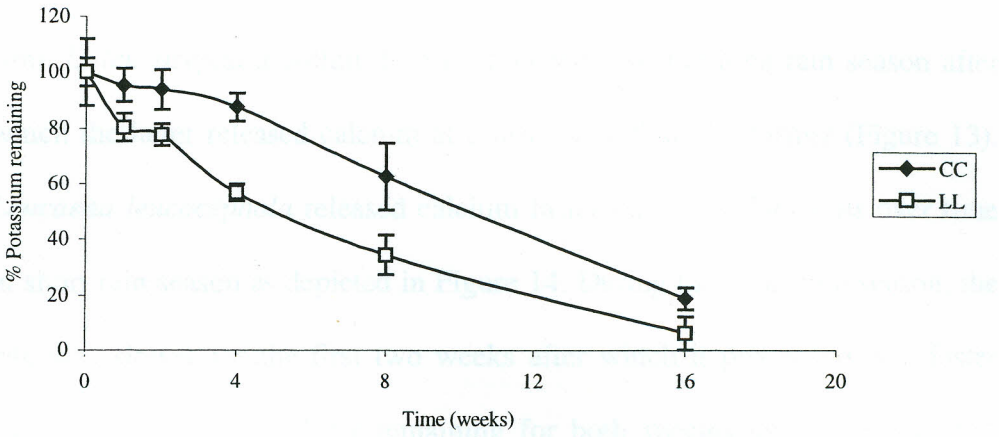

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Figure 11: Potassium release pattern of decomposing *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows during the long rain season in Embu, Kenya.

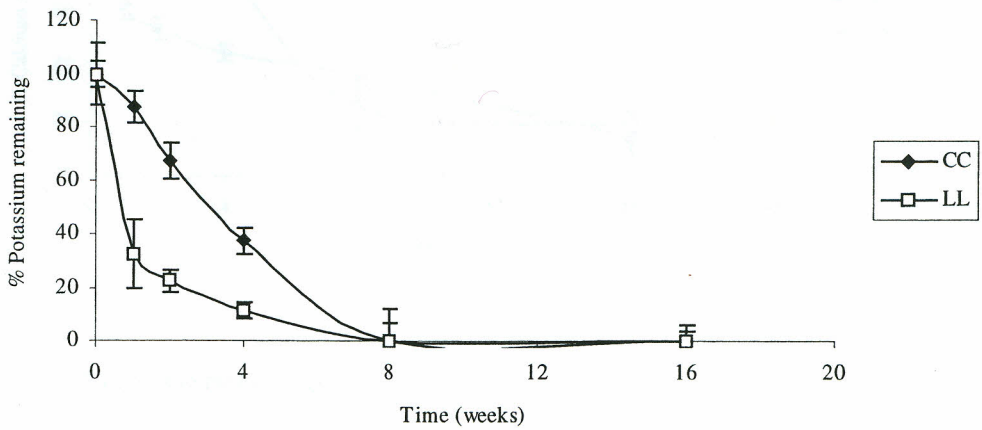

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Figure 12: Potassium release pattern of decomposing *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows during the short rain season in Embu, Kenya.

Calcium release from decomposing *C. calothyrsus* was faster than that from *L. leucocephala* within the first four week of the long rain season after which the latter released calcium at a faster rate than the former (Figure 13). *Leucaena leucocephala* released calcium faster than *C. calothyrsus* over time in short rain season as depicted in Figure 14. During the short rain season, the rate was slower for the first two weeks after which it proceeded at a faster pace. There was some litter remaining for both species even after the 16th week for the long rain season whereas all the litters had decomposed by the 8th week.

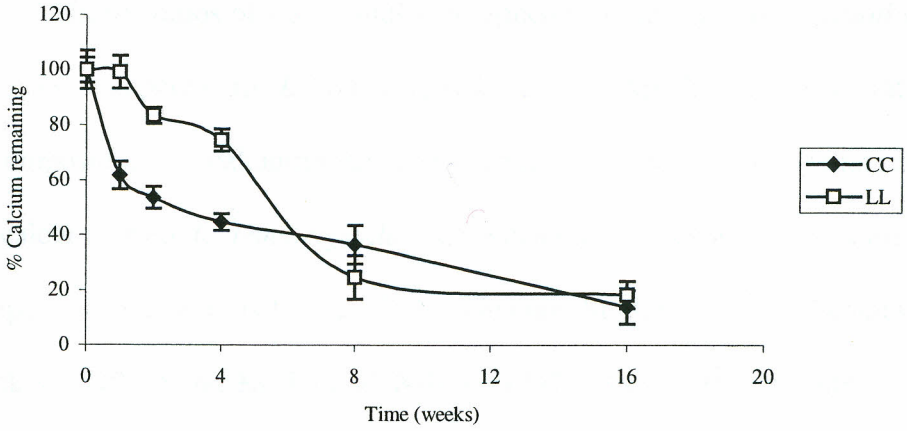

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Figure 13: Calcium release pattern of decomposing *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows during the long rain season in Embu, Kenya.

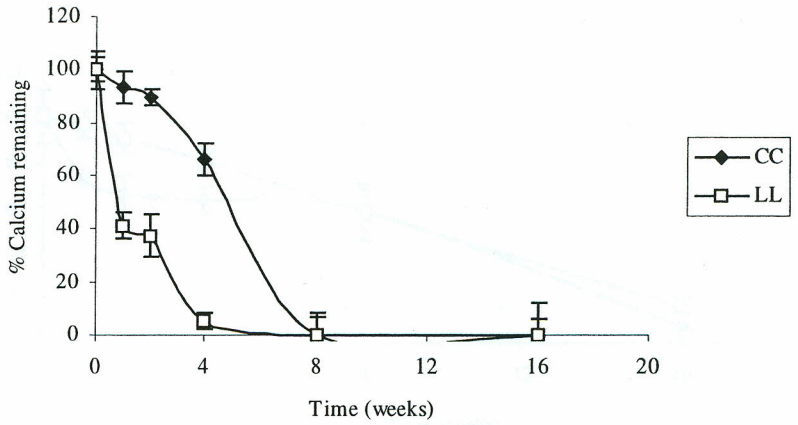

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Figure 14: Calcium release pattern of decomposing *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows during the short rain season in Embu, Kenya.

Higher ratios of lignin and/or polyphenols to nitrogen in *C. calothyrsus* biomass compared to *L. leucocephala* could explain the slow rate of decomposition and calcium release in short rain season. It could be that release of calcium from *L. leucocephala* was enhanced by favorable moisture and temperature but not so for the *C. calothyrsus*. Studies done by Thomas and Asakawa (1993) and Kochy and Wilson (1997) revealed that the attributes of litter decomposition are determined by litter traits and climatic conditions.

Magnesium release from decomposing *C. calothyrsus* was relatively faster than that from *L. leucocephala* for long rain and short rain seasons as depicted in Figures 15 and 16, respectively.

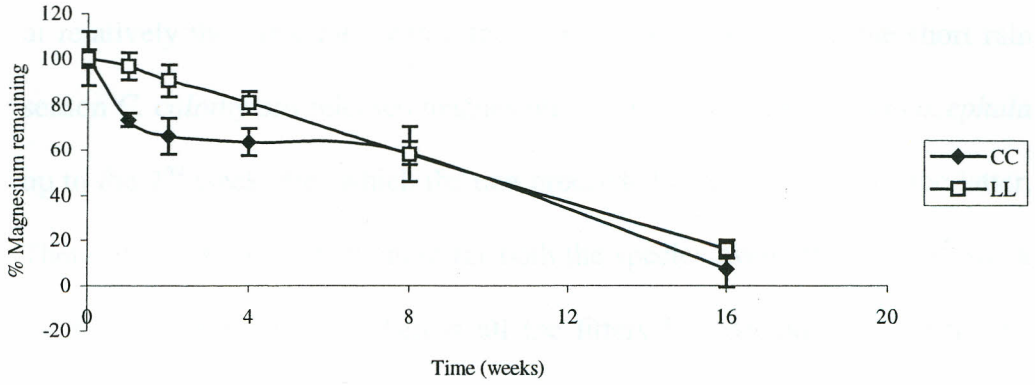

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Figure 15: Magnesium release pattern of decomposing *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows during the long rain season in Embu, Kenya.

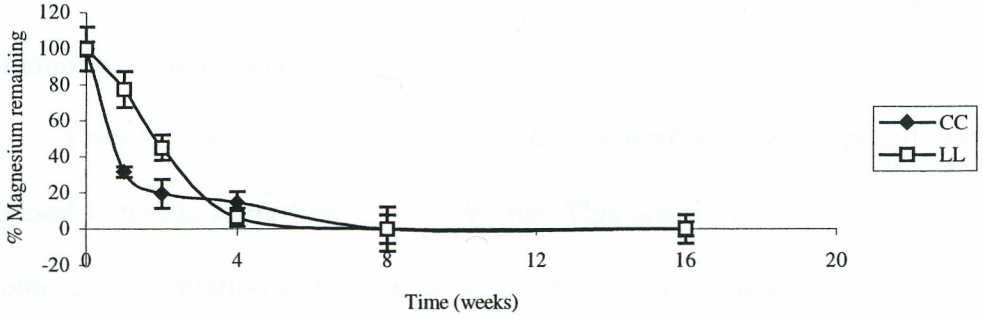

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Figure 16: Magnesium release pattern of decomposing *Calliandra calothyrsus* (CC) and *Leucaena leucocephala* (LL) within hedgerows during the short rain season in Embu, Kenya.

The release of magnesium by *C. calothyrsus* s was faster than that of *L. leucocephala* up to the 8th week after which both species released the nutrient at relatively the same rate within the long rain season. During the short rain season *C. calothyrsus* released magnesium at a faster rate than *L. leucocephala* up to the 2nd week after which the rate proceeded at a faster rate for the latter. There was some litter remaining for both the species even after the 16th week for the long rain season whereas all the litters had decomposed by the 8th week.

Calliandra calothyrsus could have decomposed and released magnesium faster than *L. leucocephala* because of the higher number of macrofauna decomposers which had preference to treatments involving the former species than the latter as was previously depicted in Figure 2. The findings corroborate studies by Upadhyay and Singh (1989), that decomposition could be regulated by variables such as decomposer communities among others.

Overall, the results depicted that *L. leucocephala* decomposed and released nutrients faster than *C. calothyrsus*. This could be due to the varied chemical concentration as previously depicted in Table 12 hence varied nature of resource quality. *Leucaena leucocephala* had higher levels of nitrogen, phosphorus, potassium and calcium but lower levels of magnesium polyphenols and lignin than *C. calothyrsus*. Higher lignin levels in *C. calothyrsus* than in *L. leucocephala* may have slowed the rate of decomposition and nutrient release. The higher concentrations of polyphenols

in *C. calothyrsus* than in *L. leucocephala* could have caused immobilization of nutrients. Lignin and polyphenolics are known to be highly resistant to microbial decomposition (Melillo *et al.*, 1982; Chesson, 1997; Mafongoya *et al.*, 2000; Mafongoya *et al.*, 1998; Handayanto *et al.*, 1997). Therefore, based on these varied nutrients concentrations *L. leucocephala* is of higher quality than *C. calothyrsus. Leucaena leucocephala* could have decomposed and released nutrients faster than *C. calothyrsus* because of their varied lignin and/or polyphenols to nitrogen ratios as previously shown in Table 13. The results also endorsed by Hamada *et al.* (2000) that litter decomposition is affected by lignin content and that the more the lignin content in a plant material the slower the rate of decomposition. Supply of nutrients by an organic input is largely determined by the rate at which such an organic decomposes, and therefore, *L. leucocephala* may be of better quality than *C. calothyrsus.*

Generally, the rates of nutrients release were faster in the short rain season (which received some rains) as opposed to the long rain season (where rains failed). This could have been due to increase in moisture and faunal activity, which promoted the release of nutrients. Decomposition and release of nutrients contained in *L. leucocephala* and *C. calothyrsus* is therefore, determined by their respective quality, the environment and the decomposer organisms present. The findings of this study concur with studies done elsewhere that rates and patterns of litter decomposition can be described as a function of season, climate and the conditions within the soil environment

(Thomas and Asakawa, 1993; Mugendi and Nair, 1997; Kwabiah *et al.,* 1999 and Mafongoya *et al.,* 2000).

4.4 Impact of litter decomposition on maize grains yield

During the long rain season of the year 2000 there was a crop failure due to drought and therefore only the short rain season yields data were used for the study. Yield of the total grains recorded were significantly different ($p < 0.05$) across treatments for the harvest of the short rain season. Higher yields were recorded with *L. leucocephala* than with *C. calothyrsus* treatments as shown in Figure 17. Incorporation of *C. calothyrsus* into the soil (Treatments 1, 5, and 7) resulted in higher yields than Treatment 3, which was without incorporation. Relatively higher yields were achieved with treatment involving litter incorporation of either *L. leucocephala* or *C. calothyrsus* combined with inorganic fertilizer application than with incorporation of litter alone (Treatments 1, 2, 5, and 6) or application inorganic fertilizer (Treatment 9).

The higher yields obtained with *L. leucocephala* than with *C. calothyrsus* treatments may possibly have been due to the faster rate of decomposition and hence faster nutrients release by the former as opposed to the latter or may be because of the higher litter quality of *L. leucocephala* than of *C. calothyrsus.*

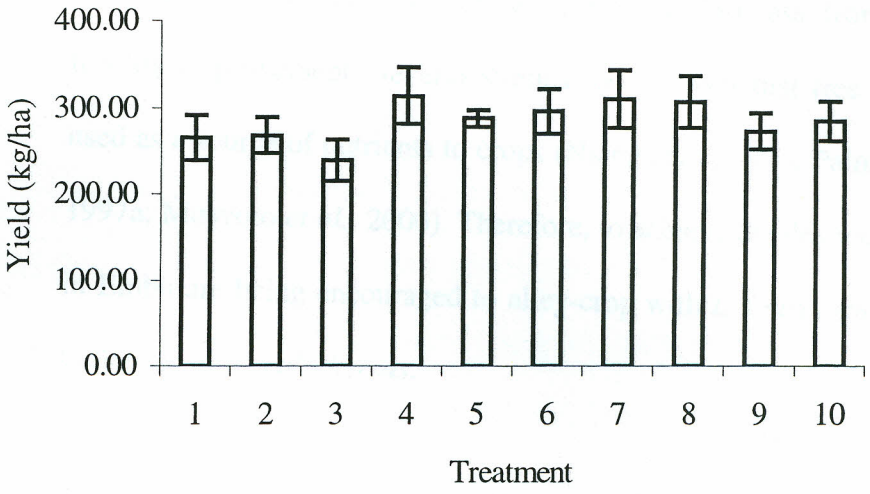

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Figure 17: Maize grains yield within hedgerows during the short rain season in Embu, Kenya.

Higher yields resulting from incorporation of the litter into the soil could have been due to conduciveness of the environment offered to the litter in terms of access to the decomposers hence nutrients release when the crop needed them as opposed to just hedgerows without litter incorporation. Higher yields achieved with treatment involving litter incorporation of either *L. leucocephala* or *C. calothyrsus* combined with inorganic fertilizer application than with incorporation of litter or application of inorganic fertilizer alone may possibly have been due to combination of nutrients released from the decomposing litter and the added inorganic nitrogen. Nitrogen released from the decomposing litter was probably not sufficient to meet the demand of the crop and therefore its addition in inorganic form corrected this imbalance hence higher yield. In Embu, farmers have live fences around their farms and

grow hedges on contours, but rarely use the biomass from these for soil fertility improvement. Several studies have shown that tree residues can be used as a source of nutrients to crops (Niang *et al.,* 1996; Palm, 1996; ICRAF, 1997a; Musvoto *et al.,* 2000). Therefore, to achieve the desired yields, farmers in Embu are being encouraged to alley-crop with *L. leucocephala* as opposed to the use of *C. calothyrsus.*

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

Results from the study depicted that soil invertebrate macrofauna abundance and biomass vary with soil depths and their trend was positively correlated to the levels of soil nitrogen, phosphorus, potassium and compactness but negatively correlated to the pH. The soil macrofauna diversity increased with soil moisture, temperature and availability of abundant and varied organic matter.

The soil invertebrate macrofauna enhanced the rate of decomposition of *C. calothyrsus* and *L. leucocephala* litter. *Leucaena leucocephala* decomposed faster than *C. calothyrsus* and the former had lower lignin and/or polyphenols to nitrogen ratio than the latter. *Leucaena leucocephala* is more suitable for use to improve maize yields in alley cropping compared to *C. calothyrsus*. This is because the former decomposed and released nutrients faster than the latter thereby making it possible for the maize crop to utilize the released nutrients when they were needed resulting to higher yields. Therefore, the rate of litter decomposition and nutrients release is related to tree species and hence resource quality.

Farmers in Embu may therefore be encouraged to use *L. leucocephala* for soil nutrients management as opposed to *C. calothyrsus*. *Calliandra calothyrsus* may be applied at some predetermined time (preferably one week)

before sowing, to make the nutrients released from the same be utilized by the growing crop.

Research is needed to investigate preferences of macrofauna groups and/or species for specific agroecosystems and more so, the preferences of the coleoptera to hedgerow agroecosystem.

Since decomposition process is mediated by the integrated activities of biotic (soil fauna), abiotic and the nature of the resource (resource quality), there is need to investigate this in the most-adopted agroforestry systems.

There is a need to develop ways of managing organic matter decomposition to optimize short-and long-term release of nutrients and the maintenance of soil organic matter thereby replenishing soil fertility.

There is also a need to investigate litter decomposition and faunal trends in an agroforestry setting in arid and semi-arid lands, which forms the highest percentage of the Kenyan land.

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APPENDICES

Appendix 1: Average monthly temperature and total rainfall during the long (march to August, 2000) and the short rain (September, 2000 to February, 2001) seasons in Embu, Kenya.

Date	Temperature °C	Rainfall mm
Mar'2000	24.0	82.5
Apr'2000	20.6	53.0
May'2000	21.4	13.0
Jun'2000	17.2	19.0
Aug, 2000	16.4	13.4
Sept'2000	16.9	34.8
Jul'2000	14.8	46.3
Oct'2000	18.3	0.0
Nov'2000	16.1	176.5
Dec'2000	17.8	22.5
Jan'2001	17.0	122.9
Feb'2001	18.5	19.0
Total	18.3	602.9