DETERMINATION OF FACTORS INFLUENCING THE EFFICIENCY OF LEGUME GREEN MANURES FOR MAIZE PRODUCTION IN EMBU, KENYA

BY:

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DECLARATIONS

Candidate's Declaration

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DEDICATION

To God my Creator and Saviour, for giving me life and hope.

To my beloved wife Jane and to our children Wesley, Angeline, Lily and Doris.

To my deceased parents Josiah Gitari Mng'ondu and Bilia Gicuku Gitari for their upbringing and contribution toward my early education that laid a good foundation for this work.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
AEZ	Agroecological zone
Ca	Calcium
CAN	Calcium ammonium nitrate
CEC	Cation exchange capacity
C:N	Carbon to nitrogen ratio
FURP	Fertilizer use recommendation project
GM	Green manure
GML	Green manure legume
GOK	Government of Kenya
INM	Integrated nutrient management
K	Potassium
KARI	Kenya Agricultural Research Institute
LCC	Legume cover crop
LH I	Lower Highland 1
LM 3	Lower Midland 3
Long rains	Long rains
Mg	Magnesium
Mg ha^{-1}	Megagrams per hectare
N	Nitrogen
NO^{-}_{3}	Nitrate
NH^{+}_{4}	Ammonium
P	Phosphorus
ppm	parts per million

RCBD	Randomized complete block design
SR	Short Rains
SOC	Soil organic carbon
SOM	Soil organic matter
SSA	Sub-Saharan Africa
t_{50}	days taken for 50% of residue to decompose.
UM 1	Upper Midland 1
UM 2	Upper Midland 2
UM 3	Upper Midland 3
UM 4	Upper Midland 4
WAP	Week after planting
WAE	Week after emergence

ABSTRACT

Land productivity in the central highlands of Kenya is mainly constrained by low and declining soil fertility. In the maize-based farming systems, continuous cultivation without adequate soil fertility enhancement measures has led to a deterioration of land quality resulting in low agricultural yields and degraded soils. Herbaceous legumes can provide an alternative to commercial fertilizers and animal manures. This study explored the use of these legumes in Embu District - situated within the central highlands of Kenya. In order to achieve this objective a survey and four field experiments were conducted to: (1) Validate farmers' knowledge and practices in soil fertility and use of plant residues; (2) Determine the performance of maize and green manure herbaceous legumes under different intercropping densities and relay-cropping regimes; (3) Investigate the relative efficiency of different legume residue management techniques and determine the need for mineral nitrogen (N) supplementation and (4) Determine the role of low quality plant residues as agents for slowing down the fast-decomposing legume residues to improve N synchrony for maize growth. The study consisted of one survey and four on-station field experiments. The survey involved a total of 134 small-scale farmers cutting across 5 major agro-ecological zones of the 30 km transect of the district. About 87 per cent of all the farmers in the district were affected by the problems of low soil fertility in their farms. Farmers gave soil colour and structure as some of the visual soil fertility assessment indicators used to determine soil fertility status in their farms but the most pronounced and elaborate local indicators seemed to be the dominance of certain weed flora. Soil pH and exchangeable bases (Ca^{++} and Mg^{++}) were the most sensitive laboratory soil parameters that corroborated farmers' perceptions and knowledge of soil fertility. Results of the field experiments showed that it is feasible to intercrop maize with any of the three green manure legume species, namely, mucuna [*Mucuna pruriens* (L.) DC. Var. utilis (Wright) Bruck], crotalaria [*Crotalaria ochroleuca* G. Don] and lablab [*Lablab purpureus* (L) Sweet cv. Rongai]. Relay-cropping these green manure legumes (GML) beyond the second week after maize emergence had a significant reduction on legume biomass production possibly due to reduced photosynthetically active radiation (PAR) under the maize canopy. Intercropped GML intercepted less than 30 per cent of the total incident radiation. Nonetheless, intercropping of maize and GML greatly improved land productivity giving relative yield total (RYT) values of between 1.0 and 1.5. Incorporation or surface mulching of the GML residues gave similar maize yield responses that was about double that of the control (no residues). Supplementation of the GML residues (raised *in situ*) with mineral N was only beneficial if the quantities incorporated were below 2.0 Mg ha^{-1}. Maize grain yield after mucuna, crotalaria and lablab residues alone (no mineral N supplemented) was 2.5, 2.3 and 1.6 times higher, respectively, than those of the control. Soil N mineralization reached a peak 4 weeks after planting (WAP) and declined thereafter until 8 WAP before picking up again for the remainder of the season. Seasonal mineral N levels ranged between 40 to 128 kg N ha^{-1}. Plots treated with GML residues gave significantly higher total N uptake than the untreated plots. Over the 3 year period, legume residue incorporation resulted in a slight reduction (0.9-1.8%) in soil bulk density, a small increase in the soil total N but no change in the soil pH. Addition of low quality residues (maize stover) to any of the three GML residues did not affect N release but appeared to enhance their performance. Soil mineralization and maize N uptake was not affected by the addition of low quality residues to the GML residues but resulted in a small increase in the total soil N and pH. However, addition of large quantities of these low quality residues (6.0 Mg ha^{-1}) significantly increased the soil organic carbon by 13 per cent and also decreased the soil bulk density by 8.3 per cent when compared to the absolute control with no residues added.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Problem

The economic growth and quality of life in many sub-Saharan countries, like other developing countries, largely depend on the agricultural sector that accounts for more than 25 per cent of the Gross Domestic Product (GDP) (Lynam, *et al*., 1998; Nandwa, 2003). In Kenya, agricultural sector employs 80 per cent of the national labour force and is the most important occupation for majority of the rural population (Central Bank of Kenya, 1998; FAO, 2001). Per capita food production in Kenya, like other sub-Saharan countries, has continued to decline due to the failure to match the food supply demand and land degradation associated with the intensification of land for subsistence farming (Sanchez, 2002; Nandwa, 2003).

Kenya is among the sub-Saharan countries with the highest nutrient depletion in the arable districts with subsistence agricultural activities (Stoorvogel and Smaling, 1990; Vanlauwe, 2004). The central highlands of Kenya region, like other parts of Eastern African highlands, have suffered gross soil nutrient mining due to continuous cropping coupled with low levels of nutrient inputs and poor nutrient conservation practices accentuated by mounting population growth and land scarcity (Smaling, *et al*., 1993; Lynam, *et al.,* 1998). For instance, the central Kenya highlands District of Embu has a population density of about 456 people km^2 (Central Bureau of Statistics, 2001) and farmers own an average of 2.5-3.0 hectares of land per farm family (Ouma *et al*., 2002). According to Kimani *et al.* (2003), nutrient budgets is the 'best first approximation estimate' of agro-ecosystems productivity and sustainability. Studies conducted in Embu District, situated in the central highlands of Kenya, have revealed that nutrient depletion in land use systems which are dominated by food crops production

averages about –126, -14 and –104 kg ha^{-1} of N, P and K, respectively, annually (Gitari *et a.*,, 1999). Further, long-term trials, in central highlands of Kenya, have shown a decline in soil organic carbon from 20 to 12 g kg^{-1} of soil in a period of only eighteen years. The decline has been greatest when no inputs are applied and minimized when a combination of inorganic fertilizer and manure are used (Kapkiyai *et al*., 1998). The end result of this loss in soil productivity has been a continuous decline of maize yields in farmers' fields to less than 2.0 Mg ha^{-1} whilst the maize cultivars grown have a potential of producing 6.0 Mg ha^{-1} (Gitari *et al.*, 1996; Hassan *et al.*, 1998).

The need to produce more stable crops for a growing population and to grow cash crops to integrate in the monetary system has forced many households to replace a once ecologically stable system by more intensive systems that heavily rely upon external inputs (Smaling, *et al*, 1993; Stoorvogel and Smaling, 1990; Van den Bosch, *et al*., 1998). This decline in land productivity has been exacerbated by widespread disappearance of soil fertility restoration practices such as fallowing coupled with inadequate and inappropriate nutrient adding/saving practices (Farsad and Zink, 1993; De Jager,1998; Hudgens, 2000).

1.2 Statement of the Problem

Degraded soils are a major constraint to agricultural production and food security in the central highlands of Kenya. The main constraint to the sustainability of smallholder farming in most farming systems in the said region is the depleted soil organic matter content. Soil organic matter is a major regulator of the various processes underlying the supply of nutrients and creation of a favourable environment for plant growth such as nutrient supply, water availability, soil structure maintenance, nutrient buffering and other miscellaneous roles such as sorption of the soil pollutants to allow for the proliferation of a wide range of useful soil microorganisms. Long term experiments, that provide some insights in the

consequences of land management strategies, point to a decline in crop yields resulting from degraded soils. Thus, in resource poor farming communities typical of Embu District and the rest of central highlands of Kenya region, the use of high biomass producing N_2-fixing leguminous species could offer a low cost opportunity to improve soil conditions for increased crop yields. It is envisaged that a system which maximizes use of natural methods of maintaining soil fertility, has more capacity for stable and sustainable crop yields in the long-term. It is also more ecologically stable with less dependency on high cost inputs.

1.3 Research Questions

The research was guided by the following research questions:

1. How can green manure legume technology be used to address soil fertility decline in Embu District of Kenya?

2. What are the temporal and spatial niches that can be exploited for integration of high biomass producing, N_2-fixing herbaceous legumes in the current maize-based farming systems of Embu District?

3. How will the integration of N_2-fixing herbaceous legumes be beneficial in the improvement of the prevailing low soil productivity?

4. What are the residue management techniques and mineral N supplementation levels that should be employed in order to maximize nutrient release and availability to a growing maize crop while minimizing the operational requirements?

5. What role would high carbon residues play in slowing down the decomposition of these green manure legumes?

1.4 Broad Objective

To develop sustainable methods of improving soil productivity using N_2-fixing, high biomass producing herbaceous legumes for smallholder resource poor farmers of Embu District and other similar areas of the central highlands of Kenya region.

1.5 Specific Objectives

i. To validate farmers' perceptions on the extent of the problem of soil infertility and the use of plant residues to arrest the problem in the study area.

ii. To determine the performance and effect of green manure/cover crop herbaceous legumes intercropped with maize.

iii. To investigate the relative efficiency of different legume residue management techniques and determine the role of mineral N supplementation.

iv. To determine the role that low quality plant residues (maize stover) can play in slowing down the rate of fast-decomposing green manure residue for timely release of N to a growing maize crop.

1.6 Research hypotheses

1. Legume cover crops integrate well with other farm enterprises of the maize-based cropping systems in the central highlands of Kenya.

2. Intercropping green manure herbaceous legumes in maize does not affect the growth of either the cereal or the legume.

3. Better legume residue management techniques lead to better nutrient synchrony with enhanced chances of adoption by the smallholder farmers.

4. Low quality organic residues (maize stover) used in combination with green manure legume residues improve their overall nutrient release synchrony.

1.7 Rationale

Soils in Embu District, like the rest of the central highlands of Kenya, are inherently infertile and are highly leached. Many of the smallholder farmers are low resource endowed giving them a narrow scope for implementing farm interventions based on purchased external inputs. The integration of high biomass producing, N_2-fixing herbaceous legumes is proposed as a useful means of overcoming the current trend in food production decline due to the fast-degrading soil environment in the area. The study explores the development of a farming system that integrates these legume cover crops through intercropping under the existing maize planting patterns. Such leguminous species will provide adequate N for the production of a reasonably high maize yields while building up a good organic matter content of the soil that will offer long-term benefit to the entire soil medium.

1.8 Justification and Significance of the study

At the 1972 United Nations Conference on Human Environment in Stockholm, the Kenyan delegation stated that land degradation was the most severe environmental problem

threatening agricultural production (Stahl, 1993). In the smallholder farms of central Kenya, small land size due to population pressure has compromised the ability to generate adequate animal manures that are necessary for enhancement of soil organic resources. Another possible source of on-farm organic resources could be the use of plant residues that are able to contribute nutrients for the immediate and consecutive crop growth. Previous research has demonstrated that legume residues have important parameters that optimise short- and long-term release of nutrients and maintain the soil organic matter. Integaration of herbaceous legumes in the farming systems of the central highlands of Kenya will improve (through incorporation into the soil) the soil physical and chemical characteristics including the organic carbon, cation exchange capacity, bulk density, soil structure and water infiltration. In addition, these legumes will offer a more effective vegetation ground cover thereby decreasing soil erosion hazards particularly in steep gradient farms that are predominant in the study area to further minimize environmental degradation. Apart from maize-legume intercrops, there may be other possible niches where these legumes could find a place in the existing farming systems. Furthermore, these legumes may in future be used to reclaim degraded portions of land that have been abandoned due to nutrient exhaustion thus increasing the area available for regular food cultivation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Environmental degradation and sustainable soil resource management

Many agricultural development policies are usually directed at developing a single resource, that is, soil or land but may have a negative impact on the other environmental resources like soil or water. Thus, there are instances where agricultural development and environmental enhancement objectives usually conflict (Nyaoro, 1996). Soil degradation has been defined as the reduction in the soil fertility or loss of the productivity capacity of the soil to sustain life (Smith, 1994; Brady, 1999). This may result from any of the processes responsible for the chemical degradation that includes salinization, loss of organic matter and soil structure as well as water logging (Doran and Parkin, 1994; Doran, 2002). According to Sanchez (2000), some of the nutrients that soils supply to plants come from the dissolution of primary or weatherable minerals. These nutrients include phosphorus, potassium, calcium, magnesium and micro-nutrients.

About 30% of tropical soils have low (less than 10%) reserves of weatherable minerals that are nutrient capital reserves. The only other source of nutrients capital reserves is soil organic matter (SOM) that contains all the nitrogen and much of phosphorus and sulphur capitals of soils (Smith, 1994; Barrios, *et al*., 1996). The main determinants of soil organic matter content are soil temperature, moisture and clay content. Clayey soils are cooler than sandy soils and have smaller pores where organic matter is better protected from decomposition. Soil organic carbon constitutes the largest stocks of carbon principal greenhouse gases, carbon dioxide, methane and nitrous oxides (Brady, 1999; Vanlauwe, 2004). It is a major source-sink in global carbon budgets and is a major component of the terrestrial sink necessary to balance CO_2 budgets (Lugo, 1992; Lal, *et al*., 1995).

Erosion of soils is another factor that is important in environmental degradation. It is rated as the third most extensive soil constraint in plant production in the tropics after low nutrient reserves and soil moisture stress (Sanchez, 2000). The key to soil erosion control is to keep the land covered with a plant canopy throughout the year (Gachene *et al*., 1997; Sanchez, 2000). Because of lack of appropriate approaches to evaluate soil degradation, the land-use planners in most countries have adopted recommendations that are derived from site-specific experiments or based on modelling approaches that are not fitted to the local conditions (Lal *et al*., 2000; Okoba, 2005).

The central highlands of Kenya region have a topography that is gently to steeply rolling with a medium to high soil erosion hazard (Jaetzold *et al*., 2006; Gachene *et al*., 1997). Erosion control experiments conducted on-station at KARI - Embu Regional Research Center by O`Neil *et al.* (1997) have established that huge amounts of soil in excess of 100 Mg ha^{-1} is lost annually. In Kianjuki catchment, situated in Upper Midland 2 agro-ecological zone of Embu District, Angima *et al.* (2003) found that the total annual soil loss varied from 134-549 Mg ha^{-1} yr^{-1} for slopes ranging between 10-53%. Gachene *et al*. (1996) reported that a two-year erosion period, for a humic Nitisol at Kabete, Kenya was enough to cause a 64% loss in maize grain yield in the most eroded plot when compared to the least eroded plot. Relative to the least eroded plot, there was therefore a decline in maize grain yield of 214 kg ha^{-1} cm^{-1} of the topsoil lost. The corresponding decline in almost all chemical properties (C, N, and available P) between the least eroded and most eroded plot were highly significant too.

Soil quality has a bearing on other environmental issues such as Lake fauna. Kinyali *et al*. (1996) investigated the impact of soil quality on the fauna of Lake Baringo in the Rift Valley province of Kenya. The study was conducted in Lorut/Sibilo watersheds that form the water catchment of Lake Baringo. The soils at the catchment are primarily Flurisols and

Cambisols while the vegetation cover comprises of grassland and shrub bushes. Annual rainfall for the area averages 630 mm per annum. The study established that infiltration rate of each of the two soils was a function of soil type, vegetation cover, land use and environmental properties. Intake rates were highest under tree/bush, followed by cultivated soils, intermediate on open grass and lowest on bare ground. The soil physical factors that influenced infiltration included bulk density and organic carbon. Low infiltration rate at the Loruk site (where soils had lower organic carbon and higher bulk density) was listed as the main cause of siltation at Lake Baringo which adversely affected the population of fish in the lake.

2.2 Environmental concerns in nitrogen leaching

In the central highlands of Kenya region, the principal method through which N is lost from the top-soil is by leaching of the nitrate-N which is the main form of mineral-N found in these soils. Both denitrification and volatilization are not prominent because the soils in this region are well aerated and have a pH of about 5.5 (Myers *et al*., 1994: Mugendi *et al*., 1999b.). Thus, most N losses occur in farming situations when the element is held in form of NH^{+}_{4} or NO_{3}^{-} which are the principal forms of N supply to the soil and uptake by plants as inorganic fertilizers.

Giller *et al*. (1997) have stated that nitrate-N moves slowly down the soil profile during the rainy seasons but leaching to below 120-cm depth in a bare fallow with approximately 1000 mm of rainfall was substantial only at the end of the rainy season, where there was water available for the mineralized NO^{-}_{3}-N to diffuse into the effective channels. In the cropping situations typical of the central highlands of Kenya, Mugendi *et al*. (2000) have noted that NO^{-}_{3}-N leaching increases as the rainfall increases. The loss is more pronounced early in the season (before the crop develops extensive root system) and progresses (in a wet season) to accumulate in the deeper soil horizons. Hogervost (1999) investigated N leaching

in three test farms selected in the Upper Highland 1 (UH 1) and Upper Midland 1 (UM 1) agro-ecological zones in Embu District, Kenya. The study was conducted using "Tensionic" ceramic cups to determine solute concentrations from the soil. The profile moisture contents were monitored using a Neutron probe at 30, 60, and 90 cm depth, twice a week. In both UH 1 and UM 1 the tensionics showed a steep rise in NO_3^- loss after the first shower followed by a steep decrease of the lost NO_3^-concentration. Calculations of the leaching values revealed that 33.9 and 51.7 kg ha^{-1} NO_3^- was leached over cropping seasons with 737 and 563 mm of rainfall, respectively, which fell during the long rains of 1999 at the UH 1 and UM 1 farms. Huge amounts of NO_3^- leached from the crop root zone in the range of 30-500 kg N yr^{-1} have been reported in the low and high input agricultural systems of the tropics (Gemma *et al*., 2000; Mugendi, *et al.,* 2000).

These huge NO_3^- leached from agricultural fields may pose an environmental problem due to increased nitrogen concentrations found in the drinking water at the regional scale (Myers *et al*., 1994; Gemma *et al*., 2000). One way of preventing this excess leaching is through the use of legume residues as a source of N in cropping lands. Mugendi *et al*. (2003) investigated the levels of NO_3^- movement under different types of N sources and found that plots with mineral N fertilizer recorded higher levels of NO_3^- in the 100-to-300 cm depth averaging 15 to 30 mg N/kg compared to 1 to 3 mg N recorded in the same depth of treatments with *Leucaena leucocephala* and *Calliandra calothyrsus* tree prunnings.

2.3 Indigenous knowledge in soil quality and soil fertility indicators

The conventional scientific theory on soil classification and soil quality determination originated in developed countries of the northern hemisphere. This temperate environment is very different from the warm tropics that are characterized by soil erosion and general land degradation (Bocco, 1991; Greenland and Szabolcs, 1994). Smallholder farmers in certain

rural areas of the world's poorer nations possess assets in the form of empirical knowledge of the individual knowledge of their ecosystems and changes that occur therein. They act as invaluable source of information that could be used to assess, monitor and evaluate changes that occur in land resources (Brokensha, *et al*.; 1980; Pieri *et al*., 1995). The indigenous knowledge systems, relative to modern science, are bodies of knowledge that develop as certain cultural or ethnic group strives to meet subsistence goals in a particular ecological setting (Pawluk *et al*., 1992).

Zimmerer (1994) examined the relationship between local soil knowledge and science and concluded that the local knowledge is relatively accurate and an inexpensive means of monitoring soil conditions in a given environment. The local inhabitants are able to identify plant life and relate the vegetation with the rest of the ecosystem where they grow and also to give detailed information of soil types and properties in the specific environment where they live (Brokensha *et al*., 1980; Steiner, 1998). Within natural vegetation, some plant species are adapted to high soil fertility (Marschnev, 1995) while others are adapted to exhausted soils with mineral deficiencies (Greenland and Szabolcs, 1994). In Kenya, smallholder farmers have used indicator weed species to denote productive and non-productive farm fields and this has corroborated well with scientific laboratory soil analysis (Barrios *et al*., 2000; Murage *et al*., 2000; Mairura, 2005).

2.4 Cereal-legume intercrops

2.4.1 Cereal-legume intercrop systems contribution to the soil N

Intercropping is defined as the growing of two or more crop species simultaneously in the same field during a growing season. This farming practice is common among the smallholder farmers in warmer climates of the world (Ofori and Stern, 1987) who have been intercropping cereals such as maize and sorghum with grain legumes like beans, cowpeas,

pigeonpeas, and green grams (Mandal *et al*., 1990). The practice is common in traditional rain-fed agricultural systems of Asia and Africa because it provides substantial yield advantage over sole cropping (Fujita and Ofosu-Budu, 1996) in addition to greater yield stability and risk evasion against natural disasters in areas subject to frost, floods or drought (Willey *et al.*, 1986).

Cereal-legume intercroppings are common systems in the highlands of eastern and southern Africa but most of the intercrops are those involving the food legumes (Peoples *et al*., 1992). Although some of the food legumes could be N_2 fixers, the levels of fixation are too low to contribute to soil N reseserves (Giller *et al.,* 1997). Thus, the potential benefits of legume inclusion are only realized if the resultant residues are returned to the soil thereby providing considerable amount of N to the soil for the benefit of the subsequent crop (Giller and Wilson, 2001). The amount of N fixed by the legume component in cereal-legume intercropping systems depends on several factors, including species, plant morphology, density of component crops, type of management as well as the competitive abilities of the component crops (Fujita *et al*., 1996; Willey, 1996). The methods that may be used to assess biological nitrogen fixation (BNF) include N^{15}-isotrope techniques, N-difference methods, ureide method, N balance acetylene reduction assay, N fertilizer equivalence as well as nodule evaluation (Fujita *et al*., 1992).

2.4.2 Competition in cereal-legume intercrops

When two or more crops are grown simultaneously in a field, they may experience *inter-crop* competition apart from *intra-crop* competition that exist in a sole crop (Willey, 1986; Fujita et al., 1996). The combined effects of these two competitive trends normally determine the efficiency of the intercrop. Factors that minimize these competitive tendencies for growth limiting factors; namely, water, nutrients and light will increase the efficiency of

the intercrop. As a general rule, the crop with relatively higher growth rate, height advantage, and a more extensive root system is favoured in the intercrop (Willey, 1986). Fukai and Trembath (1993), state that competition is greatly minimized when crops chosen to form the intercrop have different growth rates and growth habits so as to exploit different growth niches of the intercrop habitat. In addition, competition is greatly minimized by manipulating the planting densities and spatial arrangements of the component crops or by differential sowing of the crops in the intercrop (Willey, 1986; Ofori and Stern, 1987). For instance, Mureithi *et al.* (1996) observed yield depression in maize planted at the same time with cowpea but achieved a reversal of effects when the legume was planted four weeks after maize.

2.4.3 Solar radiation interception considerations in cereal-legume intercrop system

Solar radiation is important in photosynthetic processes of green plants. When nutrients and water supplies are not limiting for growth, the quantity of biomass produced is limited primarily by the quantity of solar radiation intercepted (Sinoquet and Caldwell, 1995). Intercepted radiation is normally estimated as the difference between the quantity of radiation incident upon the canopy surface and that transmitted to the soil surface (Squire, 1992). The quantity of radiation intercepted by plant canopies varies depending on their shape, leaf area and distribution, solar position and the proportion received as direct or diffuse radiation (Campbell and Van Evert, 1994). Plant architecture and overall height influence canopy structure, thereby affecting the efficiency of solar radiation intercepted and the subsequent dry matter production (Zaffaroni *et al*., 1989; Edmendes and Lafitte, 1993). According to Nobel *et al*. (1993), fractional photosynthetically active radiation (PAR) intercepted (f) for most canopies in moist conditions may be related to the leaf area index (L) by the formula:

$$f = 1 - e^{-kL}$$

Where, k is an extinction coefficient that is a dimensionless parameter and represents the fractional PAR intercepted by unit leaf area. Rearranging equation above, k can be determined as the slope of linear regression,

$$k = \ln(1- f) /L$$

Thus, *k* increases with increasing solar radiation intercepted by a given leaf area. This extinction coefficient (*k*) ranges around 0.4 for grasses and 1.3 for most broadleaved plants such as soybean and potatoes. Canopies with most leaves in the horizontal plane are termed planophile while canopies in which leaves are close to the vertical are termed erectophile (Squire, 1992). In all types of plant canopies, optimum incident PAR utilization for photosynthesis generally occurs when incident solar radiation is distributed as uniformly as possible over the exposed leaves and unequal access to light due to space occupation can have serious consequences for the shaded plants (Nobel *et al*., 1993; Edmendes and Lafitte, 1993).

2.5 A case for Green Manure Legumes (GML)

Herbaceous legumes are more widely used the world over as cover crops and green manures. The legumes offer a low cost opportunity for maintaining soil fertility by contributing N during decomposition (Ibewiro *et al*., 2000b; Tian *et al*., 2000; Baijukya *et al*., 2005; Nyambati *et al*., 2006), improve soil organic matter and soil physical properties (Mureithi et al., 2005; Cheer *et al*., 2006), conserve soil erosion (Gachene and Haru, 1997) and suppress weeds (Versteeg *et al*., 1998; Akobundu *et al*., 2000).

Screening herbaceous legumes for soil improvement in various parts of eastern Africa including Uganda (Fischler and Wortman, 1999), Tanzania (Baijukya, 2004), semi-arid eastern Kenya (Gachene and Makau, 2000) and coastal lowlands of Kenya (Saha *et al*., 2000) has been concluded. Ojiem (2006) has recently screened a range of green manure legumes in

different agro-climatic zones and under different soil fertility conditions of western Kenya and found that the total dry matter production and atmospheric N_2-fixation increased with rainfall and soil fertility status. In the central highlands of Kenya, Gitari *et al*. (2000) screened 25 different legume species for soil fertility improvement and found that mucuna [*Mucuna pruriens* (L.) DC. Var. utilis (Wright) Bruck], crotalaria [*Crotalaria ochroleuca* G. Don] and lablab [*Lablab purpureus* (L) Sweet cv. Rongai] were the most promising green manure species. The legumes were found to establish easily, nodulate profusely (in presence or absence of external rhizobia) and were resistant to insect and disease pests. In farmers' fields, phosphorus was not found to be a limiting factor in their growth and establishment (Gitari and Mureithi, 2004). A legume screening database and instructional manual has already been developed for use in Kenya (Mureithi and Gitahi, 2004).

Integration of green manure legumes (GML) into maize-based production system may be through rotational, intercropping or relay-cropping (Eilitta *et al*., 2004) but a relay maize-GML production system would be attractive to farmers in areas where the land is under continuous cultivation for household food supply (Mureithi *et al*., 2003). For effective relay in a maize-GML production system, competition for growth limiting resources should be minimal so as to produce high legume biomass without reducing maize yield (Mburu *et al*., 2003).

Decomposing residues of these legumes have been shown to increase grain yields of subsequent maize crop in Central America (Buckles, 1998; Eilittä *et al*., 2004), West Africa (Carsky *et al*., 1999: Ibewiro *et al*., 2000a), Uganda (Fischler and Wortmann, 1999; Wortmann *et al*., 2000), Tanzania (Baijukya, 2004) and Kenya (Mucheru, 2003; Mureithi *et al*., 2005). Apart from the provision of N for a growing maize crop, mucuna legume residues of 10 Mg ha^{-1} have been found to provide 300, 1140, 100 and 15-20 kg ha^{-1} of N, Ca, K and P, respectively, in Northern Honduras (Buckles *et al.*, 1998).

2.6 Organic residues decomposition: Synchrony versus asynchrony scenarios

Organic residues have an ability to improve soil fertility both in the short-term through direct nutrient provision and in the long-term through addition of soil organic matter. Decomposition is the natural process through which soil fertility enhancing factors are unlocked from these plant residues. The rate of of organic residues decomposition is governed by several factors that include their chemical composition (Palm and Sanchez, 1991: Giller *et al*., 1997), edaphic factors (Mugendi *et al*., 1997) as well as the type of residue management employed (Nandwa, 1995; Kumar and Goh, 2000). Initial N contents of residues determine the rate of their decomposition. A high N content of residues reduce the competition of available N by microorganims and consequently enhance the decomposition by maintaining a high microbial activity (Aber and Mellilo, 1982; Vigil *et al*., 1991). On the other hand, lignin is known to be a recalcitrant substance highly resistant to microbial decomposition (Mellilo *et al*., 1982), and few microorganisms can degrade lignin. High lignin content prohibits high microbial activity thereby reducing the rate of residue decomposition (Tian *et al*., 1992; Palm and Rowland, 1997). Polyphenols resist microbial breakdown by binding to organically bound N compounds (Palm and Sanchez, 1991; Vigil *et al*., 1991). Further, they are known to possess disinfectant and bactericide activities that lower the activities of micoorganisms by intertwining with the cell wall thus physically protecting cellulose and other cell contents from degradation (Cheson, 1997). Some researchers argue that it is the polyphenol-to-N and (lignin + polyphenol)-to-N ratios that are better correlated with residue decomposition and nutrient release rather than individual components (Tian *et al*., 1995; Palm and Rowland, 1997).

Palm and Sanchez (1991) studied the N release patterns of 10 tropical legumes including *leucaena* and *gliricidia.* The legume residues were incubated for 8 weeks into a soil that had a loamy sand texture. The results indicated that polyphenol and the polyphenol-to-N

ratio played a more important role of influencing mineralization patterns for leguminous leaves than either N or lignin contents of the leaves. These findings were supported by Oglesby and Fowness (1992) who measured N mineralization of 7 tropical legume species incubated in a clay soil and concluded that in the earlier stages of mineralization (weeks 1 through 8) cumulative N mineralization was negatively correlated with polyphenol content and the polyphenol-to N ratio. The lignin content and the lignin-to-N ratio were a more important determinant of N mineralization in the latter stages of mineralization (weeks 4 through 12). The findings of Palm and Sanchez (1991) and Oglesby and Fowness (1992) did not agree with those of Mugendi and Nair (1997) who studied the rate of N release from calliandra leaf prunings together with other non-legume materials in four constrasting environments of Kenyan tropical highlands. The prunings were buried into the soil of the respective environment at a depth of 15 cm and recovered at periods of between 2 and 20 weeks. They concluded that lignin has a more significant positive correlation with the rate of decomposition than the polyphenols. Their study also established that lignin-to-N and (lignin + polyphenol)-to-N ratios were also significantly correlated with the decomposition of the tree biomass. Palm *et al.* (1997) have given the critical values of nitrogen, lignin and polyphenol concentrations which will result in transition from net immobilization to net mineralization as 18-22, >150 and 30-40 g kg^{-1} for nitrogen, lignin and polyphenol, respectively. Immobilization resulting from polyphenols, particularly, tannins may be much longer than the temporary immobilization resulting from high C-to-N ratios in cereal crop residues (Giller *et al*., 1997). Researchers now recognize two phases of residue decomposition. Phase I is relatively rapid and is dependent on initial residue N content while phase II of residue decomposition is slow and is normally regulated by lignin and polyphenol concentrations (Douglas *et al*., 1992; Jama and Nair, 1996).

The term “synchrony” refers to the release of a nutrient into plant available form when it is needed by the growing plant. It refers to nutrients that are organically bound such as N, P and S. On the other hand, the term “cycling” includes the processes of conversion of these nutrients from organically bound and available form of N, P or S into available forms that are $N0_3^-$ and NH_4^+ for N, $P0_4$ for P and $S0_4$ for S (Nandwa, 1995; Palm and Rowland, 1997). Swift (1989) described various scenarios that are responsible of asynchrony in the decomposition and mineralization of N in organic residues. In the first case of asynchrony, concerning high quality litter, observed high rate and possibly amount of nutrient released due to rapid litter decay, is in advance or excess of crop uptake demand. Such excess nutrients released ahead of uptake demand are more prone to loss by leaching. The second scenario for the asynchronous release of nutrients is exhibited by low quality litter. This type of asynchrony results from slow litter decomposition, attributed probably to high phenols, lignin and carbon content or low N content, causing nutrient release later than crop demand.

2.7 Legume residue as a source of N for maize growth

Most tropical soils, including sub-Saharan Africa, are formed of Kaolinitic clay minerals that are highly leached and have inherently poor capacity to supply growing plants with nutrients (Brady, 1990; Nandwa, 2003). In African farming situations, the use of mineral fertilizers alone cannot sustain crop yields and maintain soil fertility in the long-term because of the high depletion of organic matter (Smith, 1994; Smaling *et al*., 1997). The most promising method of improving crop yields in smallholders of eastern and southern Africa is by increasing inorganic fertilizers use efficiency through the addition of small amounts of high quality organic materials especially legumes (Jones *et al.*, 1997; Phiri *et al.,* 1997). High quality legume leaf materials with low C-to-N ratio and low lignin contents may be used to

enhance crop performance through direct nutrition contributions (Giller and Cadish, 1995; Palm *et al.*, 1997).

Studies conducted by several researchers in different parts of the world including eastern and southern Africa indicate that legume leaf prunings can be used as a source of N to a growing maize crop. Mugendi *et al*. (1999a) investigated the use of agroforestry leafy prunings, *Calliandra calothyrsus* and *Leucaena leucocephala*, as a source of N to support the growth and development of a maize crop in the subhumid central highlands of Kenya and found that the application of *ex situ* calliandra or leucaena prunings with or without fertilizer resulted in higher maize grain yield compared to the non-fertilized and fertilized treatments. Nitrogen uptake by maize reached its peak in the 4-7 weeks after planting and the uptake was highest in the treatments that received prunings and lowest where prunings were removed. Studies with ^{15}N, in this work, indicated that soil application of N-rich biomass contributed more to the long-term build up of soil N than to meeting the requirements of the current season's crop: the largest fraction of N (55% to 69%) in the tree biomass that was added to the soil was left in the soil N pool at the end of the current season, 8% to 13% was recovered in the maize, and 2% to 3% in the tree hedges; 20%to 30% could not be accounted for. In Kawanda Agricultural Research Station in southern Uganda, Fischler *et al*. (1997) obtained maize grain yield increase of 39% in the first season of using crotalaria residues as a source of N for maize. Nitrogen uptake in grain and stover ranged between 26% and 44%. Similarly, Kaizzi *et al*. (2004), also working in eastern Uganda, observed that decomposing mucuna residues contributed 80-200 kg N ha^{-1} out of which 43-57% was derived from biological N-fixation.

Gilbert (1997) has given the critical biomass of green manure necessary to effect some increase in maize grain yield as 2.0 Mg ha^{-1} under the edaphic and environmental conditions that exist in Malawi. This has further been confirmed by Baijukya (2004) who,

working in the Bukoba District of Tanzania, applied residues of different leguminous materials including tephrosia, crotalaria, mucuna and macrotyloma and recorded significant maize yield gains above the unamended control. He concluded that any addition of these residues in excess of 2.0 Mg ha^{-1} was not beneficial to the maize crop. In northern Honduras, the use of mucuna legume residues has been found to provide and sustain N requirements for the production of 2.0-4.0 Mg ha^{-1} maize yields. Addition of mineral N fertilizer to these mucuna - maize cropping systems (known as Abonera system) is therefore regarded as unnecessary and wasteful (Buckles, 1998).

2.8 Residue placement as a factor that determines the synchronous release of N from decomposing residues to support maize growth

The method of application of plant residues is important since it affects the residue breakdown rates as well as the mineralization-immobilization processes (Douglas *et al*., 1992; Kumar and Goh, 2000). Unfortunately, there is no general consensus among different researchers on the most appropriate and effective mode of application of these high quality residues. Some studies indicate that burying of residues in the soil is more effective since it increases the decomposition rate and hence nutrient release. For instance, Gachene *et al.* (1999) found that the yield of maize grown after incorporating mucuna, vicia or crotalaria legume residues was 88%, 61% and 107%, respectively higher than the control treatment whilst surface mulched treatments gave 65%, 44% and 31%, respectively, higher than the control. Likewise, Mureithi *et al*. (2005) investigated the most appropriate management practice for the application of similar legume residues and found that incorporation of the residues gave higher maize yields than surface mulching. The authors attributed their results to increased N supply to the soil by legume biomass through reduced N loss by volatilisation of ammonia from the decomposing legume biomass. In contrast, Jones *et al*. (1997) found that surface application of gliricidia or leucaena leaf prunings produced a positive effect on

maize grain yield when compared to incorporation of the residues. The authors attributed the higher yields to better synchrony of nutrient release with maize demand that was better achieved in the surface application where residues were not in intimate contact with the soil. These results are in agreement with those of Fischler *et al*. (1999), who worked in eastern Uganda and demonstrated the superiority of applying crotalaria biomass as a surface mulch rather than incorporation. Their results indicated that maize grain yield was highest (4.81 Mg ha^{-1}) when crotalaria was applied as surface mulch as compared to the incorporation treatment (4.25 Mg ha^{-1}). Nitrogen uptake in grain and stover was higher (113 kg ha^{-1}) in the surface mulched treatment compared to 93 kg ha^{-1} in the incorporated treatment. Likewise, nitrogen recovery was 39% and 32% in the mulched and incorporated treatments, respectively. The authors concluded that using mature crotalaria legume residue as surface mulch has an advantage over incorporation because there is a better synchrony between the nutrient release from the decomposing mulch and nutrient uptake by maize. Working under glasshouse conditions, Cobo *et al.* (2002), obtained higher N uptake by maize from surface applied compared to incorporated mucuna residues. In the wetter windward side of the northern Tanzanian District of Bukoba, Baijukya (2004) obtained similar maize grain yields in both mulched and incorporated mucuna residue plots and attributed his results to similar decomposition and nutrient availability of mucuna residues for the nourishment of the growing maize crop.

2.9 Use of low quality residues in maize cultivation

Organic inputs can influence nutrient availability by adding nutrients, controlling net mineralization-immobilization patterns by acting as a source of carbon and energy to drive microbial activities (Palm *et al*., 1997). Most organic materials that are added to the soil are either low quality cereal residues or high quality legume materials. Giller and Cadish (1995)

state that crop recovery of N supplied by high-quality leguminous green manures is rarely more than 20% while that recovered by lower quality cereal stovers is generally much lower.

Research has been conducted in East Africa by different workers to investigate the role of maize stover in provision of N to a growing maize crop. Studies in Morogoro, Tanzania by Ishuza (1987), to investigate the effect of stover application rate on the availability of soil and fertilizer N and P have indicated that the contents of available N, extractable P, and also N and P concentration in maize plants decreased consistently with increasing rates of stover applications (0, 2.5, 5.0 and 7.5 Mg ha^{-1}). For example, from the field experiment, incorporation of 2.5 and 5.0 Mg ha^{-1} of stover resulted in decreases of 32% and 60%, respectively, of available N in the soil when the soils were sampled at 8 weeks after planting maize. Maize dry matter (glasshouse experiment) and grain yield (field experiment) also decreased considerably with increasing rate of stover application. Similar work in the same area by Msumali (1992) showed that soil available nutrients and maize grain yield also decreased consistently, with increased rate of stover application (0, 2.5, 5.0 Mg ha^{-1}) for soil available nutrients and 0, 5.0 and 7.5 Mg ha^{-1} of stover application for maize grain yield. For example, with the application of 5.0 and 2.5 Mg ha^{-1} stover, available N and P in the soil decreased by 28.6 % and 42.9 % for 5.0 Mg ha^{-1} and by 7.9% and 18.4 % when 2.5 Mg ha^{-1} of stover was applied. Application of 2.0 and 5.0 Mg ha^{-1} of stover resulted in 20.0% and 34.2% decrease in maize yields. The author attributed the decrease in maize yields to the decrease in synchrony exacerbated by increased rate of application of stover.

In Kenya (Kabete and Katumani), Nandwa (1995) studied the effects of different methods of stover placement on maize yields and the physical and chemical properties of soil. His results indicated that incorporating stover (4.0 Mg ha^{-1}) suppressed maize grain yields by 39%. Stover application, however, improved the soil physical conditions (bulk density) resulting in better soil moisture status and soil structure for root penetration. For

instance, infiltration measurements taken at the end of the second crop cycle at the Machakos (Katumani) were 0.6, 0.9, 1.5 and 2.4 cm min^{-1} for control, surface mulch, mixed placement and stover incorporation treatments, respectively. Deep incorporation of maize stover resulted in a faster decomposition (3 times) than surface mulch at Kabete and Katumani, in all four seasons of experimentation. This asynchronous release of nutrients by maize stover could be overcome by using plant residues which have been selected to match the nutrient demand pattern of a specified crop based on their decomposition and nutrient release pattern. This might be achieved by using specific plant materials or mixtures of high and low quality materials which may release nutrients slowly at first, when the crop demand is low, and provide an increasing rate of release with time, as the crop grows and demand more (Bunyasi, 1997; Mugendi *et al.*, 1999b).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 AREA OF STUDY AND FARMING SYSTEMS

The study was carried out in Embu District of Kenya. The survey was carried out by taking a transect drive across all the five agro-ecological zones of the district covering Kathanjuri and Runyenjes divisions while the field trials were conducted at the Embu Agricultural Staff Training (EAST) College. The college (neighbouring KARI – Embu) lies 3 km north of Embu town. It is located on latitude 0^0 30'S and longitude 37^0 27'E at an elevation of 1480 m above sea level. The average annual rainfall is 1252 mm and is received in two distinct rainy seasons; the long rains (mid March to September) with an average rainfall of 650 mm and the short rains (mid October to February) with an average of 450 mm. The area has a mean annual temperature of 19.5^0C, a mean maximum of 25^0C, and a mean minimum of 14.1^0C. The mean annual potential evaporation is 1422 mm while mean annual evapotranspiration is 950 mm. The site of the field experiments lies in the transition of UM 2 and UM 3 agro-ecological zones which means that mean annual precipitation covers 65-80% of the potential evaporation. The soils are mainly Typic Palehumult (humic Nitisols according to FAO-UNESCO) derived from basic volcanic rocks. They are deep, highly weathered with friable clay texture and moderate to high inherent fertility.

Embu District is located in the central highlands of Kenya and is found within the administrative districts of Eastern province. It lies on the southeastern slopes of Mount Kenya that is the most prominent physical feature found in the region. The altitudinal gradient of the district ranges from 1000 to 1800 m above sea level. According to Jaetzold *et al*., 2006) rainfall is bimodal and averages between 1000 and 1600 mm per year. The main soil types are the humic Andosols in the tea land use zones found in Upper Highland (UH) 1 and Upper

Midland (UM) 1 agro-ecological zones. Nitisols and Ando-humic Nitisols are more prominent in the tea-coffee, main coffee as well as marginal coffee land use systems located in UM 2 and UM 3 as well as UM 4 agro-ecological zones. The soil profiles are dark reddish-brown to brown friable and smeary clay loam with humic topsoil.

The main cash enterprises of the Upper Midland zones include tea, coffee and dairy whereas maize, beans and bananas form the main food crops. In the lower midlands, cotton and tobacco form the main cash crops while maize, beans, cowpeas, sorghum and sweet potatoes are the main food crops (Micheni *et al.*, 1999). Maize is the most common cereal/food crop and it is planted either as a sole crop or as an intercrop with beans. Majority of the farm families derive most of their farm earnings (70 per cent) from the sale of crop products while livestock related earnings account for the remainder 30 per cent (Gitari *et al.*, 1999). According to Murithi (1998) farms are generally small, ranging from 0.5 to 4.0 ha with a mean of 1.5 ha per farm family. The region has a high population density that ranges from 230-730 persons per km^2 with an average of 450 persons per km^2. A Participatory Rural Appraisals (PRA) study conducted in 1999 in the maize-based land use systems of the district found that the main farming constraints (as perceived by the farmers themselves) include soil erosion, low soil fertility and expensive farm inputs. The farmers listed some of the possible solutions for the declining soil fertility as composting, increased legume/cereal intercrops, improved fallows and planting of crops which are able to tolerate low soil fertility (Munyi *et al.*, 1995; Micheni *et al.*, 1999).

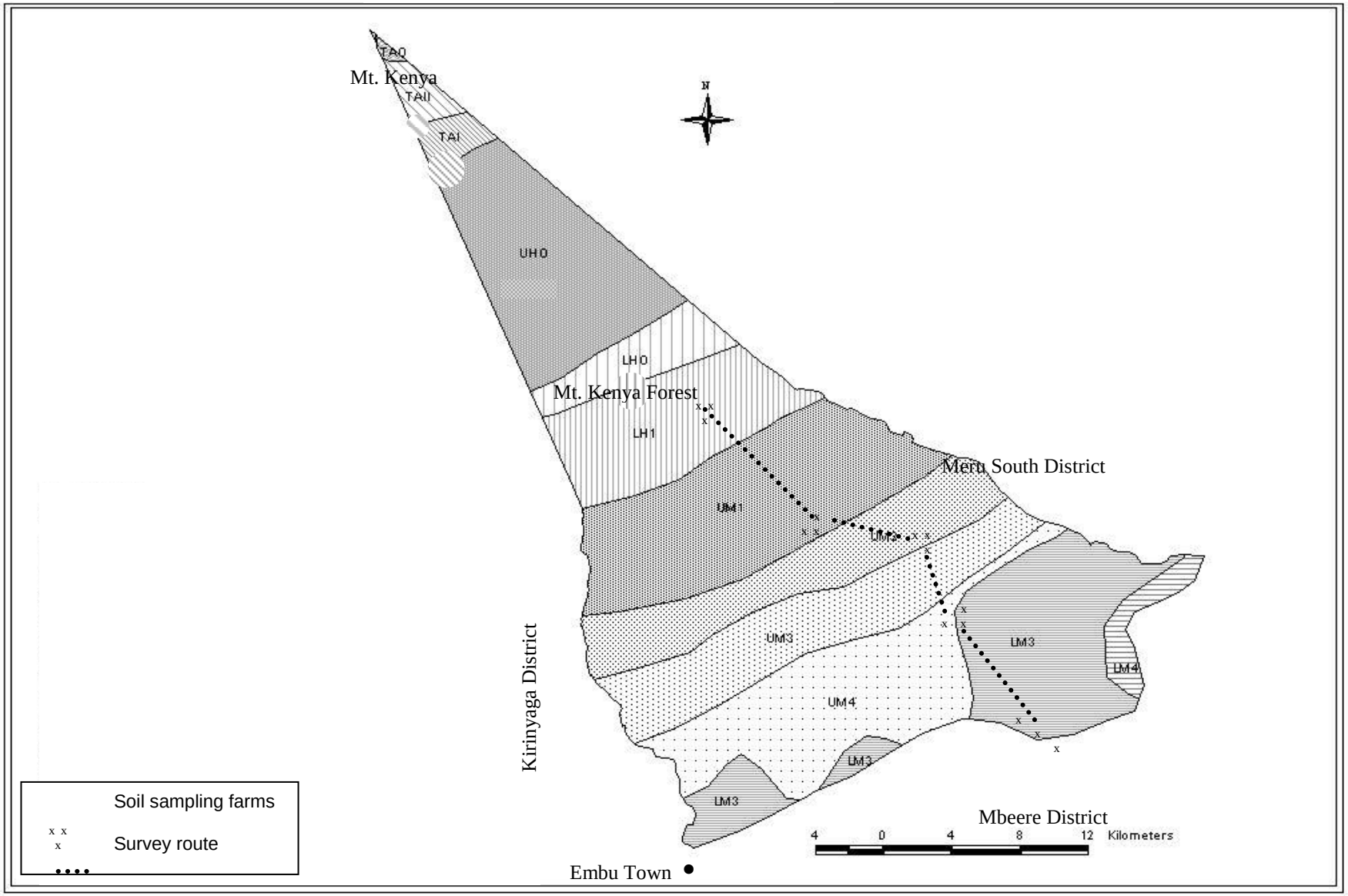
3.2 SURVEY

Title: Farmers' knowledge and practices in using soil fertility indicators in delineating on-farm fertility gradients and the use of plant residues to ameliorate soil infertility

3.2.1 Sampling scheme

The study was conducted across an altitudinal gradient of the farming area of Embu District. The survey area consisted of a transect drive starting from mount Kenya forest edge, cutting across all the five major agro-ecological zones of the District, to the lower-most section at the Ena river which forms the Embu-Mbeere district boundary (Figure 3.1). The survey route covered about 25 km passing through the following shopping centres: Rukuriri, Gitare, Runyenjes town, Gichiche and Ugweri. The five major agro-ecological zones included in the study were Lower Highland (LH) 1, Upper Midland (UM) 1, UM 2, UM 3/4 and Lower Midland (LM) 3 (Jaetzold *et al*., 2006). The survey was carried out in July, which coincides with the middle of the growing season in this area, in order to see the reproductive stages of weed and tree species for easy identification.

Stratified random sampling was used to select a total of 134 farmers (approximately 27 from each zone) for purposes of this study. Farm households were classified to identify homogeneous categories of households or target groups (Franzel and Crawford, 1987). For the purposes of this study, farmers were classified according to their wealth categorization which has a bearing on good soil management practices (Omiti *et al.*, 1999).



FiFigure 3. 1: Map of Embu District showing the survey route and soil sampling farms in the different agro-ecological zones

The categorisation of the households involved several stages;

(i) The definition of wealth categories

(ii) Selection of wealth indicators important for meeting the objectives of soil fertility improvement in farms.

(iii) Combination of wealth indicators with other relevant indicators.

A Rapid Rural Appraisal (RRA) was conducted to classify the smallholder farmers into various wealth categories. During the RRA, farmers in various zones perceived wealth to be related to the type of housing, type of livestock (cattle) structure, presence of off-farm income as well as ownership of vehicles or other automobiles. They suggested five major wealth categories as follows:

1. Stone house, barbed wire, chain link, stone water tank, steel gate, cemented zero-grazing unit and a vehicle.
2. Half-stone plus half-timber cemented house, barbed wire and a cemented zero grazing-unit.
3. Cemented timber house and a semi-zero-grazing unit.
4. Timber house (not cemented) and a semi zero-grazing unit.
5. Earth (mud) house with an iron sheets or grass-thatched roof, native or cross breed cattle or no livestock.

3.2.2 Data collection

A day prior to the commencement of the survey, all the enumerators gathered to discuss the objectives of the study and explain the sampling frame methodology. The questionnaire was discussed during this period by going through each question and agreeing on a uniform interpretation of each of the questions. The questionnaire was written in

English, but interviews were done in the local language of Kiembu. The interviews were planned to last for one day per each agro-ecological zone but due to logistic issues (such as walking through several ridges to access some farms) it took 2 days in LH 1 to complete the questionnaire administration. The survey team consisted of the author, six other researchers from Kenya Agricultural Research Institute – Embu and one extension officer. The original plan was to include one divisional extension officer and all the five locational extension staff from the survey area to act as enumerators and survey guides. However, due to the unavailability of the extension staff, local administration elders from the respective villages were used as guides. Their role was to assist in locating the respondents and also to make the initial introductory remarks about the purpose of the study for the benefit of the farmers. The interviews commenced in the morning and extended up to the late afternoon of each day. There was a farm visit during each of the interviews to different parts of the farm to observe the general characteristics of the farm, crops grown, livestock kept as well as the various types of weeds and crops in various farm niches. Information was sought on the interventions used to alleviate soil fertility problems and opinions on the role that plant residues could play in solving some of these problems. During the farm visit, weed samples for identification were collected from a 'fertile' and an 'infertile' sections of each of the farms visited. Similarly, a soil sample was collected from the 'fertile' and 'infertile' farm sections. The soil samples were collected from 15 representative farms (3 farms per zone) in each of the five agro-ecological zones. The soil samples were sampled at 20 cm depth and analyzed for soil reaction (pH), organic carbon, total N, total K^{+}, extractable P and exchangeable bases (Ca^{++} and Mg^{++}).

3.2.3 Questionnaire data analysis

The questionnaire was processed and analyzed using computer software, Statistical

Package for Social Scientists (SPSS, 2002). Data was cleaned before running to check its validity. The analysis was done for farmer characteristics, farm character, institutional factors as well as technological attributes. Comparisons were made using the procedures for crosstabulation, frequencies as well as the descriptives.

Data entry for the section dealing with soil fertility indicators and use of plant residues, was done using Excel computer spread sheet program and then subjected to an analysis of variance (ANOVA) using the SAS (2001) computer software package. The probabilities for the significance of the F-values were determined. These probabilities were for the frequency of occurrence of various weed, tree or plant residues sources. Levels of significance at the 1% and at the 5% probability levels were considered.

3.3 SOIL ANALYSIS METHODS

3.3.1 pH determination

The soil pH was determined on a 2-mm sieved soil that was previously air-dried. Five grams of the soil was weighed and 15 ml of water was added. The contents were put in an electric shaker and removed after 30 min. The mixture was left to settle down for 15 minutes after which the glass electrode pH meter (corning pH meter 215) was used to take the readings (Okalebo *et al*., 2002).

3. 3.2 Organic carbon

Soil organic carbon was determined using the complete oxidation of carbon with potassium dichromate ($K_2Cr_20_7$) and sulphuric acid mixture. The sample used had been previously ground to pass through a 0.5 mm sieve. Half (0.5) g of the sample was weighed and put in the 250 ml conical (Erlymeyer) flasks. The soil was then mixed with 10 ml

$K_2Cr_2O_7$ solution followed by 20 ml concentrated (98%) sulphuric acid (H_2SO_4) and allowed to stand for 30 minutes, then 100 ml of distilled water was added into the mixture. About 5 ml of orthophosphoric acid was added to the resultant mixture before adding the carbon indicator (Orthophenanthroline-ferrous complex with barium sulphate). After complete oxidation from the heat of the solution and external heating, the unused or residual $K_2Cr_2O_7$ (in oxidation) was titrated against ferrous ammonium sulphate. The used $K_2Cr_2O_7$ (the difference between added and residual $K_2Cr_2O_7$) gives a measure of organic C content of the soil. The end point was marked by a colour change from dark green to red (Rowel, 1995; Okalebo *et al*., 2002). The percentage organic carbon was calculated using the following formula:

$$\% \text{ Organic C in Soil (air-dry)} = \frac{(Me\ K_2Cr_2O_7 - MeFeSO_4)\ x\ 0.003\ X\ 100\ x\ (f)\ )}{Weight\ (g)\ of\ air\ -\ dry\ soil}$$

Where f = 1.33 (correction factor)

Me = Molarity of solution x volume in ml of solution used

% Organic matter of soil = % Organic C x 1.729

3.3.3 Effective Cation exchange capacity (ECEC) and exchangeable cations

Effective Cation exchange capacity (ECEC) was determined by leaching out the cations from the soil by using excess of ammonium acetate (Anderson and Ingram, 1993). In the leaching process, the negative exchange sites of the soil get occupied by the ammonium ions whose concentration is eventually determined as a measure of the CEC. In order to determine the effective cation exchange capacity (ECEC), five (5.0 g) of soil, that had been ground to pass through a 2.0 mm sieve, was weighed out and mixed with an equal amount of acid washed sand. The leaching apparatus was set out by placing the contents in a funnel

starting from the bottom in the order: cotton wool, sand, sand-soil mixture, and sand. The leaching process commenced by passing down 50 ml ammonium acetate solution five times. NH_4^+ ions that are trapped in soil pores were washed down using 28% alcohol five times. The soil was then washed with KCl (at pH 2.5). This was done to displace NH_4^+ ions attached on the negative soil sites with K^+ ions. The amount of NH_4^+ions washed from the sites is equal to the negatively charged sites of the soil. Ten (10) ml of the leachate was pipetted out and put in a distillation flask. Sodium hydroxide (0.5 N NaOH) was added to the ammonium solution so as to raise the pH of the solution to allow for release of the NH_3 gas. The released NH_3 gas was then distilled off and trapped in 2% boric acid indicator which changed the colour from pink to green. The concentration of NH^+_4 was determined by titrating the green colour boric indicator to the pink colouration by using a weak mineral acid (0.01 M HCl) (Anderson and Ingram, 1993; Okalebo *et al*., 2002). The concentration of NH_4^+in the leachate was calculated using the formula:

$$NH_4^+ = \frac{\text{Titre x Strength of acid x Dilution x 100}}{\text{Weight of soil}}$$

or

$$\frac{\text{Titre (ml) x 0.01 x 100}}{\text{x100/10}} = \text{cmol/100g} \quad \text{or} \quad \text{T x } 10/5 = \text{T x 2} = \text{cmol/100g of soil}$$

The exchangeable cations were obtained from the leachate extracted using ammonium acetate for the CEC above and were determined with absorption spectrophotometer (AAS) for Ca^{++} and Mg^{++} and by flame photometer for K^+.

3. 3.4 Total nitrogen

Total nitrogen content was determined by the Kjedahl digestion method (Anderson and Ingram, 1993). In this method, soil is oxidized with sulphuric acid in the presence of

selenium mixture as a catalyst, during which nitrogen is converted to ammonium sulphate. When the digest is made alkaline with NaOH, ammonia is released, distilled off, collected in boric acid indicator solution and titrated against a standard solution.

Procedure

One (1.0) g of soil that had been air-dried and ground to pass through a 0.5 mm sieve was weighed out and put into the digestion tube. The digesting mixture consisting of mixed catalyst made from a mixture ($CUSO_4$ + K_2SO_4 + Selenium) and concentrated H_2SO_4 was added. The mixture was heated on a digestion block for 2-6 hours until it became colourless and any remaining sand had turned white. The temperature of the digestion block ranged between 250^0C - 350^0C. The samples were removed and allowed to cool. After cooling, the samples were filtered through Whatman number 42 paper into a 100 ml volumetric flask and made up to volume. Ten (10) ml of the digest was pipetted out into the Kjedahl flask and 5 mls of 40% NaOH added together with some water (about 200 ml) to increase the volume. The aliquot was distilled with 10 ml boric acid indicator solution (H_3BO_3). The NH_3 released during distillation was received into 50 ml boric acid containing 4 drops of the mixed indicator. The distillation continued until the colour of the solution turned from pink to green. The distillate was then titrated with 0.01 N HCl until the colour changed back to pink. The percentage (%) N content in the soil was calculated as follows:

$$\% N = \frac{(T - B) \times M \times 14 \times 100 \times 10}{S}$$

in the sample

T = Volume of the titre HCl for the sample

B = Volume of the titre HCl for the blank

M = Molarity of the HCl

S = Weight of the sample in mg

NB/

0.01 N acid in the titration is equivalent to 0.14 mg ammonium N.

100 ml of digest was used from which 10 ml aliquot was distilled

3. 3.5 Extractable P

The Melich method of determining available P was preferred over the others because the soils had pH values of less than 7.0. In Mehlich method, soil-P is extracted with acids and the concentration measured colourimetrically. After grinding the soil to pass through the 0.5 mm sieve, 5.0 g was weighed out and put in 100 ml plastic bottles for shaking. 50 ml of the double acid solution (0.5 N HCl + 0.25 N H_2SO_4) was added and the mixture shaken for 30 minutes before filtering with number 42 Whatman filter papers . A few drops of toluence were added to reduce the microbial activity in the extract and then the solution was exposed to colour development. During this process, 2 ml of the extract was pipetted out into 50 ml volumetric flask and 8 ml of reagent B [(Ascorbic + Reagent A) (5N H_2SO_4 + ammonium molybdate/ antimony potassium tartrate in 5N of H_2SO_4)] 4.0 ml of water was added and colour development awaited. The solution developed a blue colouration. The intensity of the colour was read using a UV and visible spectrophotometer (Unicam SP 500 series 2 ultraviolet and visible) at 882 nm. The concentration of P in the samples was determined from standard curve that was prepared. The concentration of P in the sample (expressed in P mg kg^{-1} of soil) was calculated as follows:

$$P\ (mg\ kg^{-1}) = \frac{(a-b) \times v \times f \times 1000}{1000 \times w}$$

Where: a = The concentration of P in the sample

b = The concentration of P in the Blank

v = volume of the extracting solution

f = Dilution factor

w = Weight of the sample in g

3. 3.6 Mineral N

Procedure for measurements of NH^{+}_{4} – N and NO^{-}_{3} – N soil extracts

After mixing the sample thoroughly, 5 g of freshly sampled soil was transferred into plastic shaking bottles and 100 ml of 2 M KCl extracting solution added. The bottles were stoppered and shaken for 1 hour, allowed to settle before filtering into a clean plastic bottle fitted with Whatman No. 42 ashless filter papers.

Mineral N content was determined using steam distillation and titration method as outlined in Okalebo *et al*. (2002). The steam distillation apparatus was checked by collecting 50 ml distillate and titrating with 0.01N H_2SO_4. Five (5) ml of boric acid indicator solution was put in 50 ml conical size flask but the volume was made upto 30 ml with water. The flask was placed under the condenser of the steam distillation apparatus so that the end of tip of the condenser barely touched the boric acid solution. Steam containing $–NH_4^+$ was passed until boric acid changed from pink to green colour. The conical flask was then lowered to allow droplets of the steam to collect up to the 30 ml mark.

In order to release NH_4^+ from the soil extract, an aliquot of 20 ml of the extract was pipetted into the distillation flask and about 0.2 g of ignited and cooled MgO was scooped directly to the bulb of the distillation flask, which was attached using a spiral sted spring. The distillation process was started by closing the stopcock on steam by-pass tube. The distillation was stopped by closing the stopcock on steam-by pass tube when the distillate reached the 30

ml mark on the receiver conical flask. The tip of the condenser was rinsed with a little distilled water.

Ammonium–N content was determined in the distillate by titration with 0.01 N H_2SO_4 placed in a micro-burettee. The colour change at the end point was from green to permanent faint pink. At end point, 1.0 ml of 0.01 N H_2SO_4 = 140 µg NH_4^+-N (using the relationship: Normality x equivalent weight = number of g L^{-1}). NO^-_3–N content was determined after distilling off the NH^+_4 –N from the sample extract as described above. The stopper from the side arm of the distillation flask was then removed and about 0.2 g of Devadas' alloy was added using a spatula to reach the bulb of the flask. The stopper was replaced immediately into the neck of the side-arm and ammonia distilled into flask of boric acid which was then titrated using 0.01 N H_2SO_4 as described above

Calculation of mineralized N

The amount of NH_4^+ –N and NO_3–N in the extract was calculated as follows:

Since 100 ml KCl was used to extract NH_4^+ or NO_3^- -N from 10 g, then 20 ml KCl (aliquot in distillate) is used to extract:

$$\text{Mg N kg}^{-1} \text{ in soil} = \frac{(a-b) \times 28 \times v \times MCV \times 1000}{w \times al}$$

Where,

a = titre volume of 0.002 N H_2SO_4 for the sample in ml

b = titre volume for the blank in ml

v = volume of extracting solution or 50 ml

MCF = Moisture correction factor

w = fresh weight of the sample or 10 g

al = sample aliquot or 20 ml

28 µg N = equivalent to 1 ml 0.002 NH_2SO_4 which is equivalent to 28 µg NH^+_4-N

or NO^-_3–N

MCF = $\frac{\textit{weight of dry soil}}{\textit{Weight of wet (fresh) soil}}$

kg N ha^{-1} = $\frac{\textit{Concentration in ug N } g^{-1} \textit{of soil x depth (cm) x bulk density (g } m^{-3}\textit{) x area (cm}^{-2}\textit{)}}{10^9}$

3. 3.7 Particle size analysis

Procedure

The particle size analysis was done using the Bouyoucos or hydrometer method as outlined by Okalebo *et al*. (2002). Fifty one (51) g of air-dry soil which had been passed through a 2-mm sieve was weighed and transferred to a "milkshake" mix cup. The 51 g air dry sample represents approximately 50.0 g of oven-dry soil. Fifty (50) ml of 5% sodium hexametaphosphate was added along with a stirring rod and the sample was allowed to settle for 30 minutes. The resultant soil suspension was stirred for 15 minutes using the multimix machine. The suspension was then transferred from the cup to the glass cylinder. With the hydrometer in the suspension, distilled water was added to the lower blue line. This made the volume to 1130 ml and then the hydrometer was removed.

The cylinder was then covered with a tight-fitting rubber bung and inverted several times until the suspension was thoroughly mixed. The cylinder was then placed on a flat surface and time noted before placing the soil hydrometer immediately in the suspension slowly until it was floating. The first hydrometer reading was then taken and temperature recorded with a thermometer. After the first hydrometer reading the suspension was left to stand for 3 hours and then a second reading was taken. The temperature of the suspension was also taken. The first reading measures the percentage of silt while the second reading

indicates the percentage of 2 micron (total) clay in the suspension. The temperature readings were converted from ^{0}C to the Fahrenheit scale. For every degree over 68^0, there was addition of 0.2 to the hydrometer reading before computation while those under 68^0 there was a subtraction of 0.2. There was a subtraction of 2.0 from every hydrometer reading to compensate for the added dispersing agent. A check on (or a substitute for) the 40 seconds reading was made by sieving the entire suspension through a 300-mesh sieve to remove sand. It was then dried in the oven at 100^0C and sifted to remove any remaining silt before weighing. The weight was then multiplied by 2 and this formed the percentage of sand in the soil.

The final parameters used for calculations are as follows:

1a. Hydrometer reading at 40 seconds, $H_1 = 18$

b. Temperature reading at 40 seconds, $T_1 + 75^0$F

2a. Hydrometer reading at 3 hours, $H_2 = 8$

b. Temperature at 3 hours, $T_2 = 63^0$ F

3. Temperature correction to be added to hydrometer reading = 0.2 (T-68)

Where T = degrees Fahrenheit

4. Silt correction to be added to hydrometer reading = -2.0

3. 3.8 Bulk density

The bulk density was determined, from undisturbed soil sample, using soil sample rings which are stainless steel, seamless, smooth inside and outside surfaces, made by Eijelkamp (Netherlands). The rings were 53 by 50 mm or 100 cm^3. The soil samples were taken at the soil surface or the upper 5 cm depth of the soil by first removing topmost soil (about 2 cm) before pushing the rings into the soil. Rings were pushed into the soil by hammering them in using the accompanying ring holder and hammer. The rings were then removed from the soil by digging them out of the ground before carefully trimming the oversized sample (using the special trimming knife) to the edge of the ring. The samples were weighed (to obtain the fresh wet weight), dried at 105^0C for 48 hours to constant weight and then re-weighed to obtain the dry weight. Bulk density was calculated using the following formula:

$$\text{Bulk density (g cm}^3\text{)} = \frac{\text{Weight of dry soil}}{\text{Volume of core ring}}$$

3.4 EXPERIMENT ONE

Title: The performance of maize (*Zea mays*) and three green manure legumes under different intercropping densities and sowing intervals

Procedure:

The field trial was conducted on-station at Field 7 of Embu Agricultural Staff Training (EAST) college – neighbouring KARI- Embu. The experiment was laid out and analyzed as a complete randomized block design in a 3x2x5 factorial arrangement where there were 3 legumes planted at 2 planting densities with 5 planting weekly intervals (period) each (Table 3.3.1). All the resultant legume herbage was incorporated into the respective plots. There were three replications per treatment. Maize (Pionner Hybrid 3253) was planted

at the onset of rains. The size of each plot was 4.5 m wide and 6.0 m long containing 6 rows of maize inter- and intra-row spaced at 0.75 m and 0.5 m. Three seeds were planted in each hole but were later thinned to two, resulting in a final plant density of 53300 plants ha^{-1}. The net plot consisted of the entire plot excluding the two outer rows and the first and last hills in each row. The treatment structure of the experiment is shown in the Table 3.4.1 below.

Table 3.4 1: Treatment structure of experiment one planted in Embu, Kenya

Legume species	**Planting density**	**Intervals (weeks) of relaying the legumes after maize emergence**
Mucuna pruriens *Lablab purpureus* *Crotalaria ochroleuca*	Low and High	0, 1, 2, 3, 4

Mucuna [*Mucuna pruriens* (L.) DC. Var. utilis (Wright) Bruck] and lablab [*Lablab purpureus* (L) Sweet cv. Rongai] were planted in hills with an intra-row spacing of 25 cm, two plants per hill, resulting in a density of 106600 plants ha^{-1} for the single row or low density and 213200 for the double or high density. Crotalaria [*Crotalaria ochroleuca* G. Don] was drilled along the row at a seeding rate of 30 kg ha^{-1} for the low density and 60 kg ha^{-1} for the high density. There was no inoculation used in planting the legumes. Both the maize as well as the legumes were planted with triple super phosphate (TSP) fertilizer applied at 2.5 g per hill (20 kg P ha^{-1}). Each of the three legumes were planted in the maize crop the same day maize was planted (week or period 0) and thereafter planting was relayed at weeks 1, 2, 3, and 4 after the planting of maize. Four extra plots, one with sole maize and the others with a sole stand of each of the three legumes at both densities, were included.

All plots were maintained weed-free by weeding twice per season using hand tools in all the five cropping seasons. Maize stalk borer control was achieved by applying the insecticide bulldock, whose chemical name is beta-cyfluthrin (cyano (4-fluoro-3-phenoxy-phenyl) methyl 3-(2,2-dichloethenyl) 2,2-dimethylcyclopropanecarboxyylate) at 0.01 kg a.i

ha^{-1}. No major maize or legume disease outbreak occurred during experimentation period. There were some occasional outbreaks of termites attack in a few plots in some of the seasons but these did not result in major crop damage and no control mechanism was used. The details of planting dates are as shown in the Table 3.4.2 below:

Table 3.4 2: Dates of planting and harvesting maize for different cropping seasons in Embu, Kenya

Cropping Season	Date Planted	Date Harvested
LR 2003	16/04/03	28/08/03
SR 2003	24/10/03	02/03/04
LR 2004	29/03/04	12/09/04
SR 2004	21/10/04	09/03/05
LR 2005	07/05/05	13/09/05

Biophysical data for legume and maize were collected as the season progressed. The maize data collected included plant height (after tasseling), days to 50% tasselling, stover as well as grain yield. Harvesting of maize was carried out at maturity using the center rows for yield determination. During the initial cropping seasons the ears were weighed after sun-drying and their weight determined. Cobs were selected at random for moisture content determination using a moisture meter. The final grain yield was adjusted to 12.5% moisture content. In the latter three seasons, grain yield was determined after shelling the maize. Maize stover from the same harvest area was cut at ground level, weighed and samples taken for oven drying at 105^{o}C for at least 48 hours or to constant weight, for final stover yield determination. The legume data collected included biomass accumulation and N concentration in the foliage at harvest time of maize. Initial soil samples for site characterization were done at the beginning of the experiment before planting. A total of six sections were sampled to represent the various experimental plots (Appendix 7.2). Analysis was done for pH, N, P, K, Mg^{++}, Ca^{++} using the procedures outlined in section 3.3.

Fractional solar radiation interception

This was determined in the last (final) two seasons of SR 2004 and LR 2005. Radiation interception of the photosynthetically active radiation (PAR) was measured in both the sole crop and the intercrop using sunfleck ceptometer (SF-80 Decagon, Pullman, Washington). Reandings were taken by holding the ceptometer perpendicular to the rows. In each plot, a reading was taken outside the plot in a nearby open field to give an equivalent of the above maize canopy readings. A second reading was taken below the maize canopy but above the legume canopy whereas the last reading was taken below the legume canopy. A total of six readings were taken per plot. The measurements were taken between 11.30 a.m and 2.00 p.m (local time) at an interval of fourteen days. The PAR intercepted was calculated by subtracting the ceptometer readings below the canopy from the ceptometer readings above the canopy.

$$\% \text{ PAR intercepted} = \frac{(PAR_a - PAR_b)}{PAR_a} \times 100$$

Where:

PAR_a = PAR above the canopy

PAR_b = PAR below the canopy

Relative yield total (RYT)

The efficiency of the intercrop of maize and any of the three green manure legumes was assessed using the relative yield total (RYT) that is similar to land equivalent ratio (LER) (Willey, 1979). The RYT values were calculated by summing the relative yields (total biomass) of both the maize and the legume in the intercrop and expressing it as the ratio of the yield of sole cropped components. Generally, RYT > 1 indicates an advantage of the

intercrop compared to sole or monoculture cropped maize plot and vice versa.

$$RYT = \frac{Yield_{maize\ intercrop}}{Yield_{sole\ maize}} + \frac{Yield_{legume\ intercrop}}{Yield_{sole\ legume}}$$

3.5 EXPERIMENT TWO

Title: The effect of legume residue placement methods on N release for maize growth

Procedure

The trial was conducted on-station at Field 7 of Embu Agricultural Staff Training (EAST) college, neighbouring KARI - Embu. The experiment was laid out and analyzed as a randomized complete block design in a $3x2^2$ factorial arrangement replicated four times. Maize (Pionner Hybrid 3253) was planted at the onset of rains as outlined above in section 3.3 of experiment one. Legumes were planted between the maize rows. The treatment structure consisted of 3 green manure legume species sown at 2 planting densities that were subjected to 2 residue management techniques (Table 3.4.1). A control treatment of maize planted with no residues was included. The full treatment structure is as illustrated in the Table 3.5.1 below:

Table 3.5 1: Treatment structure of experiment two planted at Embu, Kenya

Legume species	**Planting density**	**Residue management technique**
Mucuna pruriens *Crotalaria ochroleuca* *Lablab purpureus*	Low and High	Incorporation and Surface mulch

All the resultant legume herbage was incorporated into the respective plots. (Table 3.5.2). The rest of the management procedure for this experiment is similar to that of experiment 1. Site characterization sampling was done at the beginning of the experiment but before planting. A total of five sections were sampled to represent the various experimental plots (Appendix 7.3) and the soil analysis was done as outlined above in experiment 1. Final soil sampling was done in October 2005 and the samples were analyzed for total soil N and pH. Analysis for phosphorus was not considered since a blanket P application was made in all the

plots whereas potassium analysis was missed out because the initial soil characterization (Appendix 7.3) indicated that K was not a limiting nutrient in these soils.

Table 3.5 2: Legume biomass applied (and their corresponding amount of N) in various treatments of residue management for different cropping seasons in Embu, Kenya

Treatment	CROPPING SEASON									
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005	
	Biomass (Mg ha^{-1})	N (kg ha-^{1})	Biomass (Mg ha^{-1})	N (kg ha-^{1})	Biomass (Mg ha^{-1})	N (kg ha-^{1})	Biomass (Mg ha^{-1})	N (kg ha-^{1})	Biomass (Mg ha^{-1})	N (kg ha-^{1})
MLDI	3.94	77	3.46	65	3.94	91	1.53	27	2.03	40
MLDM	4.23	77	3.85	73	4.36	100	1.32	24	2.12	42
MHDI	4.69	85	4.29	81	4.43	102	1.79	32	2.43	48
MHDM	4.35	86	4.28	81	5.16	119	2.06	37	2.43	48
CLDI	2.34	48	2.84	62	1.48	19	1.00	37	1.67	37
CLDM	2.74	54	2.99	65	0.21	18	1.28	47	1.63	37
CHDI	3.06	60	3.45	75	1.35	17	1.79	66	1.67	37
CHDM	3.44	62	3.58	78	0.23	3	1.75	65	1.36	30
LLDI	1.08	19	1.40	25	0.03	1	0.07	2	0.25	5
LLDM	2.08	31	1.70	31	0.08	2	0.06	2	0.39	8
LHDI	2.41	40	1.73	31	0.17	4	0.12	4	0.31	7
LHDM	2.91	47	3.32	60	0.12	3	0.14	3	0.34	7

KEY:

MLDI = Mucuna at Low Density, Incorporated; MLDM = Mucuna at Low Density, Mulched; MHDI = Mucuna at High Density, Incorporated; MHDM = Mucuna at High Density, Mulched; CLDI = Crotalaria at Low Density, Incorporated; CLDM = Crotalaria at Low Density, Mulched; CHDI = Crotalaria at High Density, Incorporated; CHDM = Crotalaria at High Density, Mulched; LLDI = Lablab at Low Density, Incorporated; LLDM = Lablab at Low Density, Mulched; LHDI = Lablab at High Density, Incorporated; LHDM = Lablab at High Density, Mulched.

3.6 EXPERIMENT THREE

Title: Maize performance as affected by legume green manures supplemented by different mineral N fertilizer levels

Procedure

The trial was conducted on-station at Field 7 of Embu Agricultural Staff Training (EAST) college, neighbouring KARI - Embu. The experiment was laid out and analyzed as a randomized complete block design in a 3x2x3 factorial arrangement replicated four times. The treatment structure consisted of 3 legumes planted at 2 planting densities while the mineral N fertilizer was applied to the maize at 3 levels (Table 3.5.1). A control treatment of maize planted without any legume or mineral N fertilization was included. Maize (Pionner Hybrid 3253) was planted at the onset of rains as outlined above in section 3.3 of experiment one. The full treatment structure is as illustrated in the Table 3.6.1 below:

Table 3.6.1: Treatment structure of experiment three planted at Embu, Kenya

Legume species	**Planting density**	**Mineral N supplementation (kg ha^{-1})**
Mucuna pruriens *Crotalaria ochroleuca* *Lablab purpureus*	Low and High	0, 30 and 60

All the resultant legume herbage was incorporated into the respective plots (Table 3.5.2). The rest of the procedure for this experiment is similar to that of experiment 1. Soil sampling for initial and final characterization were done at 20 cm depth. Initial soil samples were obtained for site characterization at the beginning of the experiment before planting. A total of six sections were sampled to represent the various experimental plots (Appendix 7.4). Siol analysis was done as per experiment one and two above. The final soil sampling was done in October 2005 and the samples were analyzed for total soil N and pH. Analysis for phosphorus was not considered since a blanket P application was made in all the plots

whereas potassium analysis was missed out because the initial soil characterization (Appendix 7.4) indicated that K was not a limiting nutrient in these soils.

Soil mineral N sampling

Soil sampling for mineral N was done at 4, 8 (weeks after planting) and at harvest time. Mineral N determination was done for the last two seasons of experimentation (SR 2004 and LR 2005). During the sampling for mineral N, eight augerings were done at a depth of 20 cm per plot. The soil from all the eight sampling points per plot was combined, thoroughly mixed, and then sub-sampled and packed into polythene bags. The polythene bags were then kept in a cooler box with ice and transported immediately to the laboratory for N extraction. The extraction was done with 2.0 N KCl. The extracts were analyzed for NH^{+}_{4} and NO^{-}_{3} following the method outlined in section 3.3. Soil mineral N was estimated in kg ha^{-1} using the respective bulk density that was determined per plot.

Maize N uptake sampling

For determination of N uptake, six representative maize plants (representing approximately 4% of the total plot population) were sampled by cutting at the soil surface without removing the roots. Sampling was carried out only in the net plot that consisted of the entire plot excluding the two outer rows and the first and last hills in each row. The samplings were done at 4, 8 (weeks after planting) and at harvest during the last 2 seasons (SR 2004 and LR 2005) of experimentation. To minimize gap effects, care was exercised to ensure that two consecutive plants were not removed. At each sampling date, plant sub-samples were taken for dry matter and N concentration determinations. The samples were rinsed with distilled water and oven dried at 65^{0}C for 48 hours or to constant weight to determine dry matter. The samples were ground to pass through 2-mm sieve and kept in air-tight plastic bags in a cool dry place awaiting chemical analysis.

Table 3.6.2: Legume biomass applied (and their corresponding amount of N) in various treatments of mineral N supplementation for different cropping seasons in Embu, Kenya

Treatment	CROPPING SEASON									
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005	
	Biomass (Mg ha^{-1})	N (kg ha-^{1})	Biomass (Mg ha^{-1})	N (kg ha-^{1})	Biomass (Mg ha^{-1})	N (kg ha-^{1})	Biomass (Mg ha^{-1})	N (kg ha-^{1})	Biomass (Mg ha^{-1})	N (kg ha-^{1})
MLD0N	2.46	45	3.07	52	4.28	98	2.45	44	1.93	38
MLD30N	2.35	850	2.66	49	3.95	91	2.19	39	1.22	24
MLD60N	2.99	67	2.62	43	4.30	99	1.98	36	1.25	25
MHD0N	4.02	88	3.42	59	4.82	111	3.18	57	2.71	54
MHD30N	3.52	82	3.06	52	5.14	118	3.45	62	1.66	33
MHD60N	3.78	80	2.78	49	4.58	105	3.08	55	1.89	37
CLD0N	1.05	40	3.04	70	0.43	5	1.30	48	1.09	24
CLD30N	1.43	37	2.91	68	0.73	9	0.56	23	0.63	14
CLD60N	1.01	29	2.57	60	0.38	5	0.42	15	0.60	13
CHD0N	1.85	43	4.44	96	1.14	15	1.13	42	0.80	18
CHD30N	2.07	44	4.02	90	0.60	8	0.85	31	1.00	23
CHD60N	1.52	52	3.30	77	0.40	5	0.81	30	0.65	15
LLD0N	0.54	29	0.42	7	0.12	3	0.08	2	0.28	6
LLD30N	1.05	17	0.33	6	0.11	3	0.11	3	0.23	5
LLD60N	0.55	12	0.38	7	0.12	3	0.24	6	0.39	8
LHD0N	1.06	17	0.64	15	0.19	4	0.14	4	0.44	9
LHD30N	0.80	13	0.58	10	0.17	4	0.16	4	0.23	5
LHD60N	1.18	28	0.60	13	0.17	4	0.23	6	1.00	21

KEY:

MLD0N = Mucuna at Low Density with 0N; MLD30N = Mucuna at Low Density with 30N; MLD60N = Mucuna at Low Density with 60N; MHD0N = Mucuna at High Density with 0N; MHD30N = Mucuna at High Density with 30N; MHD60N = Mucuna at High Density

KEY for Table 3.6.2 continued:

with 60N;

CLD0N = Crotalaria at Low Density with 0N; CLD30N = Crotalaria at Low Density with 30N; CLD60N = Crotalaria at Low Density with 60N; CHD0N = Crotalaria at High Density with 0N; CHD30N = Crotalaria at High Density with 30N; CHD60N = Crotalaria at High Density with 60N;

LLD0N = Lablab at Low Density with 0N; LLD30N = Lablab at Low Density with 30N; LLD60N = Lablab at Low Density with 60N; LHD0N = Lablab at High Density with 0N; LHD30N = Lablab at High Density with 30N; LHD60N = Lablab at High Density with 60N.

3.7 EXPERIMENT FOUR

Title: The use of low quality residues in slowing down the rate of fast-decomposing green manure legume residues to improve N synchrony for maize performance

Treatments

The trial was conducted on-station at Field 7 of Embu Agricultural Staff Training (EAST) College - neighbouring KARI - Embu. The experiment was laid out and analyzed as a randomized complete block design in a 3^2 factorial arrangement replicated four times. The legume as well as the stover residues formed the factors that were tested. Thus the treatments were 3 green manure legume species sown at one planting density that was subjected to the 3 stover residue levels. Maize stover residue was applied at 0, 3 and 6 Mg ha^{-1} while each of the three legume green manure residues were applied at 2 Mg ha^{-1}. Two controls were included: (1) An absolute control with no low or high quality residues as well as (2) a control with 6 Mg ha^{-1} of maize stover. The rest of the procedure for this experiment is similar to that of experiment 1. Initial soil samples for site characterization were taken at beginning of the experiment but before planting. A total of five sections were sampled to represent the various experimental plots (Appendix 7.5) and soil analysis was done as outlined above in experiment one. Final soil sampling was done in October 2005 and the samples were analyzed for total soil N and pH. Analysis for phosphorus was not considered since a blanket P application was made in all the plots whereas potassium analysis was missed out because the initial soil characterization (Appendix 7.5) indicated that K was not a limiting nutrient in these soils.

Use of litter bags

In order to determine the level of decomposition and hence the N loss in mucuna alone, maize stover alone or mucuna/maize residue mixtures were put in the respective litter

bags according to the ratios outlined in the experimental treatments. The litter bag contents were as follows: 50 g mucuna only, 20 g mucuna + 30 g stover, 13 g mucuna + 37 g stover and 50 g stover only. Leaves and stems of mucuna or maize stover were cut into small pieces of about 5-cm length, sun dried to a constant weight after which samples of 50 g each were transferred to litter bags of 2-mm nylon mesh size of 30 cm by 20 cm. The bags were then buried (in the respective plots) in the ground in a horizontal configuration at a depth of 0 to 15 cm (plough layer). Each treatment was replicated six times. One bag was removed from each block after 2, 4, 6, 8, 10, and 12 weeks after burying. The contents of the bag were carefully cleaned free of soil and oven dried at 65^0C (for 48 hours) to constant weight (Anderson and Ingram, 1993). The dry weight of the litter remaining un-decomposed was recorded. 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:

$$L_R/L_1 = e^{-kt}$$

Where: L_R = litter remaining after a given time

L_1 = 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 fraction of the material remaining (L_R/L_1) declined with time. The k values were estimated using a nonlinear module in EXCEL spreadsheet.

3.8 RAINFALL AT THE EXPERIMENTAL SITE

The amount of rainfall obtained at the trial site for each of the five cropping seasons is

shown in Figure 3.2. The long rains starts during the months of March or April while short rains seasons generally start in the month of October. The cropping seasons' for the long and short rains ends in the months of September and February/March, respectively. A preliminary maize-green manure legume crop was planted during the SR 2002 cropping season that was meant to raise legume residues for the treatment inputs for structures of experiments 2, 3, and 4.

Seasonal raifall for the LR 2003 is presented in Figure 3.2. In the LR 2003 season, rains started on April 15 and continued until May 31, 2003. The months of April and May were very wet whereas June and July were completely dry. There was a short rainfall duration that occurred between August 3, 2003 and August 12, 2003 but the rest of the season remained dry. Thus, there were about 50 days of wet soil conditions for the entire LR 2003 cropping season. Temperature readings were not recorded but the season remained cool for most of the growing season.

Seasonal raifall for the SR 2003 is presented in Figure 3.2. The SR 2003 cropping season was characterized by very heavy downpour between October 23 (when the rains commenced) and December 11, 2003. A dry period prevailed between December 11, 2003 and mid January of 2004. There were 55 days of wet soil conditions during this season. The rains ceased when maize was at the early flowering stage of crop development and the weather remained dry during the entire grain filling period.

The LR 2004 cropping season rains (Figure 3.2) commenced on March 28 and continued until May 3, 2004. This implies that there were only 40 days of wet soil conditions for the entire cropping cycle of that season's crop. Dry soil conditions prevailed during the crucial flowering and grain-filling period of the maize crop growth and development. A similar rainfall pattern also prevailed in SR 2004 cropping season (Figure 3.2). The

commencement of rainfall for this cropping season was on October 20 and it continued until December 10. Thus, there were about 53 days of wet soil conditions during this cropping season. As was the case in the preceding SR 2004, the maize crop was under dry soil conditions during the crucial flowering and grain filling stage of growth and development. Due to these very low rainfall conditions, a number of experimental plots registered no grain yield.

The final cropping season for the experiment was LR 2005. Seasonal raifall for the LR 2005 is presented in Figure 3.2. During this particular season, rains commenced on April 5, 2005 and continued for about a week. Thereafter, a dry spell that lasted for about two and a half weeks prevailed. The young maize and legume seedlings withered in the majority of the plots but there was a resumption of rains on April 25, 2005 which continued for the rest of the season. Thus, except for the initial dry spell, LR 2005 cropping season could be regarded as a normal season with adequate rainfall distributed throughout entire growing season. A total of 546 mm of rainfall was recorded during the growing season of the crop out of which 26 and 32 mm fell in the months of July and August, respectively. Therefore, the LR 2005 cropping season realized 68 days of wet soil conditions during the maize crop growth cycle.

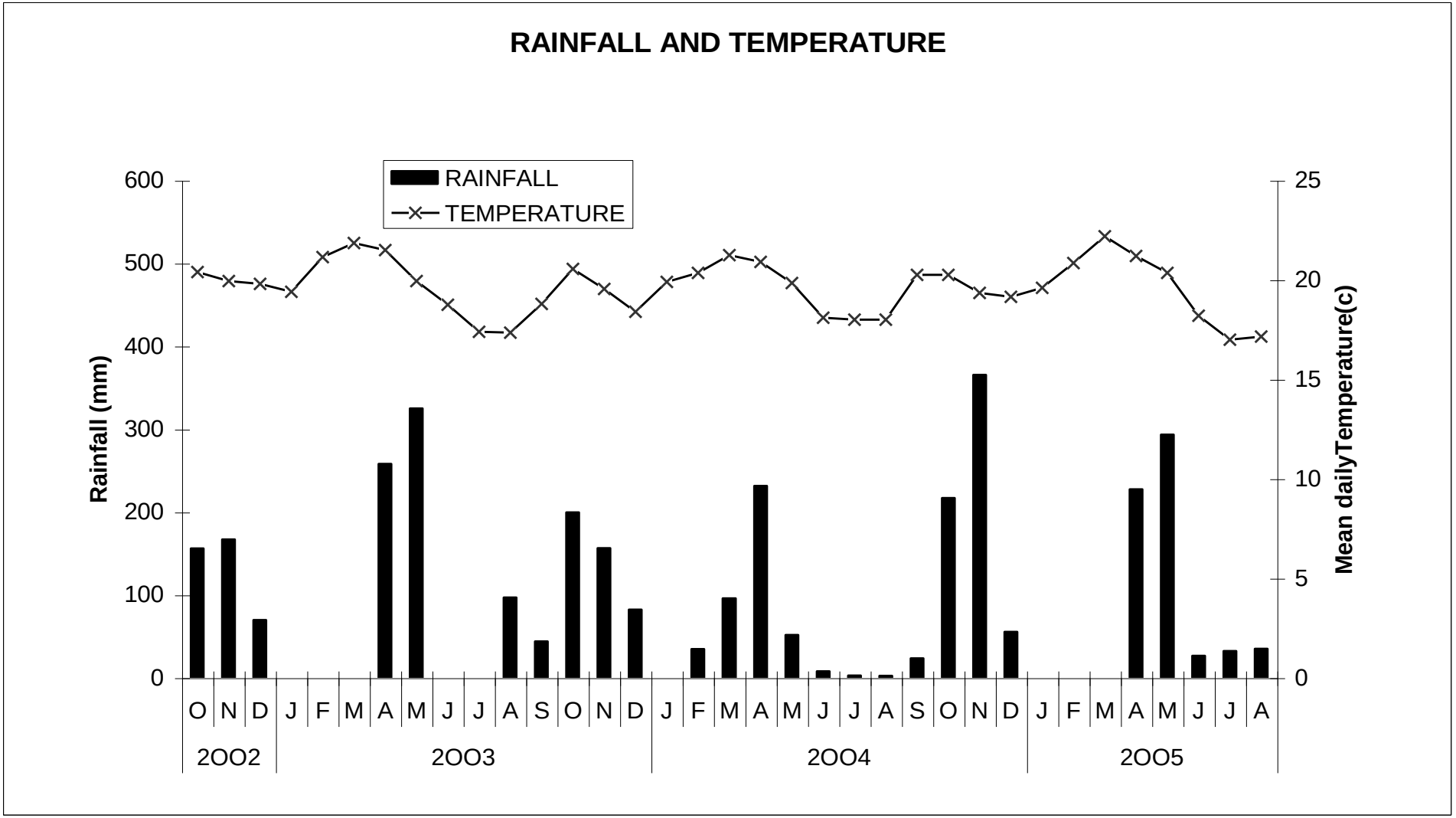


Figure 3.2: Distribution of rainfall and temperature at experimental site for the period commencing October 2002 to August 2005

3.9 CHEMICAL CHARACTERISTICS OF DIFFERENT PLANT MATERIALS USED IN THE FIELD EXPERIMENTS

Maize stovers as well as mucuna, crotalaria and lablab residues were sampled every season for laboratory chemical analysis. A composite sample across all the four experiments for each sample was analyzed (Table 3.9.1).

Table 3.9.1: Chemical composition of maize stover, mucuna, crotalaria and lablab residues for different cropping sesons in Embu, Kenya

Season	**N (%)**	**P (%)**	**K (%)**	**Org C (%)**	**Polyphenols (%)**	**Lignin (%)**
Mucuna,L.R 2003	1.98	0.08	0.47	47.75	2.78	9.82
Mucuna,S.R 2003	1.89	0.07	0.41	47.52	3.53	10.50
Mucuna, L.R 2004	2.3	0.10	0.22	46.97	5.03	10.28
Mucuna, S.R 2004	1.79	0.06	0.66	48.14	6.99	9.12
Mucuna, L.R 2005	1.98	0.08	0.44	47.41	3.78	10.20
Lablab, L.R 2003	1.68	0.07	0.70	47.15	1.41	9.02
Lablab, S.R 2003	1.81	0.06	0.22	46.45	1.49	9.62
Lablab, L.R 2004	2.37	0.09	0.21	45.91	1.65	9.96
Lablab, S.R 2004	2.46	0.08	0.22	46.29	1.36	9.40
Lablab,L.R 2005	2.08	0.06	0.37	47.24	1.47	9.50
Clotararia, L.R 2003	1.80	0.06	0.54	48.22	1.65	9.36
Clotararia, S.R 2003	2.17	0.11	0.35	48.33	1.45	8.06
Clotararia, L.R 2004	1.29	0.04	0.91	48.56	1.11	9.60
Clotararia, S.R 2004	3.71	0.19	1.10	48.18	1.45	8.94
Clotararia, S.R 2005	2.24	0.10	0.73	48.32	1.41	8.99
Maize STV L.R 2003	0.48	0.02	0.29	47.5	0.99	5.44
Maize STV, S.R 2003	0.58	0.03	0.47	47.85	1.11	2.66
Maize STV,L.R 2004	0.39	0.02	0.24	48.01	1.03	5.86
Maize STV, S.R 2004	0.41	0.02	0.41	47.86	0.53	5.28
Maize STV, S.R 2005	0.46	0.02	0.35	47.55	0.91	4.81

KEY:
L.R = Long Rain
S.R = Short Rain
STV = Stover

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 SURVEY

Title: Farmers' knowledge and practices in using soil fertility indicators in delineating on-farm fertility gradient and the use of plant residues to ameliorate soil infertility

4.1.1 Socio-economic characteristics of the study area

4.1.1.1 Farm sizes

Farm sizes in the study area ranged from 0.3 to 10.0 ha with a mean of 3.0 ha (Table 4.1.1). The results show that the size of land owned by farmers in different agro-ecological zones was almost similar. The deviation in the sizes across all the five agro-ecological zones was also wide. A large proportion of farmers from UM 4 and LM 3 agro-ecological zones who were interviewed were immigrants from other areas who had bought land and settled in these areas in the last ten to twenty years. Murithi (1998) reported comparable land holdings in the UM 1 agro-ecological zone of Manyatta and Runyenjes divisions of Embu District. Likewise, in the neighbouring division of Chuka in Meru South District, Mairura (2005) also reported a similar range of land holding per farm family.

Table 4.1.1: Mean size of farms (ha) owned by farmers in Embu, Kenya

Agro-ecological Zone	Mean	SD	Minimum	Maximum	Number of respondents
Lower Highland 1 (LH I)	3.0	2.2	0.4	7.0	26
Upper Midland 1 (UM 1)	2.5	2.0	0.3	8.0	32
Upper Midland 2 (UM 2)	2.8	1.8	0.8	7.0	21
Upper Midland 3/4 (UM 3/4)	3.0	1.9	0.7	7.0	27
Lower Midland 3 (LM 3)	3.4	2.5	1.0	10.0	27

4.1.1.2 Age and education level of farm decision makers

Figure 4.1.1 shows the distribution of the respondents by age. The majority of farm decision makers (95%) were aged between 31 to 60 years old and consisted of both male and female farmers. The highest numbers of farm decision makers (30%) were people aged 41-50 years old. This was an indication that most of the farm decision makers in the district were people with experience in the various farming activities of their respective localities.

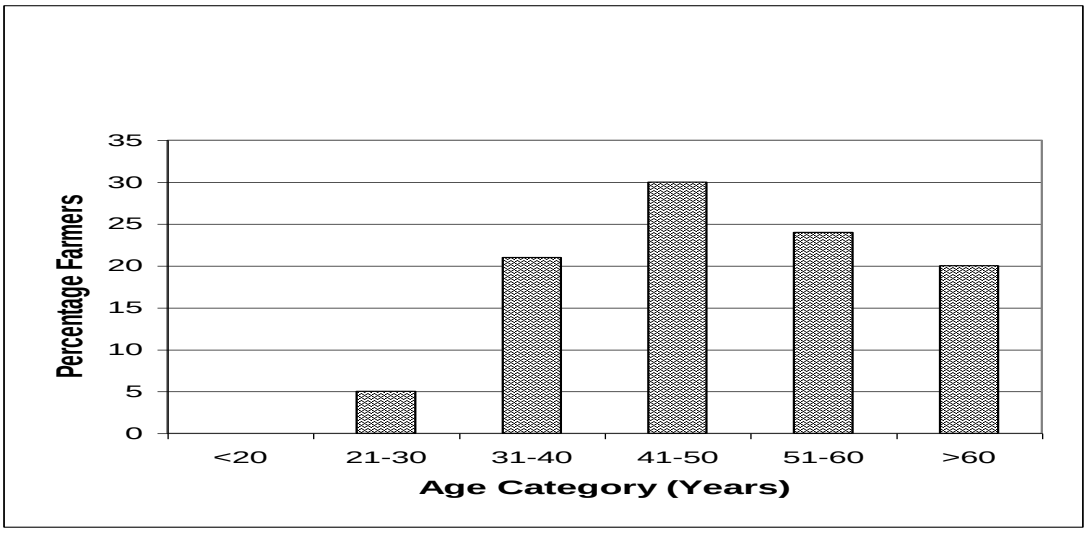


Figure 4.1 1: Distribution of farm decision makers by age groups in Embu, Kenya

Figure 4.1.2 shows the distribution of the respondents by the highest level of education attained. These results indicate that the majority of the respondents (84%) had some formal education. According to Omiti *et al.* (1999), education is a factor that determines farmer understanding in soil management strategies and is positively correlated with better soil management indices.

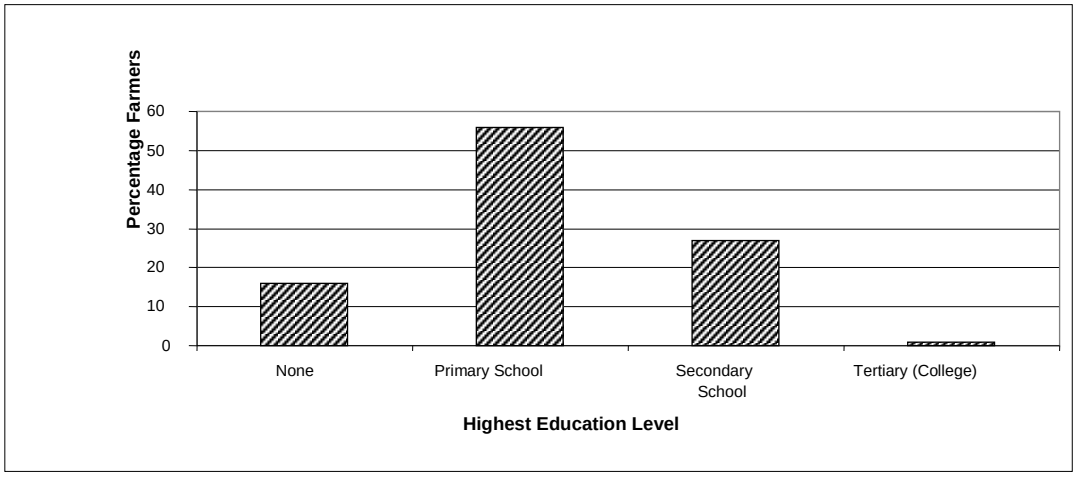


Figure 4.1 2: Distribution of respondents by highest education level attained in Embu, Kenya

4.1.2 Crop and livestock enterprises

Farmers in different agro-ecological zones were involved in the production of a wide range of enterprises both for cash generation and provision of food to the household. There was, however, no distinct criteria for the categorisation of farm enterprises as food or cash-based. For instance, certain crops such as maize and beans that were cultivated in the UM 1 and UM 2 agro-ecological zones as food crops were used in the warmer zones of UM 3 and LM 3 for cash generation in the households. Nearly all the households sampled had mixed type of farming where both crop and livestock enterprises co-exist within the farm. The main crop enterprises found throughout the entire transect of the study area were maize, beans and coffee. Using the predominant crop enterprises in the respective zones as a basis for classifying the entire study area, five cropping zones were identified. These were; tea, tea-coffee, coffee, marginal coffee and maize/beans zones for the LH 1, UM 1, UM 2, UM 3/4 and LM 3 agro-ecological zones, respectively. Similar delineation of land use zones was identified by Gitari *et al*. (1999).

Livestock farming was found to be an important farming enterprise in all the five agro-ecological zones of the district. The types of livestock kept by farmers include cattle,

goats, sheep, pigs and poultry. On average, farmers in the district owned two herd of cattle and one goat. By contrast, ownership of pigs and sheep was not evenly distributed across the five agro-ecological zones. Poultry keeping was a widespread occupation in the entire district. The population of birds kept per household was, however, higher in the UM 2 and UM 3/4 agro-ecological zones. The mean number of chicken per household was about 13. On average, each household in the district kept one type of livestock or another implying that mixed farming is the norm of the entire Embu District. Previous studies in the district have made similar conclusions (De Jager *et al*., 1998; Gitari *et al*., 1999).

4.1.3 Soil fertility management

4.1.3.1 Soil fertility improvement resources

The main soil fertility management resources used by farmers in the district were mineral fertilizers and animal manures. The types of commercial fertilizers that were most commonly used by farmers were the compound inorganic fertilizers with Nitrogen, Phoshorus and Potassium (NPK) compositions as follows: 20:20:0, 23:23:0 and 17:17:0. Diammonium Phosphate (DAP) and Calcium Ammonium Nitrate (CAN) were also commonly used. The fertilizer 20:20:0 was the most commonly used inorganic source of nutrients in maize, Irish potatoes and coffee. Maize planting accounted for the highest proportion of the total amount of mineral fertilizers used. In the usage of DAP, 16% and 15% of the total amount was applied in maize and Irish potatoes, respectively while the rest was spread across several other enterprises within the farm. In maize cultivation, most farmers (77%) applied only one single dosage of fertilizer. These results corroborate work by Ouma *et al*. (2002) who reported that about 88% of the farmers in Embu District use basal fertilizer application in maize while only 17% top dress their maize.

Farmers indicated that the use of animal manure was an important method in soil fertility management in their farms. However, majority of the respondents could not specify the exact amounts used for different crop enterprises within the farms. In Kiambu District of central Kenya, Makokha *et al*. (2001) conducted a survey to determine fertilizer and manure use in smallholder farms and established that DAP was the most commonly used fertilizer in maize, beans, Irish potatoes, and coffee. At the national level, Mugunieri *et al*. (1997) have reported that maize cultivation accounts for 20-28% of the total fertilizer consumption in Kenya.

4.1.3.2 Proportion of farm area affected by low soil fertility

The results presented in Figure 4.1.3 show that farmers in all the five agro-ecological zones were affected by low soil fertility. On average, 87% of all the farmers in the district were constrained by the problems of low soil fertility in their farms. Within the farm fields, different parts of the farm were affected differently by this problem of soil infertility. The proportion of land within different farm niches that was considered to have infertile soil is shown in Table 4.1.2. Sections of the farm that were locally positioned away from the homestead were more infertile (34%) compared to those positioned nearer to the homestead. Farm niches that lie at the steep slopes also accounted for about 20% of all the infertile sections of the farms. Tittonell *et al.* (2005) explored the diversity in soil fertility management of smallholder farms of western Kenya and found that variability in soil fertility at farm scale was mainly associated with topography, soil type and distance away from the homestead.

Table 4.1.2: Proportion (%) of land within different farm niches with infertile soil in Embu, Kenya

Farm niche	Percent (%)	Number of respondents
Steep slope (conserved)	9	12
Steep slope (non-conserved)	11	15
Far from homestead	34	46
Whole farm	11	15
None-specific	34	46
Total	100	134

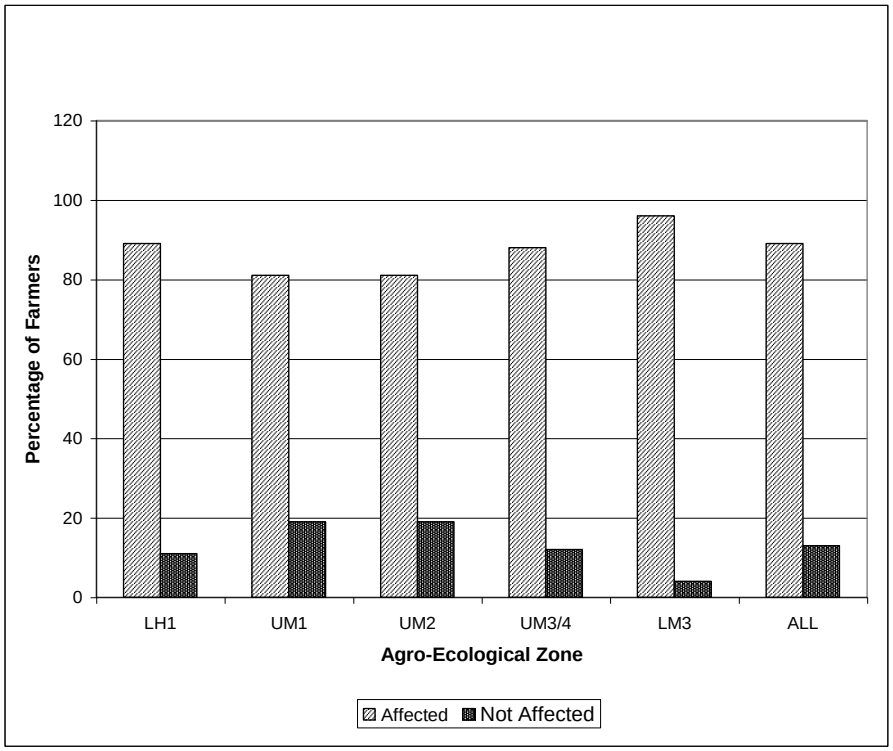


Figure 4.1 3: Proportion (%) of farmers affected by low soil fertility in Embu, Kenya

4.1.3.3 Reasons for soil infertility on farmers' fields

A summary of the ranking of the various reasons for the occurrence of soil infertility in farmers' fields in all the five agro-ecological zones of the study area show that inherent soil nature and little or no use of soil amendments were the predominant factors contributing to low soil fertility status in Embu District (Table 4.1.3). A nutrient monitoring study previously carried out in the district identified nitrogen as the main element that is lost

in large quantities in the smallholder farms and the major avenues of loss were identified as leaching, erosion and harvested crop products (Gitari *et al.*, 1999). In the present study, reasons given for the occurrence of soil infertility were comparable to those listed by farmers in Kiambu District of central Kenya who identified inadequate fertilization, removal of residues, continuous cultivation, lack of crop rotation, soil erosion and inherent soil nature as the main causes of soil infertility (Murage *et al*., 2000). Similarly, in Kwale and Kilifi Districts of coastal Kenya, farmers identified the main causes of soil infertility as continuous cropping, soil erosion, burning of plant residues, overgrazing, lack of crop rotation and shallow cultivation (Mureithi *et al*., 1996).

Table 4.1.3: Farmers' reasons for the occurrence of soil infertility (% of farmers affected) in Embu, Kenya

	Farmers' reasons for the occurrence of soil infertility						
Agro-ecological Zone	Soil erosion	Over Cultivation	Inherent soil nature	Little or no amendments	Type of trees in farm	Unknown	Mean per zone
Lower Highland 1	11	21	28	19	11	10	20
Upper midland 1	25	19	16	19	3	18	24
Upper midland 2	10	14	43	5	5	23	16
Upper midland 3/4	20	3	34	27	0	16	20
Lower highland 3	11	11	48	22	4	4	20

4.1.4 Soil fertility indicators

Farmers listed soil colouration, crop vigour as well as type of weeds as the main methods that they use to determine the status of soil fertility in their farms.

4.1.4.1 Soil colour and structure indicators

Most of the farmers (94%) gave soil colour as one of the most important visual assessment indicators used to determine soil fertility status. Farmers indicated that infertile soils were normally of red colouration whilst fertile soils generally attained a blackish or brownish-black colouration.

Some farmers (19%) listed a change in soil structure from fine and compact to one with big clods, as a second indicator that they use to denote the occurrence of a fertile soil. Other respondents (6%) did not, however, know of any relationship between the soil physical characteristics and soil fertility status. In coastal Kenya, farmers considered dark-coloured and white-coloured soils to be of high and low fertility status, respectively (Mureithi *et al*., 1996). In Tigray villages of Northern Ethiopia, farmers associate soil productivity with its depth, colour, topography and level of erosion. They consider good soil (referred locally as ‘reguid’) to be deep soils with red coloration while the poor soils (‘mehakelay’) are shallow soils, highly eroded and have a brown colouration (Corbeels *et al*., 2000).

4.1.4.2 Weed species as indicators of soil fertility

The most common weed species observed across all the five agro-ecological zones in the study were noted. Certain weed species were found in the entire transect area of the survey while others were more common in some specific agro-ecological zones. For instance, a weed species such as *Pteridium equilinum* was only found in the cooler agroecological zones of LH 1, UM 1 and UM 2 whereas weeds such as *Acanthospernum hispidum* and

Commelina diffusa were only found in the warmer agro-ecological zones of LM 3. Other weed species such as *Bidens pilosa* and *Rhynchelytrum repens* were found across all the five agro-ecological zones.

In each of the five agro-ecological zones, farmers listed weed species that they use to denote either low or high soil fertility in their farms. The frequency of prevalence in the occurrence of five weed species as indicators of high soil fertility was significantly higher ($p<0.01$) than all the other weeds listed. These were; *Commelina benghalensis, Bidens pilosa, Galinsoga parviflora, Commelina diffusa* and *Amaranthus* spp. The majority of the farm fields where these weeds were predominant had available P values ranging between 11.0 and 21.6 mg kg^{-1}; total N values of 0.44 - 0.25%; Ca^{++} values of between 6.0 and 2.2 cmol kg^{-1} whereas Mg^{++} concentrations averaged about 2.4 cmol kg^{-1}. Some of the weeds mentioned have been listed as indicators of high soil fertility by farmers in other parts of the central highlands of Kenya (Murage *et al*., 2000; Mairura, 2005), coastal lowlands of Kenya (Mureithi *et al*., 1996) as well as the Rolling Pampas of Argentina (Suarez *et al*., 2001). Other weed species that were listed as indicators of high soil fertility (although not statistically different) include *Ageratum conyzoides* and *Solanum nigrum*.

The list of the most common weed species that farmers use as indicators of low soil fertility status is given in Table 4.1.5. The red top grass (*Rhynchelytrum repens*) was the most prevalent weed species, in all the five agro-ecological zones, which farmers use to denote the occurrence of an impoverished soil. Soil chemical properties in the majority of the farm fields where this weed was predominant had available P concentrations ranging between 5.5-10.1 mg kg^{-1}; total N values of 0.22-0.16%; Ca^{++} values of between 2.9 and 0.41 cmol kg^{-1} while exchangeable Mg^{++} concentrations were 0.2-1.7 cmol kg^{-1}. Mairura (2005) also recorded *Rhynchelytrum repens* as a dominant low soil fertility indicator weed in smallholder farms of

the neighbouring Mbeere District. This weed species has been reported to inhabit farm fields after long term cultivation that has led to exhaustion or soil compaction (Terry and Michieka, 1987). In the present study, the frequency of prevalence in the occurrence of *Richardia scabra* and *Alternanthera philoxeroides* were significantly different ($p<0.01$) from all the other weed species listed in all the five agro-ecological zones. The bracken fern (*Pteridium equilinum*) was a significant indicator of low soil fertility although the occurrence was mainly limited to the higher altitude zones of LH 1 and UM1. The influence of temperature, due to altitudinal gradient, as well as soil acidity appear to have been the main factors that were important in determining the distribution of this weed in the district. Farm niches where this weed was common had pH (water) values of 4.8 to 5.0. Acid soils are known to affect the growth of many plants through the suppression of root development (Brady, 1999) and hence the reason why farmers associated the bracken fern with soil infertility. The upright starbur (*Acanthospernum hispidum)* also recorded a significantly higher ($P<0.01$) frequency of occurrence as an indicator of low soil fertility in the warmer areas of LM 3. The frequency in the prevalence of occurrence of *Oxygonum sinuatum* and *Tagetes minuta* were also significantly different ($p<0.05$) from all the other weeds listed. Suarez *et al*. (2001) elsewhere identified *Tagetes minuta* as one of the weeds that inhabit poor corn fields in the Rolling Pampas of Argentina.

Table 4.1.4: Frequency of prevalence in occurrence of weed species indicating high soil fertility status in different agro-ecological zones in Embu, Kenya

Weed species	Agro-ecological zone						
	LH 1	UM 1	UM 2	UM 3/4	LM 3	Mean	Probability of Significance
Commelina benghalensis	14	15	18	18	17	16 (1.3)*	0.0001
Bidens pilosa	14	16	16	16	12	15 (1.3)	0.0001
Galinsoga parviflora	18	22	17	13	10	16 (1.3)	0.0001
Amaranthus spp.	7	7	1	3	7	5 (1.3)	0.0001
Commelina diffusa	-	-	-	11	20	16 (3.1)	0.0001
Solanum nigrum	5	5	-	-	1	4 (2.1)	0.69
Rottboellia cochinchinensis	-	-	-	-	7	8 (3.1)	0.013
Ageratum conyzoides	-	-	3	2	-	2 (2.1)	0.33

* Figures in brackets are standard errors of the respective means.

Table 4.1.5: Frequency of prevalence in occurrence of weed species indicating low soil fertility status in different agro-ecological zones in Embu, Kenya

Weed species	Agro-ecological zone						
	LH 1	UM 1	UM 2	UM 3/4	LM 3	Mean	Probability of Significance
Rhynchelytrum repens	13	16	10	13	14	13 (1.2)*	0.0001
Richardia scabra	4	5	10	5	10	7 (1.2)	0.0001
Pteridium equilinum	9	7	3	-	-	7 (1.6)	0.0006
Digitaria velutina	-	4	2	1	-	3 (3.6)	0.14
Alternanthera philoxeroides	-	-	5	14	7	9 (1.6)	0.0001
Acanthospernum hispidum	-	-	-	-	-	13 (2.9)	0.0003
Oxygonum sinuatum	4	3	2	4	-	4 (1.4)	0.02
Tagetas minuta	-	3	1	-	6	4 (1.6)	0.04
Schluria spinnata	2	2	-	-	-	2 (2.0)	0.37

* Figures in brackets are standard errors of the respective means.

4.1.5 Role of agroforestry trees in modifying the soil environment

The list of the most common tree species observed across all the five agro-ecological zones in the study area are listed in Appendix 6.3. Some of the tree species were found in the entire transect area of the study area while others were more common in some specific agro-eecological zones. For instance, a tree species such as *Acacia mearnsii* was only found in the cooler agro-ecological zones of LH 1 and UM 1 whereas *Piliostigua thonningii* and *Combretum molle* were only found in the warmer agro-ecological zones of LM 3. Some of the tree species including *Grevillea robusta*, *Cordia africana*, *Croton macrostachyus* and *Persia americana* were found in all the 5 agro-ecological zones of the district. Within individual farms, most trees were found either along the farm boundaries delineating the various farm fields or along the main farm boundaries. Along the transect some of the tree species were found in the entire transect of the study area while others were more common in some specific agro-ecological zones. In each of the 5 agro-ecological zones, farmers were requested to list tree species whose presence either enhances or impoverishes the soil within its vicinity. There were some instances where a certain tree species was listed by some farmers in certain areas as an indicator of high soil fertility and by others as an indicator of low soil fertility status. This was particularly so in the case of *Grevillea robusta* where many farmers in the cooler, wetter zones listed it as an indicator of high soil fertility while some farmers in the warmer and less wetter agro-ecological zones of UM 3/4 and LM 3 listed it as an indicator of low soil fertility. The frequencies that a given tree species was listed as an agent of soil fertility improvement or deterioration are shown in Tables 4.1.6 and 4.1.7 for fertile and infertile farm niches, respectively.

Table 4.1.6: Frequency of prevalence in occurrence of tree species that enhance soil fertility in different agro-ecological zones at Embu, Kenya

Tree species	Agro-ecological zone					Mean	Probability of Significance
	LH 1	UM 1	UM 2	UM 3/4	LM 3		
Grevillea robusta	24	18	11	5	6	13 (1.9)*	0.0001
Persea Americana	11	1	3	4	3	4 (1.9)	0.04
Vitex keniensis	9	2	1	-	4	5 (2.6)	0.11
Croton megalocarpus	1	-	1	-	-	-4 (4.9)	0.45
Croton macrostachyus	2	2	5	8	8	5 (1.9)	0.02
Ficus sycomorus	-	1	4	8	7	6 (2.3)	0.02
Cordia africana	-	4	7	9	2	7 (2.3)	0.009
Combretum molle	-	-	-	-	13	14 (4.8)	0.007
Piliostigua thonningii	-	-	-	-	6	8 (4.7)	0.13

- Figures in brackets are standard errors of the respective means.

Table 4.1.7: Frequency of prevalence in occurrence of tree that impoverish soil fertility in different agro-ecological zones at Embu, Kenya

Tree species	Agro-ecological zone						
	LH 1	UM 1	UM 2	UM 3/4	LM 3	Mean	Probability of Significance
Eucalyptus saligna	9	7	6	2	10	7 (1.4)	0.0002
Macadamia integrifolia /tetraphylla spp.	9	11	5	4	-	7 (1.6)*	0.0004
Grevillea robusta	2	2	2	9	8	5 (1.4)	0.006
Cupressus lusitanica	4	9	2	-	-	5 (1.9)	0.02
Acacia mearnsii	2	2	-	-	-	2 (2.4)	0.38
Mangifera indica	-	2	3	7	1	3 (1.6)	0.06
Croton megalocarpus	-	1	3	4	2	3 (1.9)	0.11

- Figures in brackets are standard errors of the respective means

The frequency of prevalence in the occurrence of *Grevillea robusta, Combretum molle* and *Cordia africana* (Tables 4.1.6) as tree species that enhance soil fertility was significantly higher ($p<0.01$) than all the other tree species listed. Three other tree species; *Ficus sycomorous, Croton macrostachyus* and *Persia americana* were also listed as tree species whose presence in farms significantly ($p<0.05$) indicates the presence of high soil fertility status. Other tree species that were mentioned (though not significantly different) as soil fertility enhancing included *Vitex kinensis* and *Piliostigua thonningii.* These findings confirm work by Ashagrie *et al*. (1998) who studied the soil fertility gradient for a distance of 800 cm from the base of *Croton macrostachyus* agroforestry trees in Bure region of northwestern Ethiopia and showed a gradual decline in soil fertility with increasing distance from the base of these trees. In the central highlands of Kenya, Mugendi *et al*. (2003) demonstrated that agroforestry trees are capable of intercepting and recapturing the crop-inaccessible nutrients, below the roots of annual crops by the action of their deep roots.

Farmers also listed several tree species that were perceived to impoverish soil fertility status in their respective niches (Table 4.1.7). The blue gum tree (*Eucalyptus* spp.) was the most prevalent tree species, in all the 5 agro-ecological zones, whose presence signified deteriorated soil fertility status. The frequency of prevalence in the occurrence of this tree as well as that of *Macadamia integrifolia/tetraphylla* were significantly higher ($P<0.01$) than all the other trees listed across all the 5 agro-ecological zones. The frequency in the prevalence of occurrence of the woody tree species *Cupressus lusitanica* was also significantly different ($p<0.05$) compared to the other tree species. Other tree species that were also listed as soil impoverishing, although their frequency of prevalence was not significantly different, were *Mangifera indica* and *Acacia mearnsii* tree species (Table 4.1.7). Effects of soil impoverishing trees are, however, minimized when they are mixed with the soil improving ones. For instance, in the traditional systems of growing cacao (*Theobroma cacao*) crop under partly cleared forest known as “jungle cacao plantations”, smallholder farmers of west and central Africa intercrop young cacao trees with useful fruit trees such as *Mangifera*

indica and *Persia Americana*. Comparative assessment of selected top soil nutrients in these cacao-dominated tree gardens in southern Cameroon showed that soil fertility was higher in cacao agroforest compared to that in secondary forest that had been selectively cleared and planted to various types of food crops for one or two seasons (Duguma *et al*., 2001).

4.1.6 The role of plant residues in soil fertility

Farmers listed several sources of plant residues that were found in their farms. They also indicated whether the residues were known to enhance or impoverish soil fertility status.

4.1.6.1 Methods of increasing on-farm good performing plant residues

Most of the farmers interviewed (79%) appeared to have some knowledge of the occurrence of certain wild or domesticated plant species whose residues had a positive impact on soil fertility improvement as well as the knowledge on the methods they could use to increase the amounts of good performing plant residues in their farms (Table 4.1.8). Almost half of all the respondents (49%) indicated that they could increase the fertility of the soil by not removing any residues found in their farms in order for them to decompose *in situ.* Others (20%) considered the option of planting more land with such plant species as a feasible option. The majority of the respondents (87%) indicated their willingness to introduce new soil improving plant species in their farms.

Table 4.1.8: Methods that farmers can use to increase plant residues on-farm in Embu, Kenya

Method of increasing residues	Percent	Number of respondents
Leave existing residues in the farm	49	66
Plant more	20	34
Biomass transfer	17	23
Don’t know	14	11

4.1.6.2 Soil improving plant residues

There were three main sources of plant residues whose presence in the soil was beneficial. These sources included crops, trees and weeds. The frequency of prevalence in occurrence of soil improving plant residues is presented in Table 4.1.9. In the LH 1 agro-ecological zone there were very few sources of plant residues. The main residue sources in this zone were either the tea bushes (*Camellina sinensis)* or *Grevillea robusta* trees. The rest of the agro-ecological zones had several alternative sources of these plant residues. *Grevillea robusta* was a main source of plant residues for soil fertility improvement across all the five agro-ecological zones. Three other sources of plant residues showed a frequency of prevalence in occurrence that was significantly higher ($P<0.01$) than all the other residue sources. These three were; maize (*Zea mays*), beans (*Phaseolus vulgaris*) and *Grevillea robusta* tree leaves. Several researchers have investigated the usefulness of maize stover as a source of crop nutrients. The conclusion was that although the residues have a low content of lignin and polyphenol compounds (which govern the release of crop nutrients), the presence of high carbon-to-nitrogen ratio in these residues prolong the period when such released nutrients may be utilized by a growing crop (Nandwa, 1995; Ishuza,1997).

The frequency of prevalence in occurrence of all the other tree, crop or weed sources of plant residues was not significantly different even at the 5% level of significance. Apart from *G. robusta*, three other tree species whose leafy residues were listed as soil improving were *Cordia africana, Persea americana* and *Ficus sycomorus*. These tree species were recorded in at least three out of all the five agro-ecological zones. The plant residues of both Tithonia diversifollia and Camellina sinensis were listed to be good in soil improvement but their distribution was restricted to only two out of the five agro-ecological zones (Table 4.1.9).

Table 4.1.9 : Frequency of prevalence in occurrence of soil improving plant residues in different agro-ecological zones in Embu, Kenya

Plant residue source	Agro-ecological zone						
	LH 1	UM 1	UM 2	UM 3/4	LM 3	Mean	Probability of Significance
Zea mays	-	12	14	17	31	18 (2.4)*	0.0001
Grevillea robusta	9	11	9	8	2	8 (1.9)	0.001
Phaseolus vulgaris	-	12	11	6	6	9 (2.4)	0.002
Persea Americana	-	4	4	4	3	4 (2.3)	0.13
Vitex keniensis	-	3	1	-	-	2 (3.3)	0.52
Camellina sinensis	2	5	-	-	-	4 (3.4)	0.31
Galinsoga parviflora	-	4	-	6	1	3 ((2.7)	0.22
Ficus sycomorus	-	3	4	7	-	5 (2.7)	0.11
Cordia Africana	-	1	5	5	-	3 (3.3)	0.41
Tithonia diversifollia	-	-	3	3	-	3 (3.3)	0.39

* Figures in brackets are standard errors of the respective means.

4.1.6.3 Soil impoverishing plant residues

Plant residues whose presence in the soil has none or a negative effect on soil fertility are shown in Table 4.1.10. Two of these tree species; *G. robusta* and *P. americana* were listed by many farmers as soil improving and by a few others as soil impoverishing. Most of the farmers who listed *G. robusta* as soil impoverishing were mainly in the lower agro-ecological zones of UM 4 and LM 3. The frequency of prevalence in the occurrence of *Macadamia* spp., *Cupressus lusitanica* and *Eucalyptus saligna* were significantly different ($p<0.01$) compared to all the other plant residue sources across all the five agro-eclogical zones. Researchers such as Palm and Rowland (1997) as well as Mugendi and Nair (1997) have noted that the presence of some organic compounds such as lignin and tannins in plant residues act as an impediment to fast decomposition of such plant materials.

In the higher and cooler agro-ecological zones of LH 1 and UM 1, *Acacia mearnsii* was listed as a tree species whose residues are not associated with any soil fertility enhancing attributes. In the warmer zones of UM 4 and LM 3, farmers identified the residues of *Croton megalocarpus* and *Sorghum bicolour* as sources of soil impoverishing residues. Other tree residues listed as soil impoverishing, although not significantly different at $P<0.05$, included *C. megalocarpus* and the mango *(Mangifera indica)* fruit trees.

Table 4.1.10 Frequency of prevalence in occurrence of soil impoverishing plant residues in different agro-ecological zones in Embu, Kenya

Plant residue source	Agro-ecological zone						
	LH 1	UM 1	UM 2	UM 3/4	LM 3	Mean	Probability of Significance
Macadamia integrifolia /tetraphylla spp.	9	14	11	3	-	9 (1.6)*	0.0001
Cupressus lusitanica	9	8	9	-	-	9 (1.9)	0.0002
Eucalyptus saligna	4	3	12	7	6	6 (1.4)	0.0003
Grevillea robusta	2	2	2	8	4	4 (4)	0.02
Acacia mearnsii	2	2	1	-	-	2 (1.9)	0.37
Mangifera indica	-	-	2	6	1	3 (1.9)	0.17
Persea Americana	3	1	-	2	-	2 (1.9)	0.23
Croton megalocarpus	-	-	-	3	4	3 (1.9)	0.13
Sorghum bicolour	-	-	-	-	4	4 (3.4)	0.31

* Figures in brackets are standard errors of the respective means.

4.1.6.4 Reasons for good and poor crop performance under certain plant residues

Farmers attributed the ability of certain plant residues to either enhance or impoverish the soil primarily to the speed of decomposition of the respective residues. The majority of the respondents (86%) attributed good crop performance to the fast rate of decomposition of these residues. The reasons behind the poor performance of crops in farm niches where certain plant residues were prevalent were given as the failure of these residues to decompose (56%), slow rate of decomposition (16%), and the inability of these residues to release any plant nutrients upon decomposition (6%). Some of the farmers were not aware of any reasons behind the poor or good performance of crops under certain plant residues. These reasons given by the farmers corroborate well with those of researchers who have concluded that fast decomposing plant residues (primarily due to low carbon-to-nitrogen ratios as well as low levels of lignin and polyphenolic compounds) are important properties in determining the release of crop nutrients from such residues (Ibewiro *et al*., 2000a; Palm *et al*., 2001).

4.1.7: Soil chemical properties of samples from fertile and infertile farm sections

Table 4.1.11 presents results of various chemical properties that were determined for soils collected from the fertile and infertile sections of farmers' fields.

4.1.7.1 Soil pH

Results of soil pH (Table 4.1.11) show that soils from the wetter, higher altitude AEZs had a comparatively lower pH than those from the warmer, lower altitude parts of the survey transect. This was expected to be so since soils in higher altitude areas of Mount Kenya region are classified as humic Andosols while those of lower elevations are classified as Nitisols (Jaetzold *et al.,* 2006). Results of soil pH indicate that soils from the fertile and infertile farm sections ranged from 4.8-5.4 in Lower Highland 1 (LH 1) to 6.0 - 6.9 in LM 3. Mean soil pH of

Table 4.1.11: Selected soil chemical properties determined for soils collected from fertile and infertile farm sections of farmers' fields in Embu, Kenya

Agro-ecological zone (AEZ)	Soil parameter	Soil fertility status		SE	P value*
		Fertile section	Infertile section		
Lower Highland 1	pH (H_2O)	5.4	4.8	0.08	0.005
	Organic C (%)	4.0	2.6	0.59	0.177
	P (mg kg^{-1})	15.6	5.5	2.37	0.039
	K (cmol kg^{-1})	2.9	2.2	1.28	0.718
	N (%)	0.44	0.30	0.61	0.168
	Ca (cmol kg^{-1})	2.25	0.41	0.32	0.016
	Mg (cmol kg^{-1})	1.10	0.20	0.34	0.142
Upper Midland 1	pH (H_2O)	5.8	5.0	0.41	0.016
	Organic C (%)	3.3	2.2	0.41	0.140
	P (mg kg^{-1})	21.2	14.8	7.65	0.584
	K (cmol kg^{-1})	3.8	2.8	1.04	0.522
	N (%)	0.39	0.34	0.06	0.637
	Ca (cmol kg^{-1})	4.5	0.5	1.57	0.148
	Mg (cmol kg^{-1})	2.3	0.3	0.53	0.059
Upper Midland 2	pH (H_2O)	6.1	5.2	0.13	0.013
	Organic C (%)	2.3	1.7	0.001	0.205
	P (mg kg^{-1})	21.6	11.1	6.76	0.334
	K (cmol kg^{-1})	3.7	1.8	1.64	0.466
	N (%)	0.25	0.22	0.04	0.644
	Ca (cmol kg^{-1})	5.2	2.3	0.74	0.051
	Mg (cmol kg^{-1})	2.4	1.7	0.22	0.090
Upper Midland ¾	pH (H_2O)	6.0	5.6	0.20	0.235
	Organic C (%)	1.8	1.5	0.26	0.509
	P (mg kg^{-1})	11.0	10.1	1.10	0.622
	K (cmol kg^{-1})	1.1	3.3	1.65	0.399
	N (%)	0.16	0.16	0.02	1.000
	Ca (cmol kg^{-1})	6.1	2.9	0.55	0.015
	Mg (cmol kg^{-1})	2.6	1.7	0.29	0.096
Lower Highland 3	pH (H_2O)	6.9	6.0	0.15	0.031
	Organic C (%)	2.1	1.9	0.19	0.584
	P (mg kg^{-1})	31.5	6.1	11.9	0.209
	K (cmol kg^{-1})	2.0	1.4	0.69	0.574
	N (%)	0.18	0.19	0.02	0.766
	Ca (cmol kg^{-1})	9.0	6.6	0.90	0.132
	Mg (cmol kg^{-1})	4.1	3.0	0.75	0.358

* single degree of freedom contrasts

Soils from the infertile sections were significantly lower ($P<0.05$) than those from the fertile sections in all AEZs except UM 3/4. The combined results for all the five AEZs had a contrast P value of 0.002. Increased soil pH in soils from the fertile sections could have been due to the presence of decaying organic materials combined with higher concentrations of exchangeable bases that are responsible for neutralizing the inherent acidity (Kihanda, 1996; Nandwa and Bekunda, 1998).

4.1.7.2 Exchangeable bases (Ca^{++} and Mg^{++})

Table 4.1.11 shows that there were large differences in the concentrations of exchangeable bases between soils from fertile and those from infertile farm sections. For instance, soils from fertile farm sections in LH 1 and UM 1 AEZs had 5½ to 9 times more bases than those from infertile farm sections. The gap was narrower in the other three AEZs where a range of 1.4-2.3 times was observed. Despite these large differences, however, there were no statistical differences between these results of the two farm categories mainly due to the large variations in the data set for farms within the same farm category. For example, the coefficient of variation (CV) for Mg^{++} from the analysis of variance was 92% in LH 1 and that of Ca^{++} in UM 1 was 107%. High variation in data collected from similar category of farmers is a common phenomenon in surveys. For example, Micheni and Irungu (2003) obtained CV values of over 70% for some of the soil analysis parameters for samples collected from similar category of farmers' fields. In the current study, however, the combined results of all the five AEZs indicated that Ca^{++} and Mg^{++} had contrast P values of 0.007 and 0.02, respectively. These results are in agreement with those of Murage *et al.* (2000) who obtained significant differences in exchangeable cations of soil samples collected from good and poor farm sections of Kiambu District located in the central highlands of Kenya.

4.1.7.3 Potassium (K^+)

Analysis of variance for K^+ data for soils collected from the two farm sections showed that none of the 15 soil pairs from the 30 farms across the five AEZs were significantly different from each other (Table 4.1.11). This was probably due to the fact that K^+ has not been listed as one of the macro-elements that limit crop production in Kenya although recent work by Kanyanjua *et al*. (2003) points to a changing trend in certain parts of central and western Kenya.

4.1.7.4 Extractable Phosphorus (P)

The concentration of extractable Phosphorus (P) did not show any definite trend across the altitudinal gradient of the study area. Results (Table 4.1.11) also indicate that there were no significant differences ($p<0.05$) between soils from the two farm section categories in all AEZs except LH 1. Nonetheless, in UM 1 and UM 2, soils from the fertile farm section had 1.4 and 1.9 times, respectively, more extractable P than those from infertile farm sections. In LM 3 agro-ecological zone, soils from the fertile farm sections had 5.2 times more P than those from the infertile sections but the differences were not significant ($p<0.05$) due to the large coefficient of variation (110%) among the samples from the same category. These results corroborate those of Mairura (2005) who found no significant differences in P content of soils taken from fertile and infertile farm sections of smallholder farms of Chuka and Gachoka divisions of central Kenya. The results of the current study together with those of other workers in the region point out that P may not be a sensitive indicator of soil quality probably due to the fact that fixation of phosphate anions by aluminium and iron oxides in the soil complexes is common in the acidic soils of the upper elevations (Kihanda, 1996; Stocking and Murnaghan, 2001).

4.1.7.5 Organic carbon (OC)

Results (Table 4.1.11) indicate that as expected, soil organic carbon decreased with decreasing altitude ranging from 2.6 to 1.9% in LH 1 and LM 3, respectively. Soils from the fertile sections of higher altitude AEZs of LH 1, UM 1 and UM 2 had 1.5 times more OC than those from the infertile sections while those from the lower elevations (UM 3/4 and LM 3) had similar concentrations. However, the differences between the two farm section categories were not significant. This could be due to the large coefficient of variation among the samples from the same farm category. The results of this study do not tally with those of other workers in the same region who reported significant changes in OC from the good and poor farm categories (Murage *et al*., 2000; Mairura, 2005). In the semi-arid Districts of Mbeere and Tharaka (located in the same region), significant differences of samples from the productive and non-productive sections have been reported (Gachimbi *et al*., 2002; Micheni and Irungu, 2003).

4.1.7.6 Nitrogen (N)

Total N content of the soils decreased down the altitudinal gradient as was the case with organic carbon. Total N, was highest (0.44%) in LH 1 and lowest in UM 3/4 (0.16%) agro-ecological zone. Soils collected from UM 3/4 and LM 3 agro-ecological zones gave similar quantities of N irrespective of the farm section. Mean total N content for soil from fertile and infertile farm sections were not significantly different (Table 4.1.11). These findings corroborate those of Mairura (2005) who found no significant N level between productive and non-productive smallholder farm sections in Gachoka and Chuka divisions located within the central Kenya region. In contrast, Murage *et al*. (2000) found significant differences between total N content of samples from productive and non-productive sections of smallholder farms of Kiambu District in Central Kenya.

4.2 EXPERIMENT ONE

Title: The performance of maize (*Zea mays*) and three green manure legumes under different intercropping densities and sowing intervals

4.2.1 Germination and Establishment

Maize germination was good and emergence occurred within 5-7 days after planting in all seasons. The germination of crotalaria and lablab occurred within 5 days while that of mucuna took 7-10 days after planting. After germination, the seedling vigour of both crotalaria and lablab could be rated as good-excellent and good for mucuna. There was, however, a reversal in the seedling vigour for the lablab plants whereby they started to appear weak, stunted with some yellowing after the growth of the first trifoliate leaves and continued for the rest of the growing season. Thus, crop vigour for the three legume species in the first month could be described as good to excellent for mucuna and crotalaria and fair - poor for lablab. Low seedling vigour in lablab leading to low biomass accumulation has been reported in western Kenya by Nyambati (2002) and in northern Tanzanian District of Bukoba by Baijukya (2004) who attributed this occurrence to attack by bean fly (*Ophyiyomyia phaseoli*).

4.2.2 Performance of Maize

4.2.2.1 Maize plant height

The results of plant height (measured from the ground level to the tip of the longest tassel) for maize intercropped with the three GM legumes at the five relay cropping intervals are presented in Tables 4.2.1-3. This parameter was measured because of its importance in determining the grain and stover yields that are achieved in a given crop. The final maize plant height obtained in different treatments was greatly influenced by the amount of rainfall in a particular season. Maize heights achieved during the wetter LR 2004 and SR 2003

seasons were higher than those obtained in the less wetter LR and SR 2004 cropping seasons. For instance, the lowest and longest maize plant heights were 148 and 237 cm recorded in 2004 and 2003 cropping seasons, respectively.

The influence of intercropped GM legume on maize plant height showed that maize intercropped with mucuna at either the low or the high legume density attained similar plant heights. This finding is consistent with work by Mucheru (2003) who, worked in the central Kenya division of Chuka, and found that interplanting mucuna with maize does not affect its performance. In the present study, the time to relaying mucuna in maize did not significantly affect the height of maize (Table 4.2.1). Similar observations were also noted in low and high density lablab (Table 4.2.2) except during 2004 cropping seasons. Maize height in some of the lablab intercropped plots was significantly shorter than the rest. This observation was made in both early as well as late planted legumes at both densities. The trends were, however, not consistent in either the planting density or the relay cropping interval and hence may have resulted from other factors outside the legume effects. Furthermore, this observation was not consistent in the other parameters that were assessed such as grain and stover yields.

Table 4.2 1: Maize plant height as affected by low and high density mucuna green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		Mean	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	212	225	202	207	181	180	176	173	207	219	195	201
One	239	226	221	215	189	191	188	191	226	203	215	206
Two	203	239	201	232	178	197	189	184	193	212	189	213
Three	232	220	207	204	168	173	189	179	210	205	202	197
Four	223	223	212	192	165	178	184	169	209	191	196	191
Sole maize	227	227	216	216	177	177	183	183	191	191	197	197
CV (%)	9.9	8.9	9.6	10.2	10	8.6	7.6	7.6	12.5	15.4	5.6	6.4
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.2 2: Maize plant height as affected by low and high density lablab green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		Mean	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	227	226	177	173	157 b	171 ab	168	158	160	160	167	179
One	222	222	199	197	157 b	201 a	167	167	177	188	184	189
Two	227	220	196	172	163 b	158 b	174	174	202	160	193	172
Three	237	237	193	212	198 a	201 a	183	183	187	183	192	208
Four	232	235	209	184	164 ab	181 ab	188	188	199	154	198	186
Sole maize	227	227	216	216	177 ab	177 ab	183	183	191	184	197	197
CV (%)	10	9	13	14	11	10	11	13	21	18	13	9
$LSD_{0.05}$	NS	NS	NS	NS	34	34	NS	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Maize plant heights in the low density crotalaria intercropped plots were similar for all the intercropping intervals of this legume (Table 4.2.3). However, maize height in the high density crotalaria intercropped treatments (Table 4.2.3) was shorter in plots where the legume was intercropped at the same time with maize (period 0) when compared to all the other treatments. The differences were, however, significant in the SR 2003 and LR 2004 seasons only. As was the case with other parameters measured, this decrease in maize plant height appear to have been due to the presence of the crotalaria plants growing in close proximity with the maize plants suggesting that crotalaria plants exerted some competitive effects for the growth limiting factors such as water, nutrients or both to the maize plants (Fisher and Palmer, 1984; Fujita and Ofosu-Budu, 1996).

Table 4.2 3: Maize plant height as affected by low and high density crotalaria green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		Mean	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	231	215	223	202 b	179	153 b	204	176	197	203	208	190
One	214	234	201	224 a	164	194 a	174	188	164	216	182	211
Two	237	229	216	219 ab	188	182 a	184	188	199	235	206	210
Three	225	230	220	217 ab	181	168 a	189	186	217	203	206	194
Four	219	230	213	217 ab	190	191 a	176	188	186	225	197	210
Sole maize	227	227	216	216 ab	177	177 a	183	183	191	191	197	197
CV (%)	7.9	7.2	6.7	8.6	6.6	7.8	6.8	6.8	9.9	11.4	4.4	4.6
$LSD_{0.05}$	NS	NS	NS	17.0	NS	14.2	NS	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

4.2.2.2 Maize flowering

The variation in days to 50% flowering (tasselling and silking) across different seasons was small (68-71 days). Mucuna and lablab planting density and planting time (period) did not have a significant effect on days to 50% flowering of maize (Tables 4.2.4-5). Low density crotalaria did not significantly affect maize flowering but a high density of this legume significantly affected maize in all seasons except SR 2003 and LR 2005 (Tables 4.2.6). In all the other seasons, maize intercropped with a high density of crotalaria that was planted at the same time with maize (period 0) flowered 3-5 days later than the rest of the treatments. This phenomenon of late flowering appears to suggest that the high crotalaria density planted early in the season tends to exert some stressing effect on the maize plants (Schusser and Westgate, 1995) that are at close proximity to these legume plants probably due to competition for growth resources such as water, nutrients or both (Fujita and Ofosu-Budu, 1996). Similar results were obtained by Chui and Schibles (1984) who found that the tasselling of maize was delayed by a few days after intercropping it with soybean.

Table 4.2 4: Days to 50% flowering of maize as affected by low and high density mucuna green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Days to 50% flowering of maize											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	73	72	70	70	69	69	73	72	78	73	73	72
One	70	70	70	70	69	67	72	72	73	77	71	71
Two	72	70	71	71	70	68	72	71	77	79	73	72
Three	72	71	71	71	69	69	71	71	77	73	72	71
Four	71	70	70	70	69	70	72	72	73	75	71	72
Sole maize	70	70	71	71	69	69	71	71	77	77	72	72
CV (%)	1.9	1.9	1.7	1.7	1.3	1.4	2.0	2.0	6.2	6.8	2.0	2.4
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.2 5: Days to 50% flowering of maize as affected by low and high density lablab green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Days to 50% flowering of maize											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	70	72	70	72	69	70	71	72	80	78	73	73
One	71	71	71	72	69	68	72	72	79	76	73	72
Two	72	73	72	72	71	70	71	73	75	76	72	73
Three	72	72	72	70	70	69	72	71	74	72	72	71
Four	72	73	72	72	70	70	71	73	75	76	72	73
Sole maize	71	70	71	71	69	69	71	71	77	77	72	72
CV (%)	1.8	1.8	1.7	1.5	1.4	1.2	1.6	1.9	6.6	6.5	1.8	2.2
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.2 6: Days to 50% flowering of maize as affected by low and high density crotalaria green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Days to 50% flowering of maize											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	70	75 a	70	69	69	70 a	68	71 ab	75	78	71	73 a
One	72	70 b	70	69	70	68 b	71	73 a	79	71	72	70 b
Two	71	71 b	70	70	69	68 b	71	71 ab	70	72	70	70 b
Three	70	72 b	70	71	69	68 b	71	71 ab	71	73	70	71 ab
Four	72	70 b	70	69	69	68 b	72	70 ab	75	72	71	70 b
Sole maize	72	70 b	71	71	69	69 ab	71	71 ab	77	77	72	72 ab
CV (%)	2.1	1.9	1.9	1.8	1.7	1.9	3.1	2.0	4.6	5.6	2.1	2.2
$LSD_{0.05}$	NS	2.02	NS	NS	NS	1.85	NS	2.62	NS	NS	NS	2.12

Means with same letter in each column are not statistically different at P<0.05

4.2.2.3 Maize stover yield

Results for maize stover yields for mucuna and lablab treatments are presented in Tables 4.2.7-8. The range in stover yields was 3.36 - 8.77 Mg ha^{-1}. Highest and lowest stover yields were recorded during the SR 2003 and LR 2004 seasons when most of the mucuna and lablab plots registered about 7.0 and 4.0 Mg ha^{-1} of stover, respectively. Neither the planting density of mucuna/lablab nor the period to relaying the legumes had any adverse effect on maize stover production across all the five cropping seasons. Rapid vegetative growth of maize early in the season ensures temporal light use because of differences in maize versus mucuna/lablab phenologies leading to dominance of maize over the legumes (Fukai and Trebath, 1993; Gachene and Wortman, 2004).

Results for stover yields as affected by intercropping maize with crotalaria are presented in Table 4.2.9. Crotalaria density and relay-cropping period had a significant effect on stover biomass production. The period by density interactions were also significant. A high crotalaria density intercropped at the same time with maize reduced stover yields by between 10 and 47% when compared with sole cropped maize. This reduction in stover yield was highest (47%) during the driest season (Figure 3.2) of LR 2004. The reductions in stover yields were, however, less severe when compared to the reduction in grain yield. This was mainly attributable to the rainfall distribution pattern whereby high amounts of rain were received within 1-1½ months after the onset. Thus, for most of the cropping seasons, vegetative growth of maize was seldom affected by this late season moisture deficit. Temporal as well as spatial resource competition may have been responsible for this observation in maize/crotalaria intercrop plots (Schusser and Westgate, 1995, Fujita and Ofosu-Budu, 1996).

Table 4.2 7: Maize stover yield as affected by low and high density mucuna green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize stover yield (Mg ha^{-1})											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	6.81	5.87	8.51	6.87	2.89 c	5.11	5.70 a	4.00	4.40	4.52	4.88	5.27
One	6.82	7.24	8.09	6.83	6.36 a	3.75	5.49 a	4.69	5.33	4.80	6.42	5.49
Two	6.32	7.05	7.04	8.23	3.91 bc	5.69	5.70 a	5.11	4.11	3.89	5.42	5.99
Three	7.05	5.15	7.66	7.53	5.24 ab	4.45	5.22 a	4.91	5.28	4.95	6.09	5.40
Four	5.78	4.94	7.81	6.77	4.27 bc	5.16	3.89 b	4.18	4.49	3.92	5.25	5.00
Sole maize	6.76	6.76	7.98	7.98	4.64abc	4.64	4.65 a	4.65	4.80	4.80	5.77	5.77
CV (%)	35	28	16	20	24	27	12	15	31	38	17	17
$LSD_{0.05}$	NS	NS	NS	NS	2.04	NS	1.14	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Table 4.2 8: Maize stover yield as affected by low and high density lablab green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize stover yield (Mg ha^{-1})											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	4.78	6.59	5.83	6.54	5.80	3.80	4.11	4.04	3.39	3.97	4.79	4.49
One	5.76	6.72	7.23	6.26	4.04	4.16	4.18	5.07	3.97	3.63	5.04	5.17
Two	5.47	6.24	7.25	6.36	4.40	4.00	4.46	4.13	4.54	3.46	5.22	4.84
Three	5.52	7.64	7.20	7.43	4.57	4.58	4.73	5.29	3.27	4.98	4.98	5.94
Four	5.53	6.98	7.60	7.26	4.80	3.89	5.16	4.00	4.22	5.02	6.23	5.23
Sole maize	6.76	6.76	8.00	7.98	4.64	4.64	4.65	4.65	4.80	4.80	5.77	5.77
CV (%)	35	17	18	21	21	18	18	24	30	40	18	19
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.2 9: Maize stover yield as affected by low and high density crotalaria green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize stover yield (Mg ha^{-1})											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	5.82	3.93 b	5.82	6.40 b	5.56	3.36 b	6.11 a	4.78	4.38	5.47	6.11	4.79 b
One	6.00	5.96 ab	6.00	7.67 ab	3.11	4.06 ab	4.76 b	4.82	3.69	5.29	5.03	5.56 ab
Two	7.33	5.36 ab	7.33	8.32 ab	3.65	5.87 a	4.96 b	5.20	4.18	5.84	5.87	6.12 ab
Three	6.87	4.71 ab	6.87	7.64 ab	5.53	4.44 ab	5.47 ab	5.22	3.78	5.08	5.42	5.42 ab
Four	6.88	5.29ab	6.88	8.96 a	4.02	6.33 a	4.46 b	5.18	3.11	6.21	5.22	6.39 a
Sole maize	6.76	6.76 ab	6.76	7.98 ab	4.64	4.64 ab	4.65 b	4.65	4.80	4.8	5.77	5.77 ab
CV (%)	25	27	25	19	30	29	12	14	29	34	15	15
$LSD_{0.05}$	NS	2.27	NS	1.92	NS	1.87	1.11	NS	NS	NS	NS	1.52

Means with same letter in each column are not statistically different at P<0.05

4.2.2.4 Maize grain yield

The results of maize grain yield as affected by mucuna and lablab intercrops show that the density as well as the period of relay-cropping these legumes did not have a significant effect on maize grain yield (Tables 4.2.10-11). The density by period interactions were also not significant. The range in maize grain yield across the five seasons was 1.14-4.94 Mg ha^{-1} and 1.24-5.70 Mg ha^{-1} in mucuna and lablab plots, respectively. The highest and lowest maize grain yield were obtained in LR 2003 and LR 2004 seasons, respectively. This large seasonal variation in maize yields was attributable to variations in the rainfall amounts and its distribution (Table 3.2) during different seasons For instance, the seasonal rainfall totals for LR 2003 and LR 2004 cropping seasons were 589 mm and 303 mm, respectively, distributed over a period of 48 and 30 days for the LR 2003 and LR 2004, respectively (Figure 3.2). Occurrence of drought at the grain filling stage of maize reduces the photosynthetic rate and impairs assimilate translocation in kernels leading to reduced maize grain yield (Schussler and Westgate, 1995).

Intercropping mucuna or lablab with maize did not affect the final grain yield production which was an indication that the legumes did not exert any competitive effects for either water, nutrients or both probably due to the fact that these legumes exploit different horizons of water and light leading to complementary roles rather than competition (Natarajan and Willey, 1986; Squire, 1992).

Table 4.2 10: Maize grain yield as affected by low and high density mucuna green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize grain yield (Mg ha^{-1})											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	4.62	4.62	4.02	3.93	2.16	2.01	3.89	3.76	3.54	3.45	3.40	3.26
One	4.31	4.41	4.15	4.33	1.74	2.16	4.09	3.88	3.22	3.61	3.69	3.93
Two	3.95	4.94	3.89	3.87	1.38	1.88	3.89	3.76	3.08	2.96	3.24	3.48
Three	4.25	4.63	4.04	3.97	1.14	1.54	4.35	3.59	3.34	3.51	3.65	3.45
Four	4.19	4.22	4.55	3.10	1.23	1.66	2.60	3.14	3.22	2.94	3.14	2.84
Sole maize	4.81	4.81	3.61	3.61	2.94	2.94	3.36	3.36	3.07	3.07	3.15	3.15
CV (%)	40	22	31	33	26	36	20	19	34	42	22	25
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Table 4.2 11: Maize grain yield as affected by low and high density lablab green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize grain yield (Mg ha^{-1})											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	3.89	4.33	2.97	2.63	1.52 b	1.37	3.31	2.80	2.39	2.08	2.47	2.83
One	4.42	4.21	4.30	3.23	1.52 b	1.24	2.61	3.44	2.35	2.28	3.01	2.88
Two	4.35	4.51	2.97	2.81	1.40 b	2.73	3.55	3.65	2.61	2.07	2.95	2.79
Three	5.70	5.20	3.60	4.24	1.52 b	2.94	3.57	2.01	2.30	2.95	3.51	3.77
Four	5.54	4.41	4.10	3.34	1.66 b	1.59	3.85	3.36	2.94	3.00	3.58	2.99
Sole maize	4.81	4.81	3.63	3.63	2.94 a	2.94	3.36	3.36	3.07	3.07	3.15	3.15
CV (%)	21	19	25	22	20	18	28	24	52	46	15	18
$LSD_{0.05}$	NS	NS	NS	NS	0.66	NS	NS	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Low density intercropped crotalaria did not have a significant effect on maize grain yield in all seasons other than the LR 2004 (Table 4.2.12). However, high density intercropped crotalaria adversely affected maize grain yield. Intercropping crotalaria at the high density reduced maize grain in all seasons except SR 2004 (Table 4.2.12). Crotalaria planted at the same time (period 0) with maize had the highest maize yield depression. For example, early (period 0) crotalaria intercropped plots realized 66 and 30% yield reductions during the LR 2004 and LR 2003 seasons, respectively, when compared with the sole cropped maize plot. This decline in maize yields in high density intercropped crotalaria plots could mainly be attributed to competition for growth resources especially moisture. The effects of low moisture status on maize yields was exacerbated by its occurrence at the critical silking and grain filling stages of the maize crop development (Schussler and Westgate, 1995). Thus, a high density of crotalaria intercropped to maize exerted some competitive effects. These results corroborate the findings of Mucheru (2003) who, working in the central Kenya division of Chuka, also recorded lower maize yield in the high density crotalaria plots when compared with the mucuna intercropped ones for four consecutive seasons. Intercropping studies with grain legumes by Mureithi *et al.* (1996) also gave depressed maize grain yield due to cowpea intercropped at the same time with maize whilst the effect was reversed when cowpea was planted four weeks after maize. The authors attributed their results to temporal separation of resource use by the two component crops in the intercrop.

Table 4.2 12: Maize grain yield as affected by low and high density crotalaria green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize grain yield (Mg ha^{-1})											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	4.21	3.19 b	3.97	3.23 c	1.36 c	0.86 c	4.46	2.78	2.88	2.93	3.37	2.60
One	4.88	5.15 a	3.93	4.33 ab	1.84 bc	1.94 ab	3.20	3.11	2.50	3.95	3.27	3.70
Two	4.88	4.73 a	4.83	4.50 a	2.55 ab	1.91 ab	4.63	3.25	3.34	4.12	4.43	3.70
Three	4.03	4.67 a	3.77	4.07 ab	1.37 c	2.03 ab	3.62	3.71	3.05	3.65	3.17	3.62
Four	5.17	4.82 a	3.93	3.93 abc	1.48 c	1.90 b	3.32	3.34	2.25	3.56	3.23	3.51
Sole maize	4.81	4.81 a	3.63	3.63 bc	2.94 a	2.94 a	3.36	3.36	3.07	3.07	3.15	3.15
CV (%)	19	20	18	16	29	22	26	12	28	39	12	13
$LSD_{0.05}$	NS	1.42	NS	0.71	1.04	1.03	NS	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

4.2.2.5 Maize harvest index

Maize harvest index was lowest in LR 2004 due to the occurrence of drought (Figure 3.2) during the critical grain filling of maize crop (Tables 4.2.13-15). Generally, the period of relaying any of the three legumes into the maize crop did not affect the harvest index of maize. The legume by density, legume by period or legume by density by period interactions were also not significant. Low harvest index during drier seasons is mainly attributable to reduced production and translocation of assimilates to the developing kernels (Edmeades and Lafitte, 1993; Schusser and Westgate, 1995).

Table 4.2 13:Maize harvest index as affected by low and high density mucuna green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya.

Period (weeks) to relaying legume in maize	Maize harvest index											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	0.49	0.42	0.44	0.40	0.43	0.29	0.41	0.37	0.44	0.44	0.41	0.41
One	0.44	0.44	0.37	0.38	0.21	0.34	0.42	0.45	0.38	0.43	0.39	0.39
Two	0.40	0.41	0.40	0.35	0.27	0.25	0.40	0.42	0.43	0.42	0.38	0.38
Three	0.42	0.47	0.37	0.44	0.18	0.26	0.45	0.42	0.39	0.42	0.38	0.380
Four	0.40	0.41	0.46	0.39	0.23	0.26	0.40	0.43	0.42	0.43	0.38	0.38
CV (%)	15	10	26	15	17	27	12	14	10	21	16	17
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.2 14:Maize harvest index as affected by low and high density lablab green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize harvest index											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	0.43	0.47	0.43	0.47	0.43	0.47	0.43	0.47	0.43	0.47	0.43	0.47
One	0.44	0.39	0.44	0.39	0.44	0.39	0.44	0.39	0.44	0.39	0.44	0.39
Two	0.46	0.44	0.46	0.44	0.46	0.44	0.46	0.44	0.46	0.44	0.46	0.44
Three	0.52	0.45	0.48	0.45	0.48	0.45	0.48	0.45	0.48	0.45	0.48	0.45
Four	0.37	0.39	0.37	0.39	0.37	0.39	0.37	0.39	0.37	0.39	0.37	0.39
CV (%)	17	22	30	19	26	33	11	12	36	14	24	20
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.2 15: Maize harvest index as affected by low and high density crotalaria green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Maize harvest index											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density	Low density	High density
Zero	0.43	0.45	0.43	0.45	0.43	0.45	0.43	0.45	0.45	0.45	0.43	0.45
One	0.45	0.46	0.45	0.46	0.45	0.46	0.45	0.46	0.46	0.46	0.44	0.46
Two	0.46	0.47	0.46	0.47	0.46	0.47	0.46	0.47	0.47	0.47	0.46	0.47
Three	0.46	0.48	0.46	0.48	0.46	0.49	0.46	0.48	0.48	0.48	0.48	0.48
Four	0.43	0.48	0.43	0.48	0.43	0.48	0.43	0.48	0.48	0.48	0.37	0.48
CV (%)	10	10	19	19	19	19	14	14	11	11	24	15
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.2.2.6 Relative yield total (RYT)

The results of RYT for the maize-GM legume intercrops are presented in Tables 4.2.16-18. There were no differences between the RYT for the low as well as the high legume densities and hence combined values are presented. The range in RYT for all legumes across different seasons was 0.9-1.5. In majority of the seasons, RYT was greater than unity indicating that intercropping the GM legumes at various intervals was more efficient than planting a monoculture of maize. Relay planting mucuna early (0 to 2 weeks) resulted in significantly higher RYT than late planted legume, possibly due to the ability of this legume to grow fast before being shaded by the maize canopy. The beneficial effects of inter-planting any of these GM legumes with maize was probably attributable to the fact that maize being a C_4 plant has a higher growth rate (16 g m^{-2} day^{-1} in Kabete, Kenya) (Nkonge, 2005) than the legumes (3.4 g m^{-2} for mucuna in Los Tuxtlas region of southern Mexico) (Eilittä *et al*., 2004) and hence the cereal is able to establish faster and intercept more radiation than the legumes.

Table 4.2 16: Maize relative yield total (RYT) as influenced by combined low and high density mucuna green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Relative yield total (RYT)					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Zero	1.2 abc	1.2 ab	1.5 a	1.3 a	1.2	1.4
One	1.4 a	1.4 a	1.4 ab	1.4 a	1.3	1.4
Two	1.3 ab	1.2 ab	1.4 ab	1.3 a	1.4	1.3
Three	1.1 cd	1.1 b	1.2 b	1.2 a	1.5	1.3
Four	1.0 c	1.0 b	1.3 ab	0.9 b	1.2	1.1
CV (%)	19	16	20	13	17	17
$LSD_{0.05}$	0.28	0.24	0.34	0.20	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Table 4.2 17: Maize relative yield total (RYT) as influenced by combined low and high density crotalaria green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Relative yield total (RYT)					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Zero	1.3	1.3	1.5	1.5 a	1.3	1.4
One	1.5	1.4	1.5	1.4 ab	1.3	1.4
Two	1.5	1.4	1.4	1.3 bc	1.5	1.5
Three	1.3	1.1	1.4	1.2 c	1.5	1.3
Four	1.3	1.1	1.3	1.1 c	1.4	1.3
CV (%)	23	19	33	16	28	25
$LSD_{0.05}$	NS	NS	NS	0.27	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Table 4.2 18: Maize relative yield total (RYT) as influenced by combined low and high density lablab green manure relayed in the maize crop at five different intervals for different cropping seasons in Embu, Kenya

Period (weeks) to relaying legume in maize	Relative yield total (RYT)					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Zero	1.1	1.1	1.3	1.4 ab	1.3	1.4
One	1.2	1.4	1.5	1.1 ab	1.3	1.5
Two	1.1	1.3	1.4	1.1 b	1.5	1.5
Three	1.2	1.4	1.5	1.5 a	1.5	1.3
Four	1.2	1.4	1.1	1.1 b	1.4	1.3
CV (%)	23	26	32	21	28	26
$LSD_{0.05}$	NS	NS	NS	0.32	NS	NS

Means with same letter in each column are not statistically different at P<0.05

4.2.3 Performance of legumes - Dry matter production

Legume dry matter (biomass) production across the five cropping seasons are presented in Figures 4.2.1a-e for mucuna, Figures 4.2.2a-e for crotalaria and Figures 4.2.3a-e for lablab. There were seasonal variations in legume biomass production due to rainfall intensity and distributions during different seasons. For example, the seasonal rainfall totals for LR 2003 and LR 2004 cropping seasons were 589 mm and 303 mm, respectively,

distributed over a period of 48 and 30 days for the LR 2003 and LR 2004, respectively.

Legume dry matter production was in the order, highest to lowest; mucuna at high density (HD) > mucuna at low density (LD) > crotalaria HD > crotalaria LD > lablab HD > lablab LD. There were no significant legume by planting density interaction in all the seasons but the legume by period interactions were highly significant in all seasons except SR 2003 and LR 2005.

Early (period or weeks 0 and 1) intercropped mucuna (Figure 4.2.1a-e) produced more dry matter than late (period 3 and 4) intercropped mucuna. However, only mucuna that was planted at the same time with maize (week or period 0) produced biomass that was significantly different from the one relay-cropped 3 or 4 weeks later for all seasons and densities except LR 2005 and LR 2003 low density.

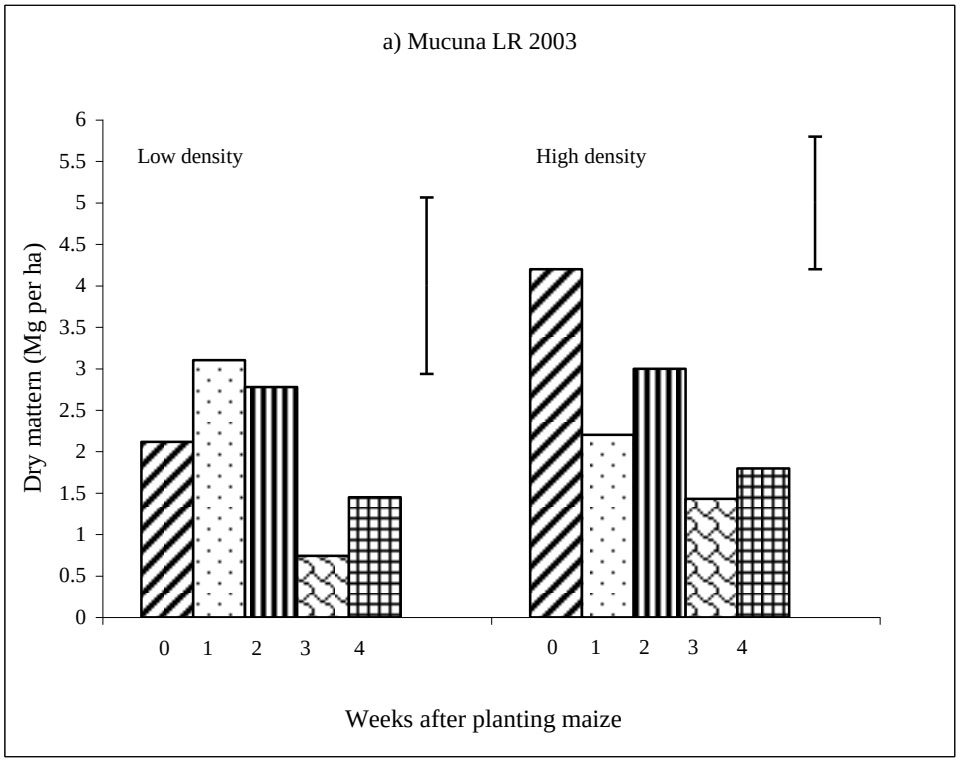


Figure 4.2.1 a: Mucuna dry matter production for different planting densities during Long Rains (LR) 2003 season.Significant difference ($LSD_{0.05}$) bars shown

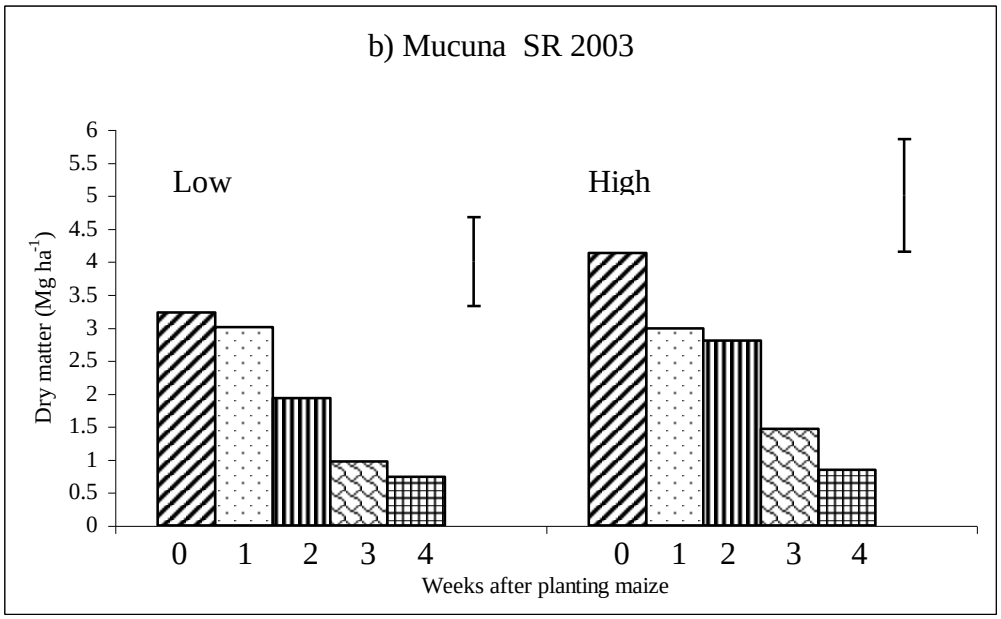


Figure 4.2.1 b: Mucuna dry matter production for different planting densities during Short Rains (SR) 2003 season. Significant difference ($LSD_{0.05}$) bars shown

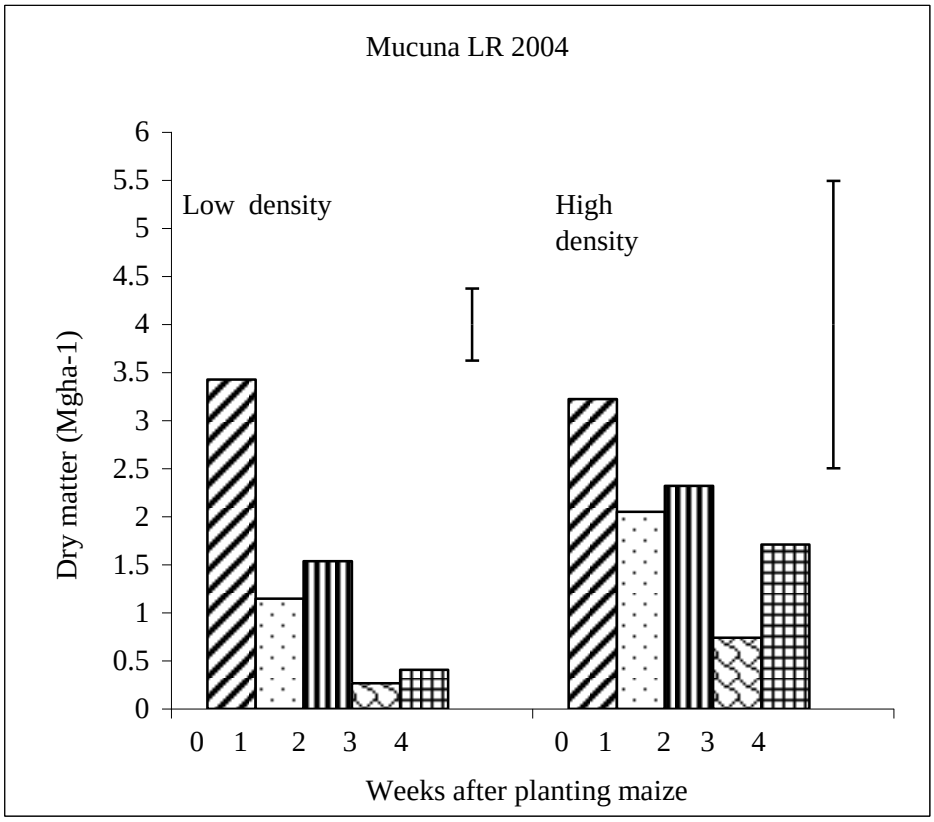


Figure 4.2.1 c: Mucuna dry matter production for different planting densities during Long Rains (LR) 2004 season. Significant difference ($LSD_{0.05}$) bars shown

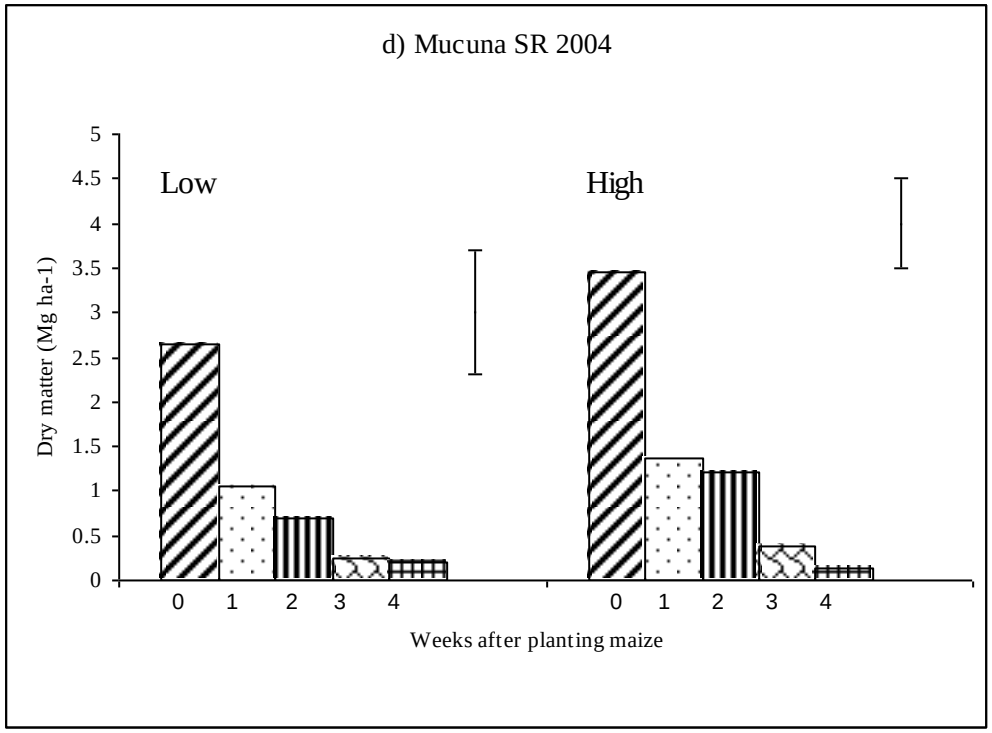


Figure 4.2.1 d: Mucuna dry matter production for different planting densities during Short Rains (SR) 2004 season. Significant difference ($LSD_{0.05}$) bars shown

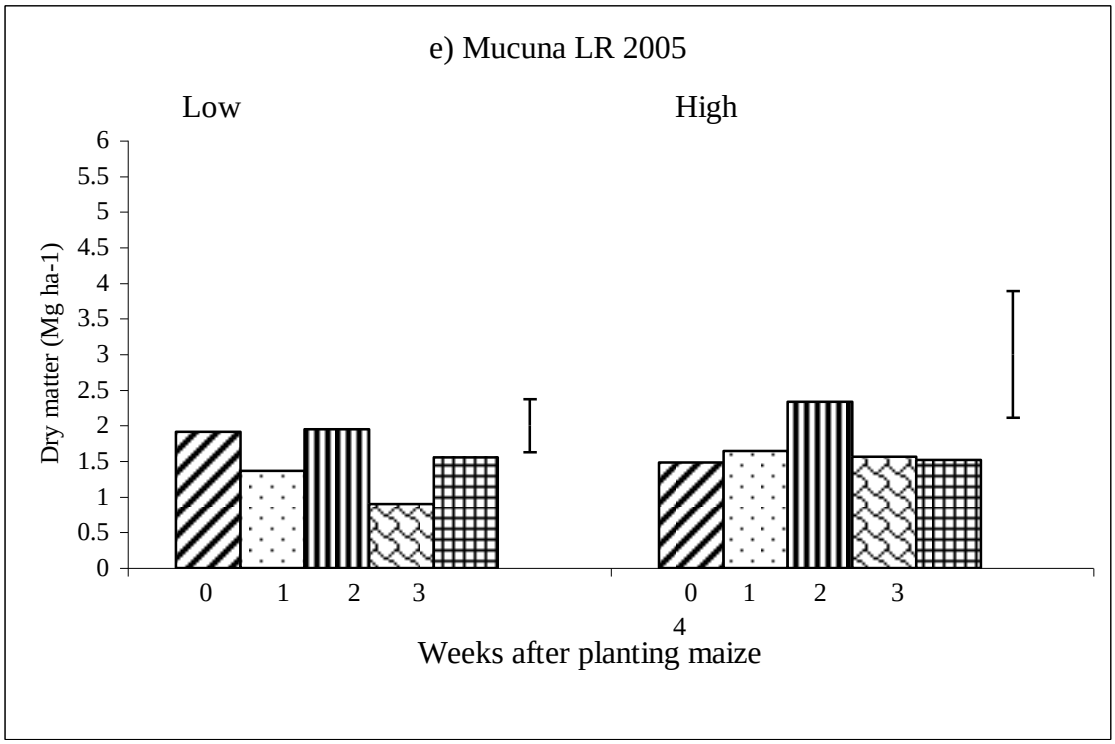


Figure 4.2.1 e: Mucuna dry matter production for different planting densities during Long Rains (LR) 2005 season. Significant difference ($LSD_{0.05}$) bars shown

Trends in crotalaria biomass production (Figure 4.2.2a-e) were similar to those of mucuna although only the latest (week 4) intercropping gave a significantly lower biomass yield than the rest for all seasons except that of the high density crotalaria plots in LR 2003 and LR 2005.

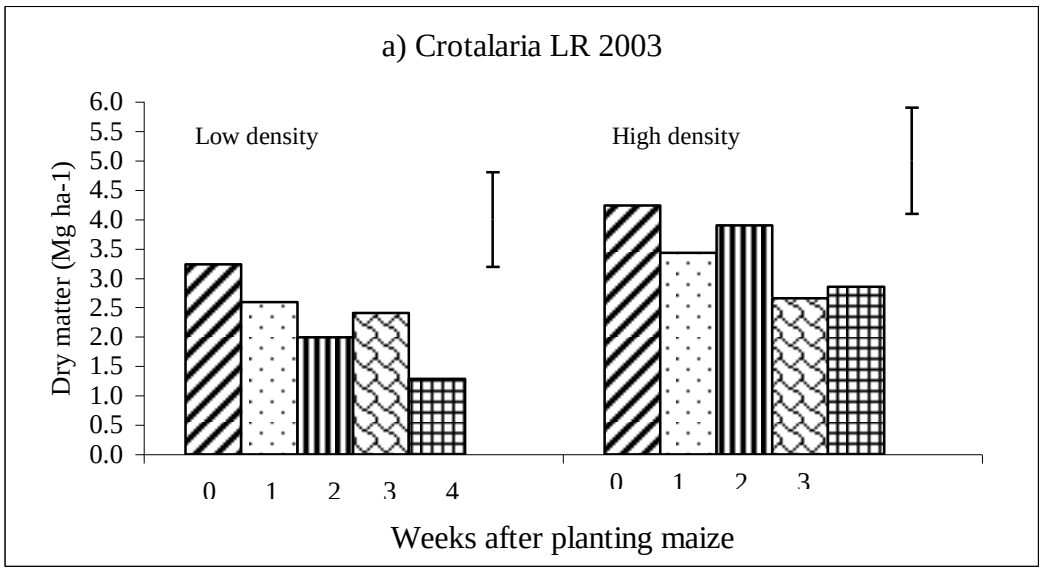


Figure 4.2.2 a: Crotalaria dry matter production for different planting densities during Long Rains (LR) 2003 season. Significant difference (LSD) bars shown

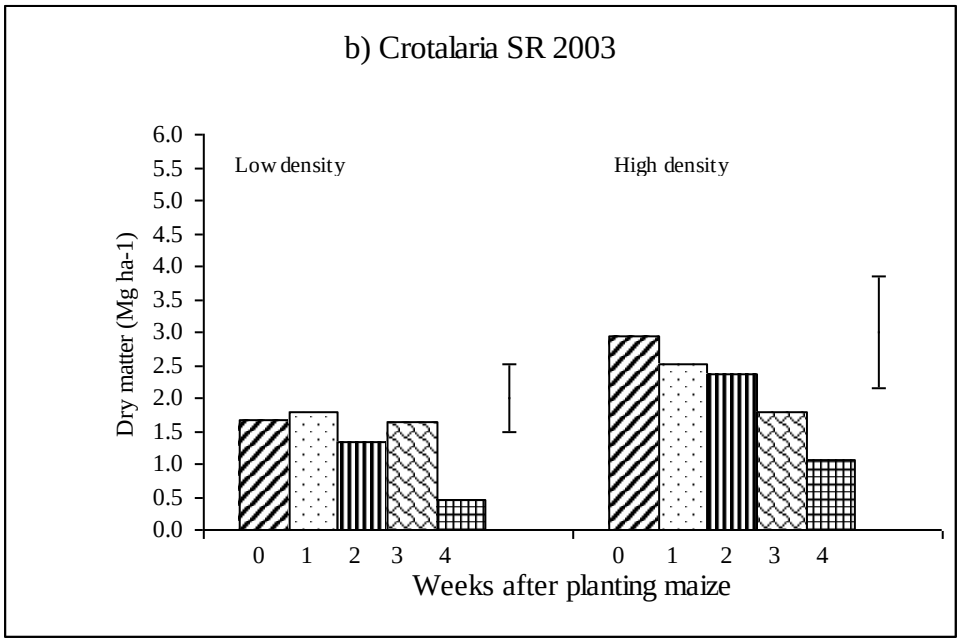


Figure 4.2.2 b: Crotalaria dry matter production for different planting densities during Short Rains (SR) 2003 season. Significant difference ($LSD_{0.05}$) bars shown

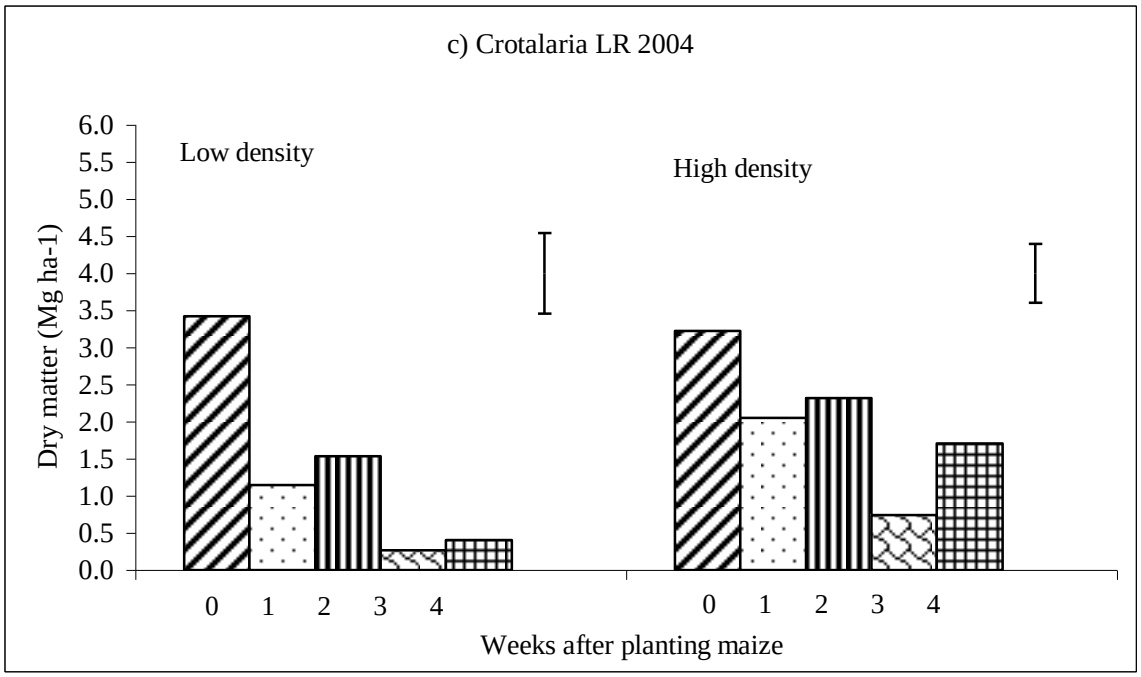


Figure 4.2.2 c: Crotalaria dry matter production for different planting densities during Long Rains (LR) 2004 season Significant difference (LSD) bars shown

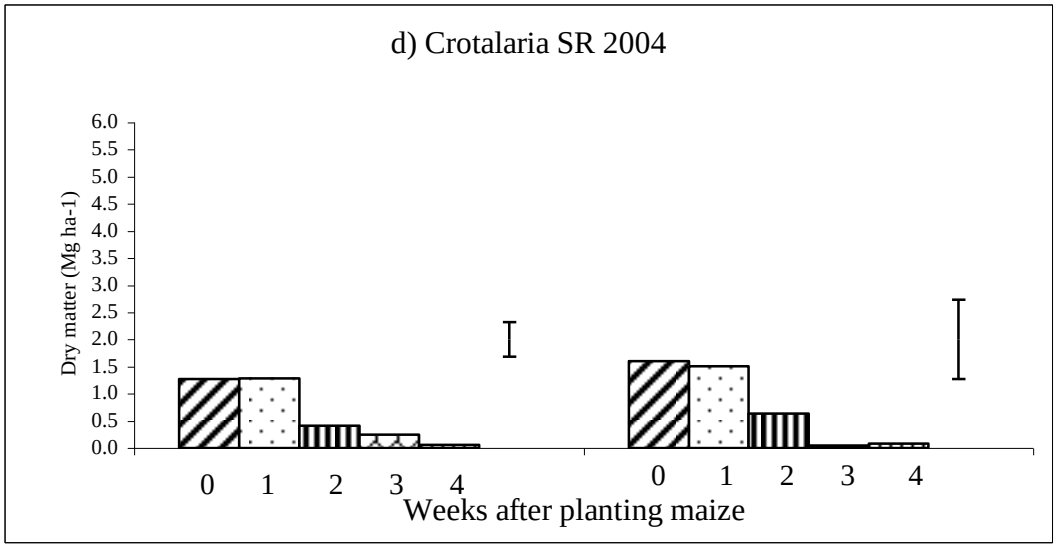


Figure 4.2.2 d: Crotalaria dry matter production for different planting densities during Short Rains (SR) 2004 season. Significant difference ($LSD_{0.05}$) bars shown

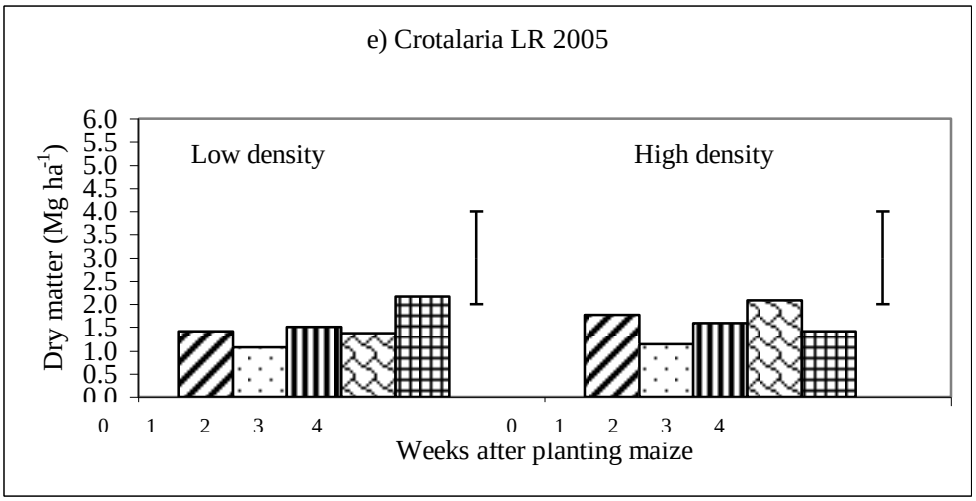


Figure 4.2.2 e: Crotalaria dry matter production for different planting densities during Long Rains (LR) 2005 season. Significant difference ($LSD_{0.05}$) bars shown

Legume biomass production for lablab (Figures 4.2.3a-e) was relatively low in all intercropping intervals when compared with the other two legumes (mucuna and crotalaria). For example, lablab biomass yield was below 1.0 Mg ha^{-1} for the low density stand in all seasons other than LR 2005. On average, lablab biomass was about 4 to 10 times lower than that of mucuna. The decreased biomass production in lablab could in part be attributed to the low seedling vigour exhibited early in the season. Lablab planted early (week 0) did not show significant biomass production from the ones planted late in the season at either low or high planting density. Other researchers, Nyambati (2002) and Baijukya (2004) also recorded low biomass yields with lablab in farmers' fields in northwestern Kenya and the northern Tanzanian District of Bukoba, respectively.

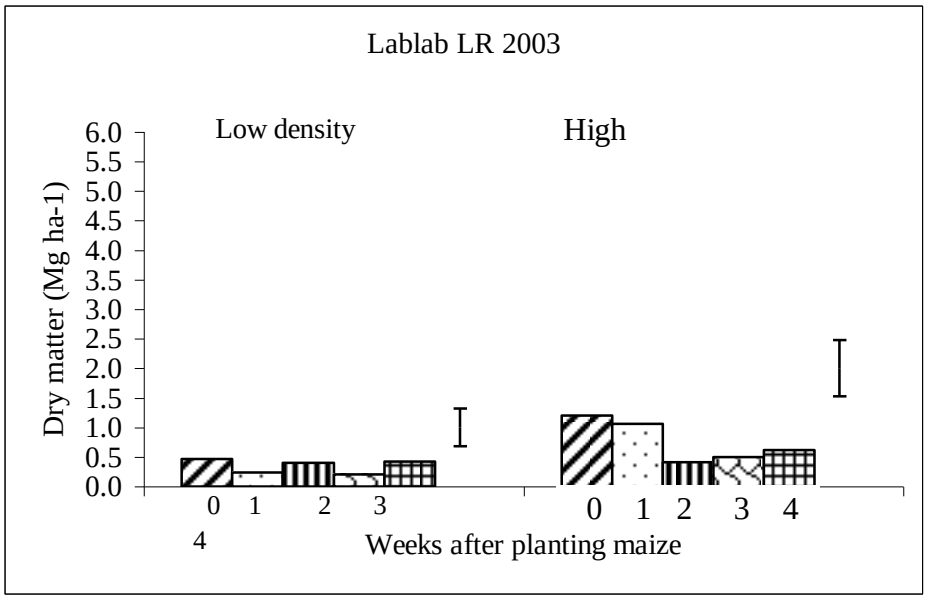


Figure 4.2.3 a: Lablab dry matter production for different planting densities during Long Rains (LR) 2003 season. Significant difference ($LSD_{0.05}$) bars shown

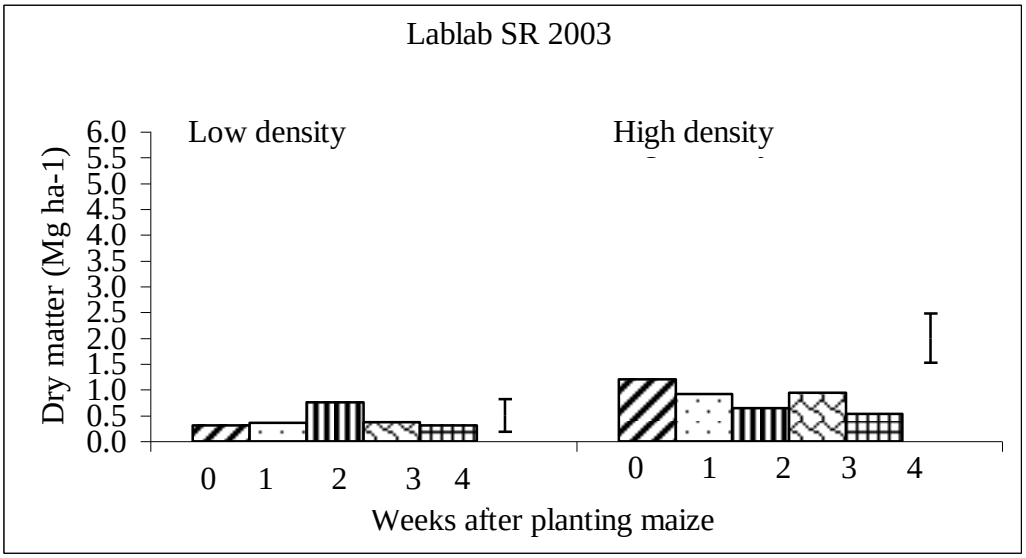


Figure 4.2.3 b: Lablab dry matter production for different planting densities during Short Rains (SR) 2003 season. Significant difference ($LSD_{0.05}$) bars shown

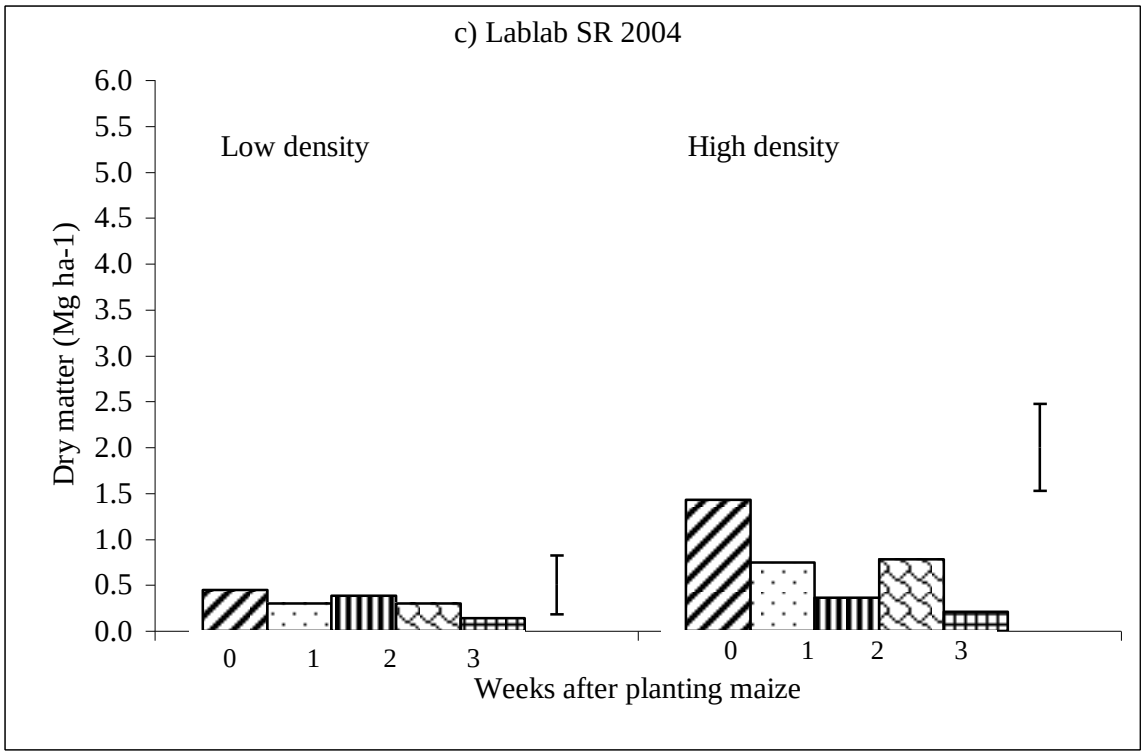


Figure 4.2.3 c: Lablab dry matter production for different planting densities during Short Rains (SR) 2004 season. Significant difference ($LSD_{0.05}$) bars shown

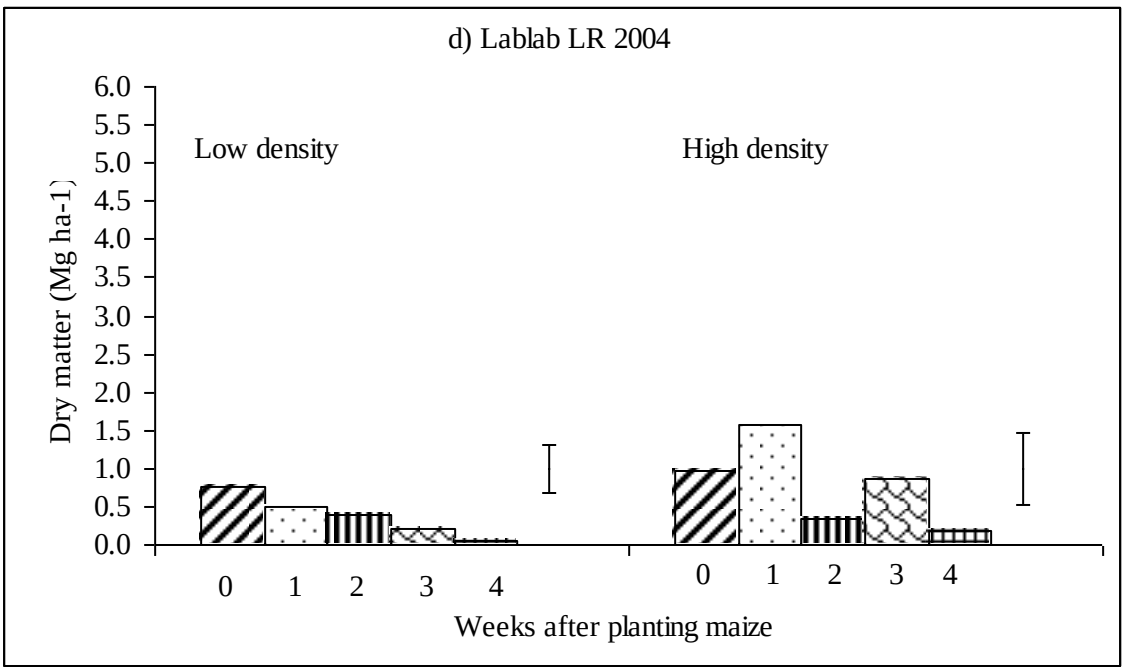


Figure 4.2.3 d: Lablab dry matter production for different planting densities during Long Rains (LR) 2004 season. Significant difference ($LSD_{0.05}$) bars shown

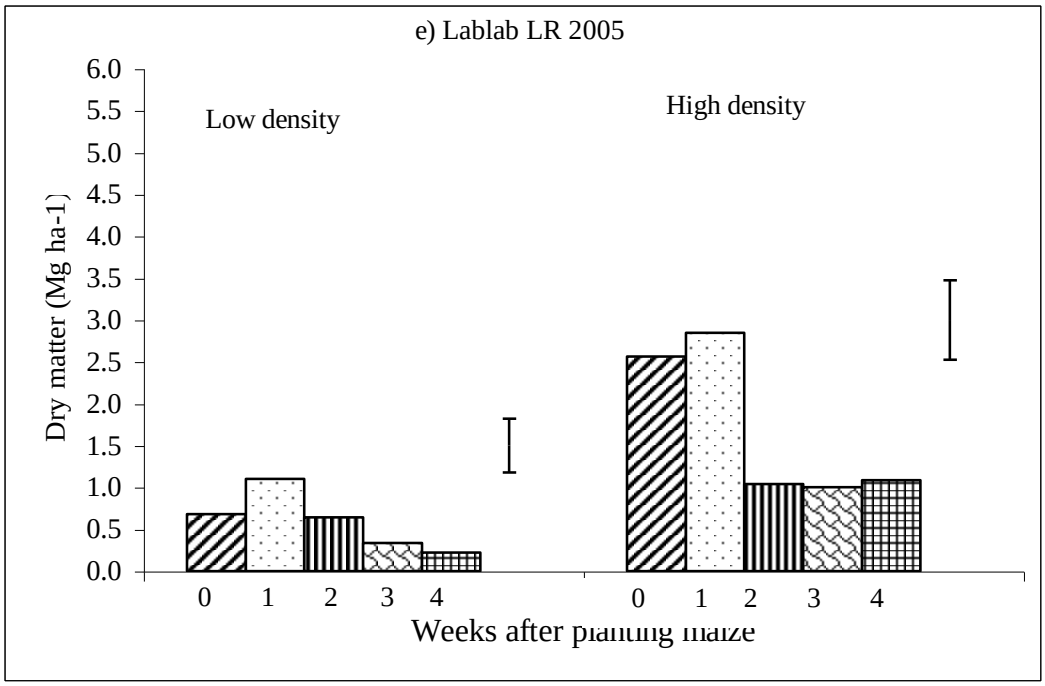


Figure 4.2.3 e: Lablab dry matter production for different planting densities during Long Rains (LR) 2005 season. Significant difference ($LSD_{0.05}$) bars shown

In conclusion, it is noteworthy that intercropping any of the three green manure (GM) legumes with maize had a negative effect on the legume herbage production in all legumes across all seasons. For instance, when compared against the sole cropped mucuna plot, intercropped mucuna planted at the same time with maize (week or period 0) at a high legume density produced only 25, 27, 46, 48 and 33% of the total herbage produced in the sole cropped mucuna stand during the LR 2003, SR 2003, LR 2004, SR 2004 and LR 2005 seasons, respectively. Similar trends were apparent in crotalaria and lablab. This reduction in legume herbage production seems to suggest that in a maize/GM legume intercropping situation (under the weather conditions typical of this experiment), maize acts as the dominant component crop in the cropping mixture and thus suppresses the growth and development of the legume component. This observation is in agreement with that of Ofori and Stern (1987) who stated that in a cereal-legume intercrop, the cereal component with relatively high growth rate, height advantage, and a more extensive root system, is favoured

in competition with the associated legume and hence the cereal becomes the dominant component while the legume component becomes the dominated component of the intercrop. Maize is a C_4 plant that has higher growth rate and hence its canopy established faster and highly shaded the shorter growing GM legumes ((Eilittä *et al*., 2004; Nkonge, 2005).

4.2.4 Canopy interception of Photosynthetically Active Radiation (PAR)

4.2.4.1 Effect of legume on PAR interception

Measurements of PAR were carried out during the SR 2004 and LR 2005 seasons. The measurements started at the sixth week so as to allow for germination of legumes planted at latter (period 3 and 4) intervals. Sole-cropped legumes intercepted significantly more solar radiation than either sole maize or intercrop legumes throughout the season during both SR 2004 and LR 2005 seasons. The amount of light intercepted by intercropped legumes progressively decreased with time during SR 2004. For instance, intercropped mucuna intercepted 36 and 21% of the total PAR at the sixth and twelfth week, respectively. This drop in PAR interception as the season progressed was probably attributable to the rainfall pattern (Figure 3.2) whereby most of the mid and late stages of the cropping season remained dry. In contrast, the amount of PAR intercepted by intercropped legumes increased gradually during the LR 2005 cropping season. However, the total PAR intercepted by these legumes never exceeded 30% or about one third of the total PAR intercepted by the sole crop legumes during the entire season. Muchow *et al*. (1993) and Wanderi (2004) observed increased PAR interception by both maize and pigeonpea over time but thereafter decreased as the two crops reached physiological maturity when leaves senesced. The authors attributed higher PAR capture in maize compared with pigeonpea to the differences in crop growth rates where maize has an initial rapid growth rate compared to the slow growth rate of the legume crop. Thus, canopy development in the intercropped legumes

gradually increased as the legumes grew but was greatly hindered by the shading effect of the taller maize component crop. Favourable moisture conditions in LR 2005 may have contributed to the prolonged period of growth during this season when compared to the previous season. The PAR results also indicate that although mucuna intercepted more light than crotalaria or lablab, the differences were not significant.

4.2.4.2 Effect of density on PAR interception

The amount of photosynthetically active radiation (PAR) intercepted by the two densities of each of the three legumes are presented in Figures 4.2.4a-f. Legume planting density did not have any significant effect on PAR interception. The legume by density interactions were also not significant in all the three legumes in both seasons. Both the low as well as the high density of each of the three legumes appeared to intercept similar amounts of light. Legume canopy development in the two seasons of SR 2004 and LR 2005 (when PAR was assessed) was dependent upon seasonal rainfall (Figure 3.2) and probably temperatures.

As indicated earlier, the SR 2004 cropping season was characterized by hot and dry period conditions whereas LR 2005 was relatively cool and moderately wet during the entire season. In SR 2004, mucuna and crotalaria showed a decrease in solar radiation interception as the season progressed while the converse was true for the LR 2005 season. Lablab, on the other hand, recorded higher PAR interception during the mid and late parts of the growing season in SR 2004 but not in the LR 2005. The amount of PAR intercepted by the two legume densities ranged between 15 and 36%. In the early and mid growth (week 4 to week 10) low density crotalaria canopy intercepted significantly lower PAR compared to the high density canopy (Figures 4.2.4a and 4.2.4b). However, PAR interception at the late stages of crop growth was similar for the two planting densities as was the case for mucuna and lablab. This seasonal

variation in light capture was possibly due to the growth habit as well as the nature of canopy development in the three legumes. Mucuna and lablab are creeping or spreading legumes whereas crotalaria has an erect growth pattern (Yost and Evans, 1988) that contribute differently to PAR capture particularly during the early growth stages.

Low densities of mucuna and lablab intercepted almost equal amounts of light throughout the season in both years but low density crotalaria captured about two thirds of the radiation intercepted by the high density canopies during the LR 2005 season. At the latter periods of the LR 2005 cropping season, both densities of each of the three legumes intercepted similar amounts of light (18-30%). These trends in PAR interception by both the high as well as the low densities of the legumes appear to suggest that canopy development by the low density was as high as that of the high density throughout the season. This may have been due to prolific branching of the stems of the legumes whereby low density stands may have developed more branches than the higher density ones thus contributing equally to PAR interception. Zaffaroni and Schneiter (1989) have noted that row arrangement and plant architecture influence canopy structure, thereby influencing the efficiency of solar radiation interception by green plant tissue.

The inter-seasonal variation in PAR capture was probably attributable to crop growth differences whereby SR 2004 cropping season was characterized by premature drying and senescence while wet soil conditions in LR 2005 promoted continuous foliage growth and development over the entire cropping season. In a similar environment at Kabete, Kenya, Mburu *et al*. (1999) observed inter-seasonal variation in intercepted PAR of bean canopy and attributed it to leaf growth variation due to rainfall differences. At the same site, Wanderi (2004) also observed inter-seasonal variations in PAR capture of a maize/pigeonpea intercrop and attributed them to leaf drying and senescence which became more pronounced during the drier seasons.

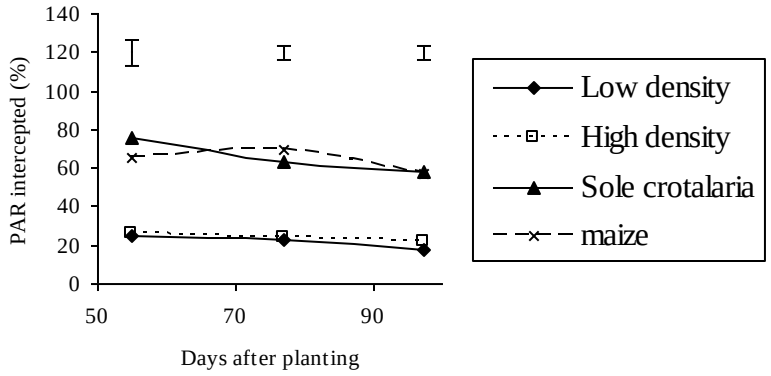


Figure 4.2.4 a :Canopy photosynthetically active radiation (PAR) interception by maize and crotalaria over time for short rains (SR) 2004 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

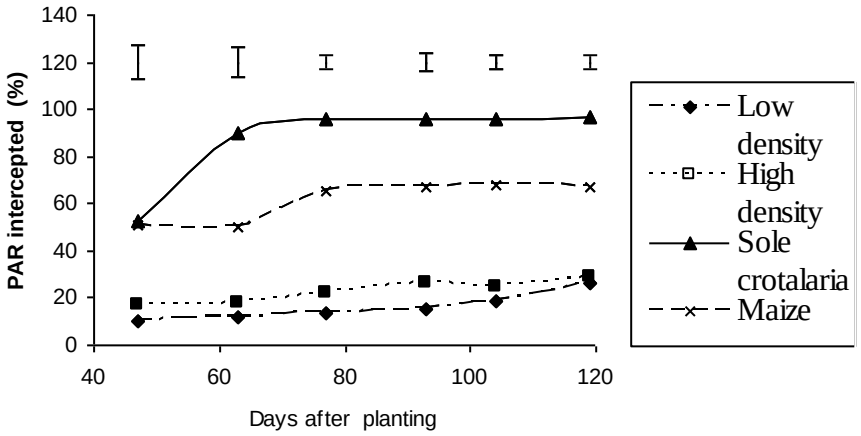


Figure 4.2.4 b: Canopy photosynthetically active radiation (PAR) interception by maize and crotalaria over time for short rains (LR) 2005 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

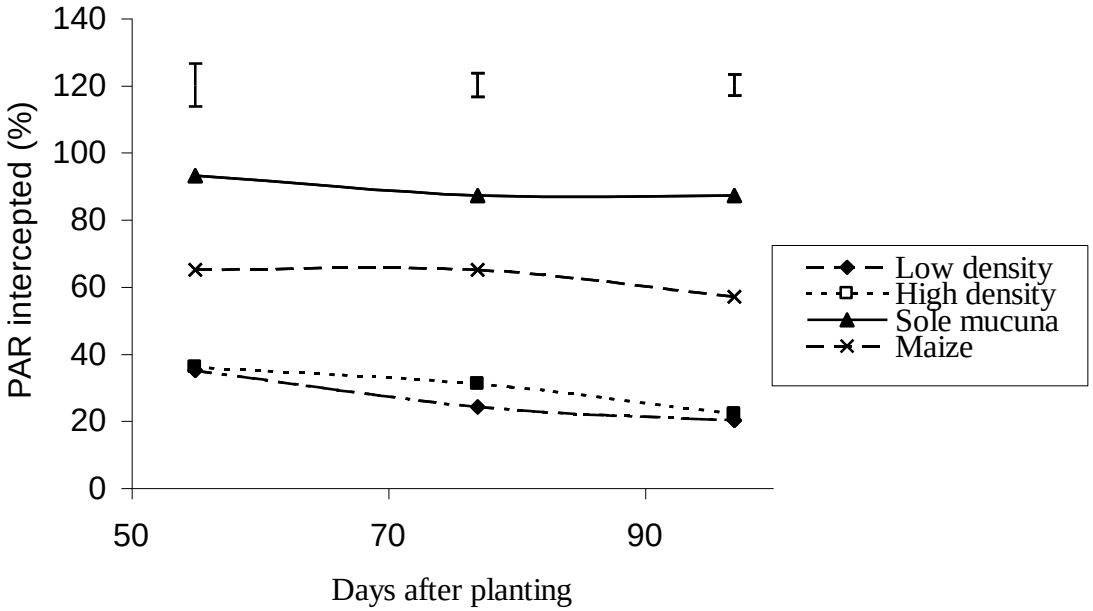


Figure 4.2.4 c:Canopy photosynthetically active radiation (PAR) interception by maize and mucuna over time for short rains (SR) 2004 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

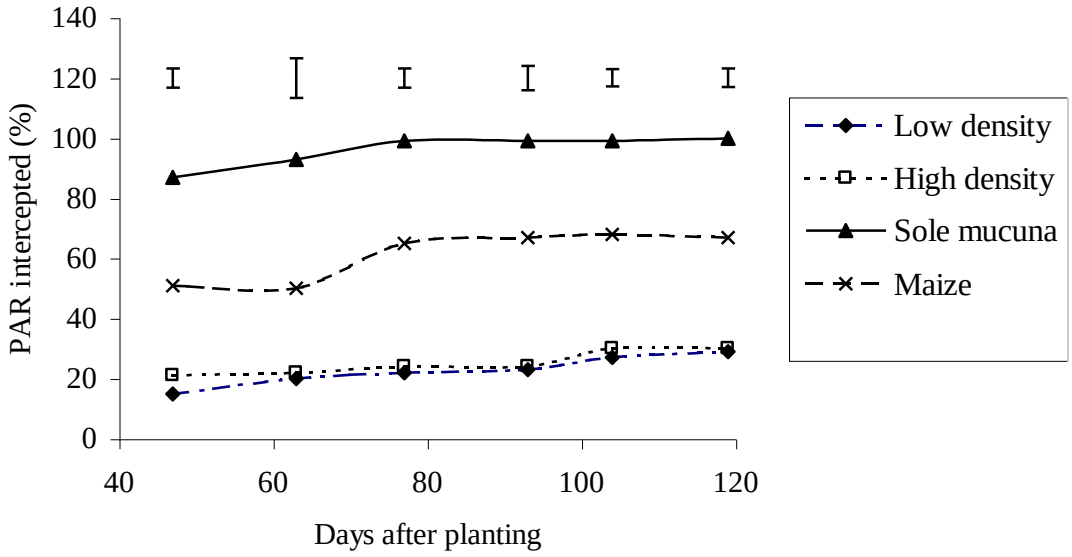


Figure 4.2.4 d: Canopy photosynthetically active radiation (PAR) interception by maize and mucuna over time for short rains (LR) 2005 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

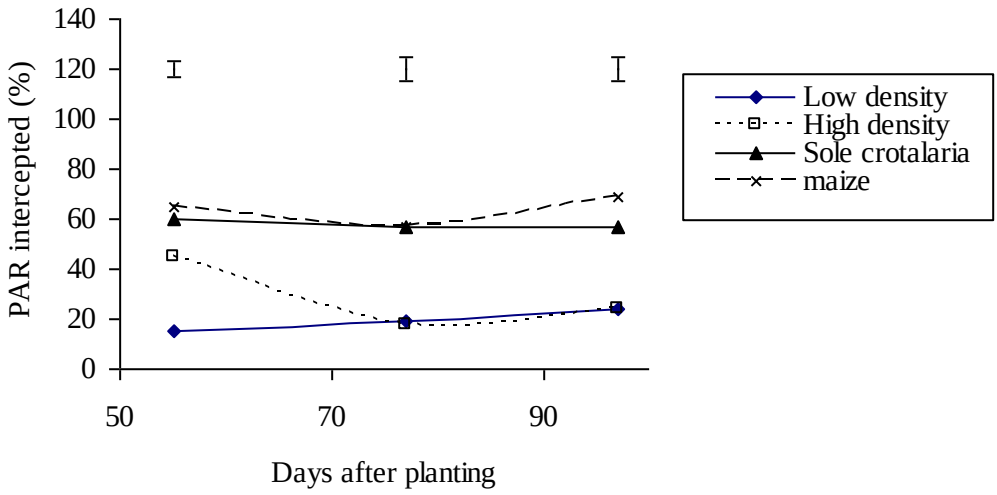


Figure 4.2.4 e:Canopy photosynthetically active radiation (PAR) interception by maize and lablab over time for short rains (SR) 2004 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

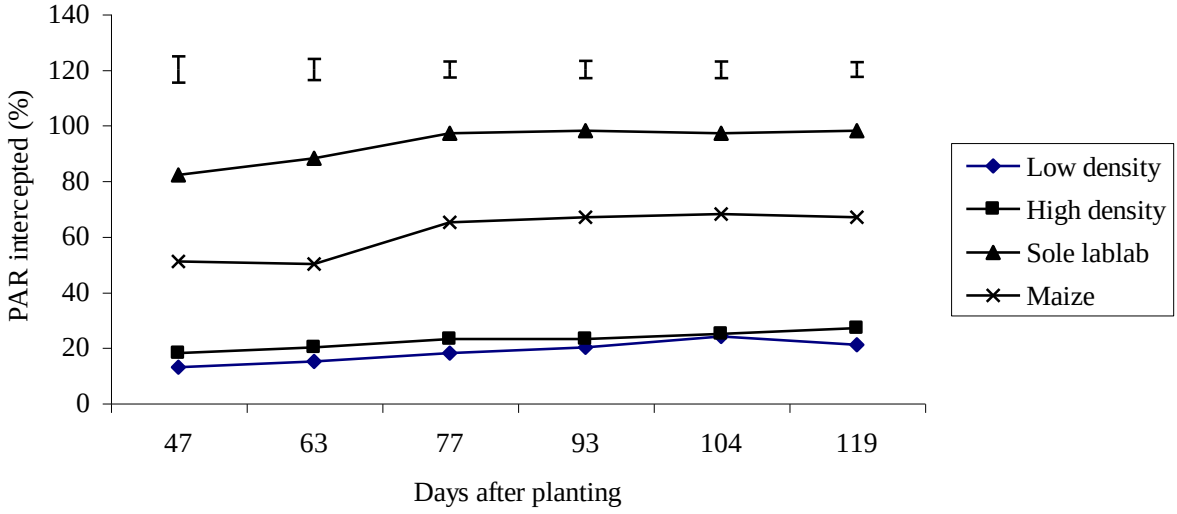


Figure 4.2.4 f:Canopy photosynthetically active radiation (PAR) interception by maize and lablab over time for long rains (LR) 2005 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

4.2.4.3 Effect of period to relay-cropping the legumes on PAR interception

Figures 4.3.5a-l present the results of PAR intercepted by different legumes that were relay-cropped at varying periods or intervals in the maize crop. The amount of PAR intercepted by each of the three legumes was dependent upon the period at which the legume was relay-cropped to maize. For example, early (week or period 0 and 1) intercropped mucuna intercepted about one third of the total incident radiation while the late planted mucuna (period 3 and 4) captured below 20% of the total incident radiation. These differences were, however, not significant when compared against sole mucuna or maize which intercepted about 65 and 99% of the total incident radiation, respectively. Differential sowing of legumes relative to maize improves overall productivity since it minimizes competition for growth limiting factors such as light (Ofori and Stern, 1987) and ensures full utilization of these growth factors because crops occupy the land throughout the growing season (Willey *et al*., 1986).

For the majority of the assessments made, early interplanted crotalaria intercepted twice as much PAR as the late planted one. At the initial stages of the assessment, crotalaria plants planted late in the season intercepted relatively small proportions (8-10%) of the total incoming radiation, particularly during the LR 2005 cropping season. Similar observations were made with respect to lablab. Ofori and Stern (1987) state that there is better utilization of light in the intercrop during the early growing part of the season because the legume is able to accumulate substantial dry matter before shading by the component maize crop becomes a limiting factor. The limitation in PAR capture by late planted legumes may have greatly limited their growth and development resulting in low biomass production (Figures 4.2.1a-e to 4.2.3a-e). There was a significant period by density interaction for all legumes in both seasons.

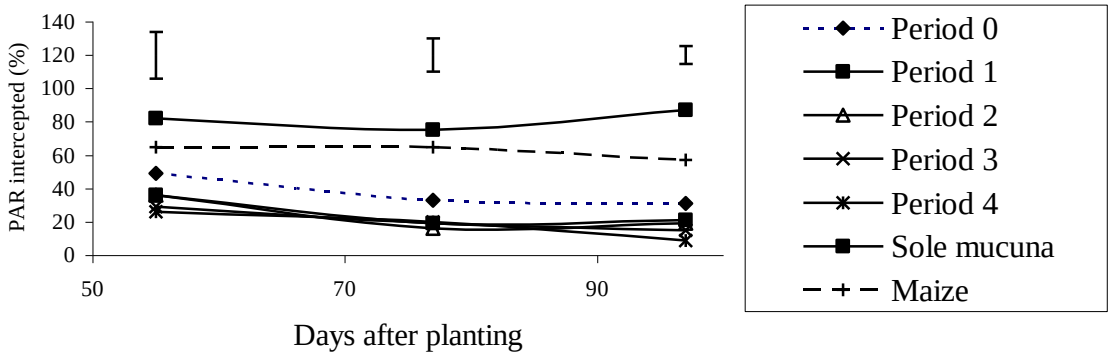


Figure 4.2.5 a: Canopy photosynthetically active radiation (PAR) interception by maize and low density mucuna green manure relay-cropped at different intervals or periods in maize during short rains (SR) 2004 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

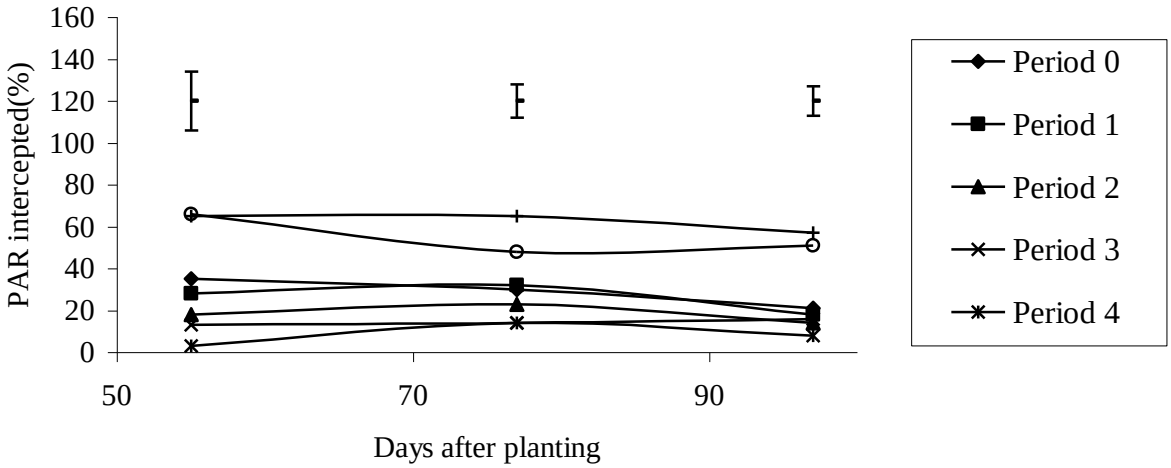


Figure 4.2.5 b:Canopy photosynthetically active radiation (PAR) interception by maize and low density crotalaria green manure relay-cropped at different intervals or periods in maize during short rains (SR) 2004 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

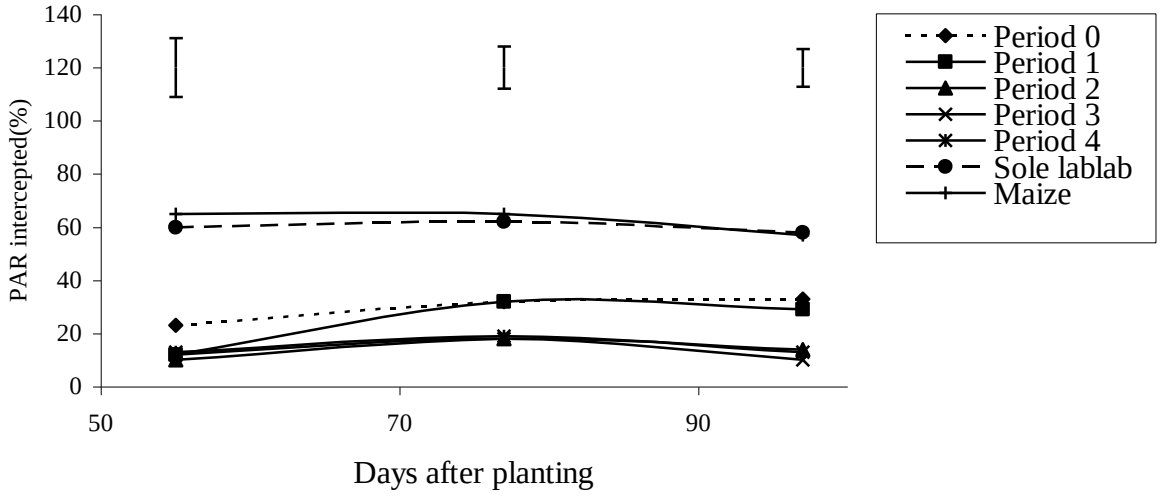


Figure 4.2.5 c: Canopy photosynthetically active radiation (PAR) interception by maize and low density lablab green manure relay-cropped at different intervals or periods in maize during short rains (SR) 2004 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

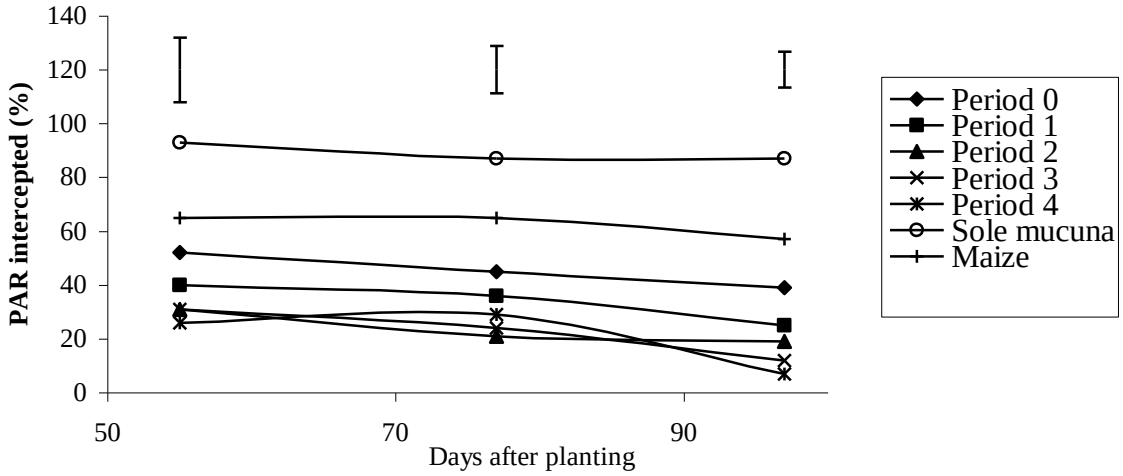


Figure 4.2.5 d: Canopy photosynthetically active radiation (PAR) interception by maize and high density mucuna green manure relay-cropped at different intervals or periods in maize during short rains (SR) 2004 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

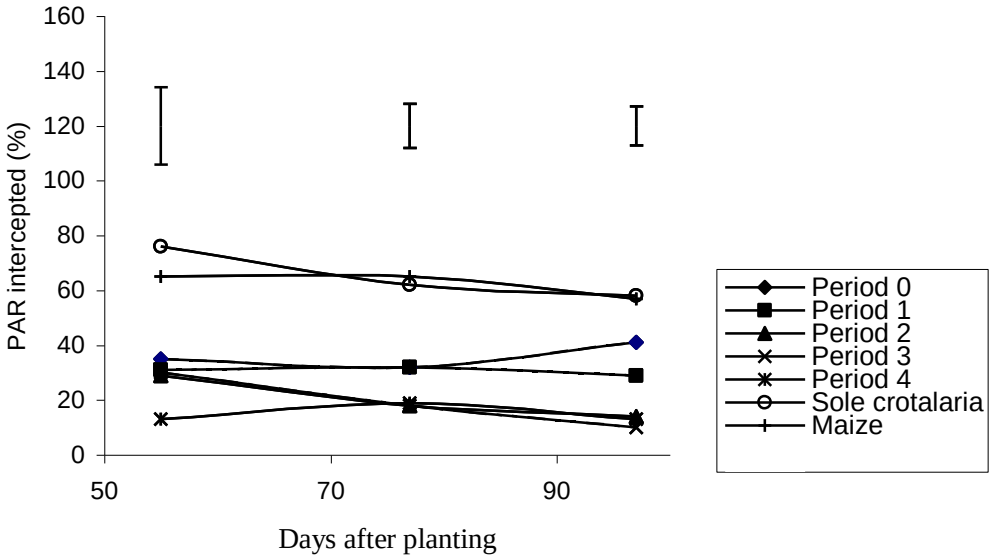


Figure 4.2.5 e: Canopy photosynthetically active radiation (PAR) interception by maize and high density crotalaria green manure relay-cropped at different intervals or periods in maize during short rains (SR) 2004 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

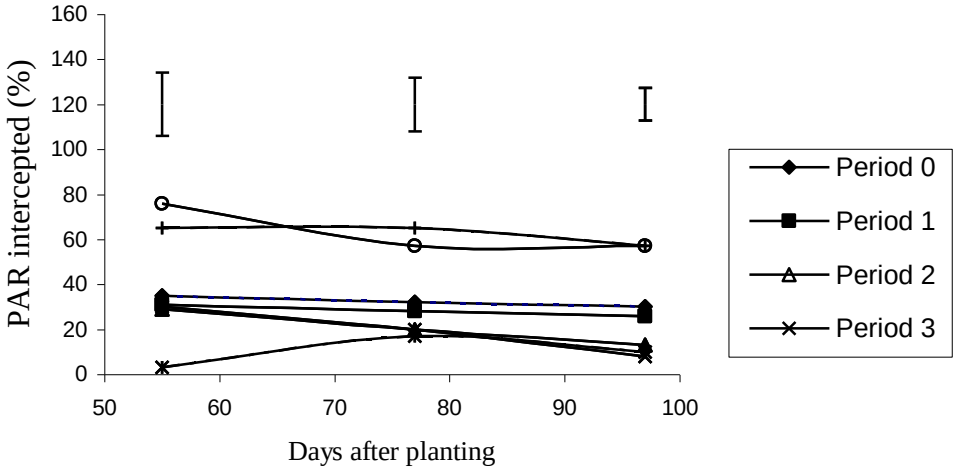


Figure 4.2.5 f: Canopy photosynthetically active radiation (PAR) interception by maize and high density lablab green manure relay-cropped at different intervals or periods in maize during short rains (SR) 2004 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

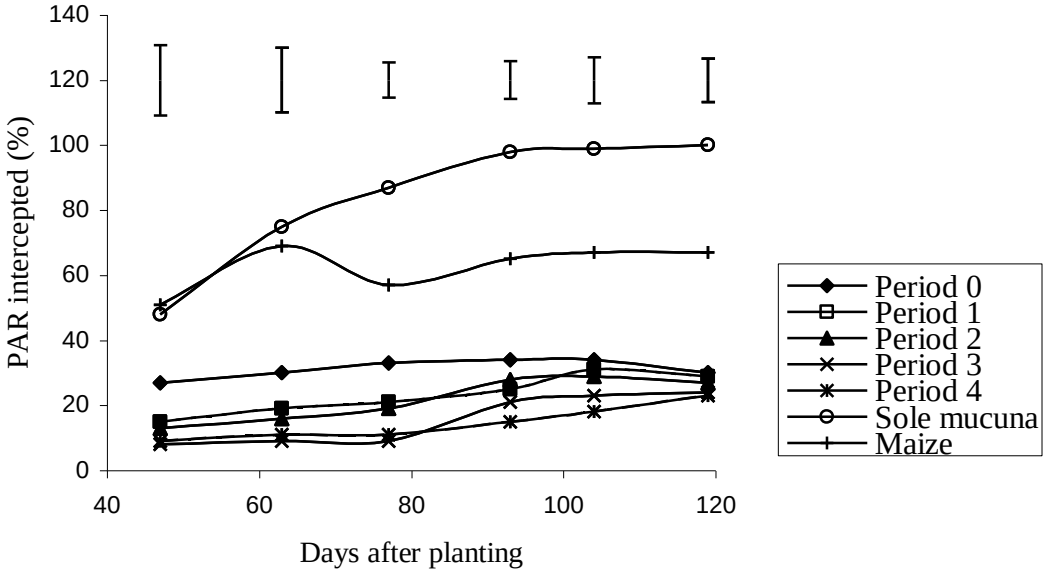


Figure 4.2.5 g: Canopy photosynthetically active radiation (PAR) interception by maize and low density mucuna green manure relay-cropped at different intervals or periods in maize during short rains long rains (LR) 2005 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

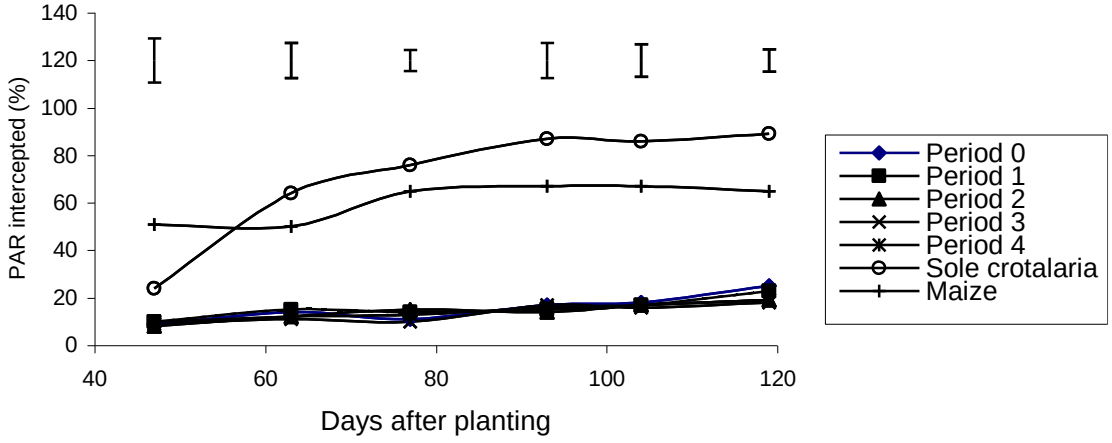


Figure 4.2.5 h: Canopy photosynthetically active radiation (PAR) interception by maize and low density crotalaria green manure relay-cropped at different intervals or periods in maize during long rains (LR) 2005 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

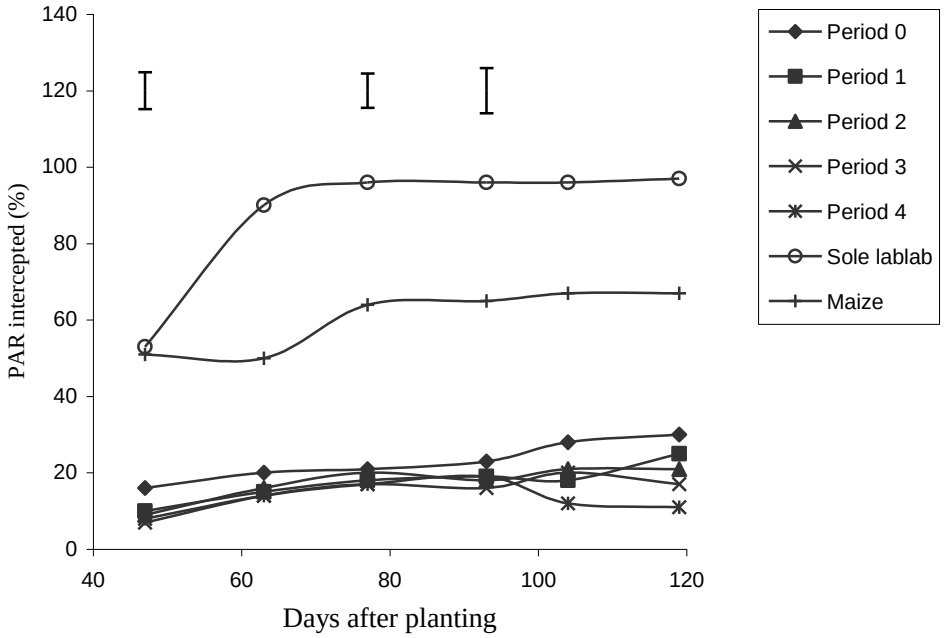


Figure 4.2.5 i: Canopy photosynthetically active radiation (PAR) interception by maize and low density lablab green manure relay-cropped at different intervals or periods in maize during long rains (LR) 2005 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

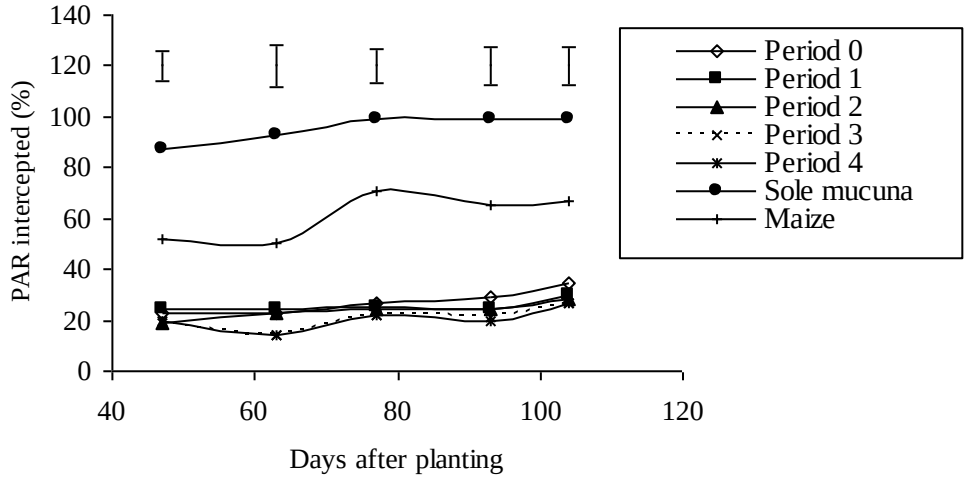


Figure 4.2.5 j: Canopy photosynthetically active radiation (PAR) interception by maize and high density mucuna green manure relay-cropped at different intervals or periods in maize during long rains (LR) 2005 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

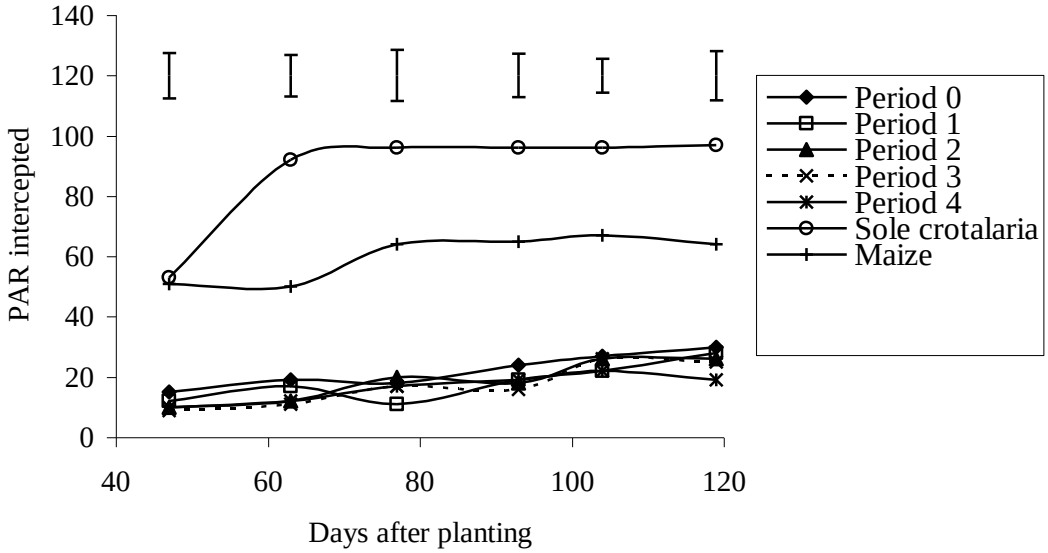


Figure 4.2.5 k: Canopy photosynthetically active radiation (PAR) interception by maize and high density crotalaria green manure relay-cropped at different intervals or periods in maize during long rains (LR) 2005 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

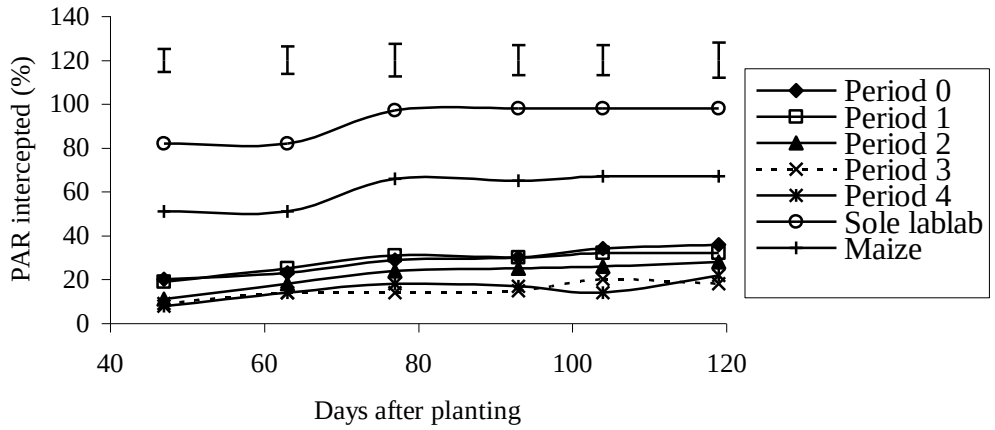


Figure 4.2.5 l: Canopy photosynthetically active radiation (PAR) interception by maize and high density lablab green manure relay-cropped at different intervals or periods in maize during long rains (LR) 2005 in Embu, Kenya. Significant difference ($LSD_{0.05}$) bars shown

4.3 EXPERIMENT TWO

Title: The effect of legume residue placement methods on N release for maize growth

4.3.1 Maize seedling vigour

The results of maize seedling vigour (Table 4.3.1) show that the quantity of residue, rather than the type or method of residue management used was more important in determining the overall early maize seedling growth vigour. Generally, plots with mucuna or crotalaria residues gave significantly higher visual scores than those of lablab or control treatments, irrespective of the type of residue management used. Similar results have been reported by Nyambati (2002) in northwest Kenya and Baijukya (2004) in the northern Tanzanian District of Bukoba. In the present study, the exception was LR 2005 cropping season during when no significant responses of different GM residue application was observed. This was due to the occurrence of an early season moisture deficit period that stressed maize seedlings in all the plots resulting in high coefficient of variability (CV) during data analysis rendering the statistical comparison for all the parameters assessed less sensitive.

Table 4.3.1: Early seedling vigour of maize as affected by different green manure residue management for different cropping seasons in Embu, Kenya

Residue management	Early seedling vigour (visual rating)											
	LR 2004			SR 2004			LR 2005			MEAN		
	Mucuna	Lablab	Crotalaria	Mucuna	Lablab	Crotalaria	Mucuna	Lablab	Crotalaria	Mucuna	Lablab	Crotalaria
Incorporated	4.0 a	3.7 a	4.5 a	3.7 a	3.0 a	3.8 a	2.6	2.5 ab	2.3	3.7 a	3.2 a	3.7 a
Mulch	4.0 a	3.2 a	4.1 a	3.9 a	2.9 ab	4.1 a	3.0	2.0 b	2.5	3.5 a	2.7 b	3.5 a
Control	2.5 b	2.5 b	2.5 b	2.7 b	2.7 b	2.7 b	3.0	3.0 a	3.0	2.8 b	2.7 b	2.8 b
CV (%)	18	17	17	12	19	14	23	30	38	12	13	15
$LSD_{0.05}$	0.7	0.5	0.6	0.4	0.6	0.5	NS	0.8	NS	0.4	0.4	0.5

Means with same letter in each column are not statistically different at P<0.05

Key for the visual scores of the seedling vigour:
5 = Very high
4 = High
3 = Medium
2 = Low
1 = Very Low

4.3.2 Maize plant height

Results of maize plant height presented in Tables 4.3.2-4 show that the type of residue management (mulched or incorporated) used did not affect the performance of any of the three GML residues. Both the early as well as the late season assessments showed that plots mulched or incorporated with mucuna residues were significantly taller than the control in all the 5 cropping seasons of experimentation (Tables 4.3.2). On average, maize plant height in mucuna residue mulched and incorporated plots was 46 and 41 cm, respectively, taller than the control. These results do not support those of Boateng (1997) who observed that incorporating mucuna residues in Kwadosa and Ejura sites in Ghana resulted in taller maize plants compared to the surface mulching of the residues.

Crotalaria plots produced significantly taller plants than the control in all seasons except during the final assessment of the LR 2005 cropping season (Tables 4.3.3). Results of the 5 seasons' average indicate that maize plots in crotalaria plots were 38 and 31 cm taller than those of the control for incorporated and mulched treatments, respectively. Lablab, on the other hand, gave significantly taller maize plants in four out of the eight height assessments made (Tables 4.3.4). Low responses in lablab residue plots during the other cropping seasons was attributed to the small quantities of this legume's residues that were generated *in situ* and applied into the plots (Table 3.5.2). Increased plant height is advantageous because height is related to the final grain yield in that the stem of maize can serve as a reservoir of labile nonstructural carbohydrates which are mobilized as sugars and translocated to the filling grains during postflowering period. The stem reserves also serve a role in maintaining the rate of grain filling against longer-term effects of persistent postflowering stress such as drought (Edmeades and Lafitte, 1993).

The planting density of mucuna and lablab GM legumes (Tables 4.4.17 and 19) did not appear to influence the plant height of maize but the higher planting density of crotalaria had a tendency to negatively affect maize plant height particularly during the less wetter seasons of LR and SR 2004 (Tables 4.4.18).

Table 4.3 2: Plant height of maize (taken at 4 weeks after planting and at harvest) as affected by mucuna green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		Mean	
	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest
Incorporated	65 a	145 a	83 a	201 a	76 a	138 a	59 a	121 a	78 a	183 a	71 a	154 a
Mulch	65 a	170 a	75 b	195 a	74 a	144 a	54 b	121 a	77 a	179 a	69 a	159 a
Control	53 b	99 b	55 c	137 b	57 b	77 b	44 c	77 b	66 b	141 b	56 b	113 b
CV (%)	13	21	9.9	9.6	7	16	6.2	12.9	11	19	7	15
$LSD_{0.05}$	7	27	7.3	17	5	21	3.4	14.6	8.6	34	4.8	23

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 3: Plant height of maize (taken at 4 weeks after planting and at harvest) as affected by crotalaria green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		Mean	
	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest
Incorporated	62 a	133 a	84 a	201 a	75 a	137 a	61 a	120 a	73 ab	170	71 a	151 a
Mulch	61 ab	126 b	82 a	208 a	74 a	129 a	56 a	108 a	78 a	177	70 a	144 a
Control	53 b	19 b	55 b	137 b	57 b	77 b	44 b	77 b	66 b	141	56 b	113 b
CV (%)	15	31	7	8	8	14	10	17	13	27	7	17
$LSD_{0.05}$	8	32	6	15	6	17	6	18	10	NS	5.4	25

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 4: Plant height of maize (taken at 4 weeks after planting and at harvest) as affected by lablab green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		Mean	
	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest
Incorporated	58	128 a	64 a	160 a	66	119	43	111 a	71	160	61 a	131
Mulch	58	125 ab	58 b	154 a	64	112	42	88 b	73	150	59 ab	126
Control	53	98 b	54 b	137 b	61	99	44	77 b	66	141	56 b	113
CV (%)	12	24	7.1	9.2	9	25	9	13	10	19	7	16
$LSD_{0.05}$	NS	27	4	14	NS	NS	NS	13	NS	NS	4.5	NS

Means with same letter in each column are not statistically different at P<0.05

4.3.3 Maize flowering

The effect of different modes of residue placement on time to tasselling and silking (flowering) of maize plants revealed that mulch or incorporated plots flowered between 1-6 days earlier than the control irrespective of the method of residue management used (Table 4.3.5-7). The five seasons' average for days to 50% flowering of maize in plots that were either mulched or incorporated with any of the three GM legume residues were significantly fewer than those of the control suggesting that the efficiency of N release by these residues was similar irrespective of the mode of residue placement that was employed. Uhart and Andrade (1995) carried out a study to investigate the effect of N availability on maize crop development and found that N deficiencies produced a delay in crop phenology relative to the control. Likewise, Jacob and Pearson (1991) also reported that N stress delayed tasselling and silking of maize.

In the current study, the planting densities of each of the three GM legumes did not influence the period to flowering of the maize crop except for lablab in the LR 2005 cropping season (Tables 4.3.17-19). There were no positive interactions for residue management, planting density or type of legume that were observed.

Table 4.3 5: Days to 50% flowering for maize as affected by mucuna green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Days to 50% flowering of maize					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Incorporated	75	72 b	70 b	77	78 ab	75 b
Mulch	75	73 ab	70 b	78	75 b	74 b
Control	76	75 a	73 a	76	81 a	77 a
CV (%)	3	3	1.4	3	4.0	1.5
$LSD_{0.05}$	NS	2.4	1.1	NS	3.3	1.2

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 6: Days to 50% flowering for maize as affected by crotalaria green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Days to 50% flowering of maize					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Incorporated	75	72 a	70 b	78	78	75 b
Mulch	75	73 ab	71 b	80	78	76 b
Control	76	75 b	73 a	78	81	78 a
CV (%)	3	3	2.3	3	7	1.8
$LSD_{0.05}$	NS	2.4	1.7	NS	NS	1.4

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 7: Days to 50% flowering for maize as affected by lablab green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Days to 50% flowering of maize					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Incorporated	76 b	72 b	70 b	79 a	78	75 c
Mulch	77 b	74 a	71 ab	80 a	79	76 b
Control	79 a	75 a	72 a	80 a	81	77 a
CV (%)	2.8	1.6	1.7	2.2	3.2	1.0
$LSD_{0.05}$	2	1.2	1.3	1.6	NS	0.8

Means with same letter in each column are not statistically different at P<0.05

4.3.4 Maize Stover yields

The response of maize biomass production to the methods of GML residue management is shown in Tables 4.3.8-10. In general, the five (5) seasons' average dry matter stover yields in mucuna were 40% higher than those of the control for both the mulching and incorporation treatments while those of crotalaria were 60% and 30% higher than the control for incorporated and mulched plots, respectively. These results do not agree with those of several researchers who have obtained higher stover yields in incorporated compared to mulched GM treatments. For example, in Gatanga division of central Kenya, Mureithi *et al.* (2005) obtained three times more stover dry matter yields in mulched than in incorporated

mucuna plots. In situations of low moisture regimes, however, the reverse is normally true whereby surface mulched plots give higher yields than the incorporated ones (Boateng, 1997; Gachene *et al*., 2002). In the present study, similar performances in grain and stover dry matter irrespective of the mode of residue placement were mainly attributable to the fast breakdown of GM legume residues in mulched plots by termites (Njunie, 2002; Mwangi *et al*., 2004).

Mulching or incorporating lablab residues gave significantly higher stover yields than the control only during the initial LR 2003 cropping season. Low stover yields in lablab plots could mainly be attributed to the low GML residues and hence N that was produced and applied into the plots (Table 3.5.2). Similar performance in the mulched and incorporated lablab plots was attributable to comparable rates of residue breakdown for the two residue management strategies. Ibewiro *et al*. (2002b) observed a rapid dry matter loss of mulched lablab residues in the derived savanna of West Africa. They reported that lablab residues lost most of the initial dry weight in about four weeks, after the surface placement.

In the present study, planting densities in each of the three GM legumes did not influence the performance of stover dry matter (Tables 4.3.17-19). Likewise, there were no positive interactions for residue management, planting density or type of legume that were observed.

Table 4.3 8: Stover yield of maize as affected by mucuna green manure residue management for different cropping seasons in Embu, Kenya

Residue management	Stover yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Incorporated	2.65 ab	5.92 a	3.06 a	5.45	3.28	3.95 a
Mulch	3.55 a	5.36 a	3.44 a	5.16	3.36	4.10 a
Control	1.70 b	3.88 b	1.33 b	5.26	1.79	2.87 b
CV (%)	40	22	19	17	55	23
$LSD_{0.05}$	0.98	1.20	0.52	NS	NS	0.90

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 9: Stover yields as affected by to crotalaria green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Stover yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Incorporated	2.65 ab	5.92 a	2.39	5.45	2.93	4.05 a
Mulch	3.55 a	5.36 a	2.16	5.16	2.34	3.85 a
Control	1.70 b	3.88 b	1.82	5.26	1.78	2.87 b
CV (%)	40	22	30	17	76	24
$LSD_{0.05}$	0.98	1.20	NS	NS	NS	0.94

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 10:Stover yield of maize as affected by lablab green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Stover yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Incorporated	4.50 a	3.91	2.29	4.65	1.85	2.98
Mulch	4.50 a	3.51	2.06	4.12	2.35	2.91
Control	3.28 b	3.88	1.82	5.26	1.79	2.87
CV (%)	40	11	30	20	66	22
$LSD_{0.05}$	0.84	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

4.3.5 Maize grain yield

The results of maize grain yield are presented in Tables 4.3.11-13. Mucuna residue plots gave significantly more grain yield than the control during each of the five cropping seasons but there were no differences between mulched and incorporated treatments (Table 4.3.11). Similarly, crotalaria residue treated plots (Table 4.3.12) had significantly more grain yield than the control during all the cropping seasons except LR 2005. Maize grain yield in mucuna residue treated plots was 2.1 and 2.5 times more than that of the control plot for mulched and incorporated treatments, respectively while that of crotalaria residues mulched and incorporated plots produced 1.7 and 1.8 times more grain yield than the control,

respectively. When averaged across all the five cropping seasons, both mucuna and crotalaria treatments significantly out-yielded the control irrespective of the type of management that was employed on the residues (Tables 4.3.11 and 4.3.12).

Unlike mucuna and crotalaria, lablab residues applied either as surface mulch or incorporated significantly out-yielded the control only during the wetter LR 2003 and SR 2003 cropping seasons (Table 4.3.13) when an equivalent of 30-60 kg ha^{-1} N was applied in form of lablab GM residues (Table 3.5.2). Low responses during the rest of the seasons were thus attributable to the low quantities generated *in situ* and applied in these plots.

Table 4.3 11: Maize grain yield as affected by mucuna green manure residue management for different cropping seasons in Embu

Residue management	Maize grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Incorporated	2.49 a	5.15 a	0.69 a	1.32 b	2.67 ab	2.14 a
Mulch	2.94 a	4.32 a	0.81 a	1.76 a	2.74 a	2.48 a
Control	0.78 b	1.32 b	0.23 b	0.63 c	1.32 b	1.01 b
CV (%)	23	25	67	12	58	43
$LSD_{0.05}$	0.76	0.98	0.41	0.16	1.38	0.85

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 12: Maize grain yield as affected by crotalaria green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Maize grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Incorporated	1.35 a	3.24 a	0.46 a	1.42 a	2.41	1.70 a
Mulch	1.18 a	3.94 a	0.40 a	1.37 a	2.04	1.82 a
Control	0.78 b	1.32 b	0.23 b	0.63 b	1.32	1.01 b
CV (%)	21	28	72	19	77	34
$LSD_{0.05}$	0.36	1.05	0.28	0.22	NS	0.55

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 13: Maize grain yield as affected by lablab green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Maize grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
Incorporated	1.15 a	1.96 a	0.28	0.91 a	1.51	1.09
Mulch	1.13 a	1.78 ab	0.28	0.58 b	1.92	1.25
Control	0.78 b	1.32 b	0.39	0.63 b	1.32	1.01
CV (%)	36	32	69	23	70	51
$LSD_{0.05}$	0.32	0.57	NS	0.17	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Overall, the type of management employed on the residues (surface mulch or incorporated) for any of the three GM legumes did not affect their performance with respect to N release for maize crop nutrition. These results are in agreement with those of Baijukya (2004) who obtained similar maize grain yields in mulched and incorporated mucuna residue plots under the conditions of high rainfall in the windward side of Bukoba District of northern Tanzania. The author attributed his observation to similar decomposition and nutrient availability by mucuna residues under the two different management strategies. Likewise, Jama *et al.* (1996), working under tropical semi-arid conditions of eastern Kenya, recorded similar decompositions rates for both buried and surface placed leguminous litter. The results of the present study do not, however, tally with those by Gachene *et al*. (2002) and Mureithi *et al*. (2005) who used mucuna, crotalaria and vicia as either mulch or incorporation in the central highlands of Kenya and found that incorporation of the residues resulted in higher maize yield compared to leaving the biomass on the surface as mulch. Elsewhere in West Africa, Carsky *et al*. (2001) and Houngnandan (2000) reported that maize grain yield increase from mucuna fallow was greater if the mucuna residues were incorporated into the soil rather than being left on the soil surface as mulch. Conversely, in a drier site of Machakos, Kenya, Gachene *et al*. (2002) observed that mulching of mucuna

biomass gave double the maize grain yield of the incorporated plots during the less wetter seasons and attributed this increase to the moisture conservation effect of the mulch.

In the current study, the performance of each of the three GML residues was similar for both incorporated and mulched treatments possibly due to the rapid breakdown of the residues observed during each of the five cropping seasons of experimentation. The presence of termites, in particular, greatly hastened the breakdown of surface applied residues and hence the leaching down of N into the soil for eventual uptake by the growing maize plants. Mwangi *et al*. (2004) investigated the role of soil macrofauna on the rate of agroforestry litter decomposition in the neighbourhood of the current study site here in Embu and reported that termites formed the major macrofauna group contributing 76% of the total macrofauna population observed. The results of the current study also corroborate work by Njunie (2002) who placed dried green lablab residues in nylon mesh bags and left them to decompose on the soil surface in the coastal lowlands of Kenya and observed that the percentage of initial dry matter remaining was greatly reduced after 2, 4, and 8 weeks after placement due to occurrence of termites that cut into the mesh bags and accessed the residues resulting in a great reduction of the residues in mesh bags that were attacked by termites. The observations made in the present study together with those of previous workers point out that the presence of macrofauna, especially termites (*Macrotermes* species), may be an important factor in determining the decomposition and nutrient release process of surface mulched GM legume residues. Furthermore, Kumar and Goh (2000) have stated that incorporated straw decompose faster than surface straw during the first initial 15 days but the differences abate thereafter. The initial lag in the decomposition of residues on the soil surface is possibly due to litter on the surface being more subjected to unfavourable conditions for decomposition, particularly with respect to fluctuations in temperature and moisture-limiting microbial activity than in

materials buried in the soil.

In the present study, the planting density of each of the three GM legumes did not significantly influence the performance of maize grain yield during all the five seasons of experimentation (Tables 4.4.17-19). Similarly, there were no positive interactions for residue management, planting density or type of legume that were observed. A comparison of individual performance of the three GM legumes, irrespective of the mode of residue placement, indicated that mucuna gave the highest maize yields followed by crotalaria whereas lablab and control plots registered the lowest maize grain yields.

4.3.6 Maize harvest index

Maize harvest index was higher in wetter seasons of 2003 than during the drier seasons of 2004 (Tables 4.3.14-16). Generally, neither the type of GML residues nor the method of their placement seemed to influence the harvest index of maize, in most seasons. The legume by placement interactions were also not significant. Low harvest index in drier seasons and in plots with N stress is mainly ascribed to reduced production and translocation of assimilates to the developing kernels (Edmeades and Lafitte, 1993; Schusser and Westgate, 1995).

Table 4.3 14: Harvest index of maize as influenced by mucuna green manure residue management for different cropping seasons in Embu, Kenya

Residue management	Harvest index				
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005
Incorporated	0.39 a	0.42 a	0.16	0.21	0.45
Mulch	0.48 a	0.40 a	0.17	0.18	0.45
Control	0.24 b	0.24 b	0.15	0.15	0.38
CV (%)	24	13	40	38	18
$LSD_{0.05}$	0.08	0.04	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 15: Harvest index as influenced by crotalaria green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Harvest index				
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005
Incorporated	0.25	0.34 a	0.13	0.20	0.49 a
Mulch	0.29	0.40 a	0.11	0.16	0.47 ab
Control	0.24	0.24 b	0.15	0.15	0.38 b
CV (%)	33	17	42	60	22
$LSD_{0.05}$	NS	0.06	NS	NS	0.10

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 16: Harvest index of maize as influenced by lablab green manure residue management techniques for different cropping seasons in Embu, Kenya

Residue management	Harvest index				
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005
Incorporated	0.27	0.31	0.11	0.11	0.45
Mulch	0.35	0.31	0.11	0.11	0.45
Control	0.24	0.24	0.15	0.14	0.37
CV (%)	44	24	39	44	19
$LSD_{0.05}$	NS	NS	NS	NS	NS

Table 4.3 17: Effect of mucuna legume density (at different residue management techniques) on maize seedling vigour, maize grain and stover yields, plant height and days to flowering for different cropping seasons in Embu, Kenya

Cropping Season	Legume Density	Biomass Incorporated (Mg ha^{-1})	Maize Seedling vigour	Grain yield (Mg ha^{-1})	Stover yield (Mg ha^{-1})	Plant height (cm)	Days to 50% flowering
	Low density	3.65 b	-	2.79	3.28	115	75
LR 2003	High density	4.28 a	-	2.84	3.32	116	76
	CV (%)	29	-	46	40	21	3
	$LSD_{0.05}$	1.28	-	NS	NS	NS	NS
	Low density	2.72 b	-	3.77	6.02	201	78
SR 2003	High density	3.13 a	-	3.23	5.23	196	79
	CV (%)	33	-	26	22	9.8	3.2
	$LSD_{0.05}$	1.09	-	NS	NS	NS	NS
	Low density	4.15	4.0	0.91	3.24	141	70
LR 2004	High density	4.80	4.0	0.51	3.27	142	70
	CV (%)	26	18	67	19	16	1.4
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
	Low density	1.42	3.8	0.79	5.14	120	78
SR 2004	High density	1.92	4.0	0.70	5.46	122	78
	CV (%)	34	12	12	17	14	7
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
LR 2005	Low density	1.65 b	3.0	2.42	3.00	174	77
	High density	2.43 a	2.6	2.98	3.63	188	75
	CV (%)	22	23	58	55	19	4
	$LSD_{0.05}$	0.49	NS	NS	NS	NS	NS
	Low density	2.72	3.6	2.36	4.06	155	75
MEAN	High density	3.32	3.6	2.27	3.99	158	75
	CV (%)	19	12	43	23	15	1.5
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 18: Effect of crotalaria legume density (at different residue management techniques) on maize seedling vigour, maize grain and stover yields, plant height and days to flowering for different cropping seasons in Embu, Kenya

Cropping Season	Legume Density	Biomass Incorporated (Mg ha^{-1})	Maize Seedling vigour	Grain yield (Mg ha^{-1})	Stover yield (Mg ha^{-1})	Plant height (cm)	Days to 50% flowering
	Low density	2.91 b	-	1.19	2.55	78	76
LR 2003	High density	3.51 a	-	1.27	2.28	80	77
	CV (%)	15	-	43	37	4	4
	$LSD_{0.05}$	0.54	-	NS	NS	NS	NS
	Low density	3.73 b	-	3.23	6.70	206	71
SR 2003	High density	4.59 a	-	3.95	6.67	203	70
	CV (%)	17	-	28	17	8	3
	$LSD_{0.05}$	0.78	-	NS	NS	NS	NS
	Low density	0.85	4.2	0.48	3.08	140 a	73
LR 2004	High density	0.79	4.4	0.37	3.11	126 b	75
	CV (%)	100	16	72	21	14	57
	$LSD_{0.05}$	NS	NS	NS	NS	13	NS
	Low density	1.14	3.8	1.43	6.36 a	128 a	79
SR 2004	High density	1.77	4.1	1.35	5.31 b	100 b	78
	CV (%)	44	14	19	14	11	2.4
	$LSD_{0.05}$	NS	NS	NS	0.86	12	NS
LR 2005	Low density	1.75	2.6	2.25	2.51	165	77
	High density	1.48	2.3	2.21	2.75	183	78
	CV (%)	37	38	77	76	7	7
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
	Low density	2.08 b	3.6	1.74	3.86	148	75
MEAN	High density	2.47 a	3.6	1.78	4.04	147	76
	CV (%)	14	15	34	24	17	1.8
	$LSD_{0.05}$	0.10	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Table 4.3 19: Effect of lablab legume density (at different residue management techniques) on maize seedling vigour, maize grain and stover yields, plant height and days to flowering for different cropping seasons in Embu, Kenya

Cropping Season	Legume Density	Biomass Incorporated (Mg ha^{-1})	Maize Seedling vigour	Grain yield (Mg ha^{-1})	Stover yield (Mg ha^{-1})	Plant height (cm)	Days to 50% flowering
	Low density	1.55	-	1.66	2.74	125	76
LR 2003	High density	2.52	-	1.87	2.26	127	77
	CV (%)	84	-	46	40	24	2.8
	$LSD_{0.05}$	NS	-	NS	NS	NS	NS
	Low density	0.41	-	2.11	3.89	160	74
SR 2003	High density	0.79	-	1.63	3.53	153	73
	CV (%)	93	-	32	11	9	1.6
	$LSD_{0.05}$	NS	-	NS	NS	NS	NS
	Low density	0.05	-	0.27	2.06	122	71
LR 2004	High density	0.14	-	0.27	2.29	106	71
	CV (%)	89	-	70	31	6	1.6
	$LSD_{0.05}$	0.10	-	NS	NS	NS	NS
	Low density	0.07	3.0	0.79	4.45	106	79
SR 2004	High density	0.15	3.2	0.70	4.32	93	79
	CV (%)	64	19	23	20	12	1.9
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
LR 2005	Low density	0.48	2.4	1.67	2.04	154	77 b
	High density	0.30	2.1	1.76	2.16	156	80 a
	CV (%)	87	30	70	66	7	3.2
	$LSD_{0.05}$	NS	NS	NS	NS	NS	2.7
	Low density	0.50	2.9	1.20	3.07	132	76
MEAN	High density	0.75	3.1	1.14	2.82	124	76
	CV (%)	70	13	51	22	16	1.0
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

4.3.7 Soil chemical characteristics

Table 4.3.20 presents results of the total N and pH (water) for soils sampled from the various treatments. The results indicate that after five consecutive seasons of mulching or incorporating GML residues, the total soil N was slightly higher than that of the control (no residues) applied. The mode of application of the residues did not affect the final total N content that was added into the soil. Overall, there were no significant total N or pH interactions (legume by residue management, legume by density, residue management by density or legume by residue management by density) that were observed. These results are in agreement with those of other authors who observed modest gains in total soil N following legume residue incorporation into different types of soils. Mureithi *et al*. (2005) obtained slightly higher N in the mucuna and crotalaria incorporated plots when compared to the mulched ones. Similarly, increase in total N has been reported in mucuna fallows of southern Benin (Carsky *et al*., 2001) while Vanlauwe *et al*. (2001) pinpointed that it was the N concentration in the particulate organic matter (POM) fraction that showed a marked increase after one cycle of mucuna and lablab residues application.

Table 4.3.20: Soil chemical properties (0 – 20 cm depth) as influenced by different green manure legumes applied under different residue management techniques in Embu, Kenya

Residue management	Chemical characteristic					
	Mucuna		Crotalaria		Lablab	
	Nitrogen (%)	pH (water)	Nitrogen (%)	pH (water)	Nitrogen (%)	pH (water)
Incorporated	0.34	5.6	0.32	5.5	0.32	5.5
Mulch	0.34	5.5	0.31	5.5	0.30	5.5
Control	0.30	5.4	0.30	5.4	0.29	5.4
SE	0.01	0.09	0.01	0.07	0.01	0.05
Effects	----------P values----------					
Residue management (RM)	0.121	0.226	0.162	0.355	0.325	0.063
Density (D)	0.780	0.856	0.119	0.523	0.591	0.839
RM x D	0.69	0.82	0.55	0.52	0.687	0.082

4.3.8 Soil physical characteristics - bulk density

Table 4.3.21 presents results of soil bulk density for soils sampled from the various treatments. Mulching or incorporating GML residues (raised *in situ* from the respective plots) for a period of three years had a slight but non significant change in the bulk density of the soil. The small reduction was probably attributable to the modest quantities of residues applied (Table 3.5.2) as well as the relatively short duration of experimentation needed to effect a change in this parameter. Mugendi *et al*. (1997) and Waswa (2004), working in a neighbouring farm here in Embu, also never recorded any change in soil bulk density as a result of incorporating calliandra or leucaena agroforestry tree prunings. The authors attributed their results to the short duration of experimentation. In contrast, Fischler *et al*. (1999), working with different type of soils in eastern Uganda, found that incorporating crotalaria residues for two seasons resulted in a small reduction in soil bulk density but the mulching treatment was less effective. Despite the small reduction in soil bulk density, the authors obtained remarkably high increase in water infiltration which they attributed to the high proportion of macropores created by decomposing crotalaria residues.

Table 4.3. 21: The influence of different residue management techniques for three green manure legumes on soil bulk density in Embu, Kenya

Residue management	Soil bulk density (g cm^{-3})		
	Mucuna	Crotalaria	Lablab
Incorporated	1.007	1.002	1.026
Mulch	1.016	1.034	1.022
Control	1.019	1.019	1.019
CV (%)	3.5	3.0	2.5
$LSD_{0.05}$	NS	NS	NS

4.3.9 Nodulation in green manure legumes

Nodulation was assessed by recording the nodule fresh weight from nodules sampled from six plants per plot in each of the treatments. Overall, mean nodule fresh weight was highest in mucuna (1.39 g plant^{-1}) followed by crotalaria (0.12 g plant^{-1}) and lablab (0.02 g plant^{-1}). Thus nodulation in mucuna was 11 and 69 times higher than crotalaria and lablab, respectively. A similar range in nodule fresh weight was reported by Sanginga *et al.* (1996) when they evaluated the symbiotic properties of mucuna at several sites in the derived savanna of southern Benin, West Africa. Table 4.3.22 shows that the method of GML residue management employed on different plots did not significantly affect the levels of nodulation in any of the three legumes. The legume species by residue management technique interaction was also not significant.

Table 4.3.22: Effect of different residue management techniques for three green manure legumes on nodule fresh weight in Embu, Kenya

Residue management	Nodule fresh weight (g plant^{-1})		
	Mucuna	Crotalaria	Lablab
Incorporated	1.69	0.11	0.02
Mulch	1.11	0.12	0.02
CV (%)	48	28	42
$LSD_{0.05}$	NS	NS	NS

4.4 EXPERIMENT THREE

Title: Maize performance as affected by legume green manures supplemented by different mineral N fertilizer levels

4.4.1 Maize seedling vigour

The results of maize seedling growth vigour after application of the three green manure legume (GML) biomass treatments are presented in Table 4.4.1. The seedling vigour was high, medium and low in treatments that were mineral N supplemented, GM alone and control, respectively. This trend was, however, more prominent in mucuna and crotalaria residue plots. The majority of the lablab plots with residues alone had similar maize seedling vigour to that of the control plot. These responses were attributable to the low N content released by the small quantities of lablab residues that were generated *in situ* and applied (Table 3.6.2). Plots with legume residue alone tended to show lower seedling vigour than those supplemented with mineral N possibly due to the initial lag period of N release by decomposing legume residues. Furthermore, the concentration of decomposing residues and hence N release that is in proximity of the maize seedling roots is low compared to that of inorganic N which is placed in the same hole with maize seeds (Carsky *et al*., 1999; Eilittä *et al*., 2003). The low responses observed in different GM residues during the LR 2005 season were attributable to the occurrence of an early season moisture deficit period that stressed maize seedlings in all the plots resulting in high coefficient of variability (CV) that rendered the statistical comparison for all the parameters assessed less sensitive.

Table 4.4.1: Effect of mineral N supplementation to different green manures on early seedling vigour of maize for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Early seedling vigour (visual rating)											
	LR 2004			SR 2004			LR 2005			MEAN		
	Mucuna	Lablab	Crotalaria	Mucuna	Lablab	Crotalaria	Mucuna	Lablab	Crotalaria	Mucuna	Lablab	Crotalaria
0 N	3.6 b	2.9 b	3.3 b	3.5 b	3.0 b	3.6 b	3.2	2.3	2.6	3.4 b	2.9 b	3.3
30 N	4.2 a	4.2 a	4.3 a	5.0 a	4.4 a	4.8 a	3.4	3.1	2.9	4.1 a	4.0 a	4.6
60 N	4.0 a	4.2 a	4.3 a	4.8 a	4.7 a	4.8 a	3.5	2.8	3.3	4.1 a	3.9 a	4.2
Control	2.6 c	2.8 b	2.5 c	3.0 c	3.0 b	3.0 c	2.8	2.8	2.6	2.8 c	2.8 b	2.8
CV (%)	21	11	25	8	11	10	30	32	35	57	13	57
$LSD_{0.05}$	0.50	0.43	0.58	0.34	0.43	0.44	NS	NS	NS	0.62	0.48	NS

Means with same letter in each column are not statistically different at P<0.05

Key for the visual scores of the seedling vigour
5 = Very high
4 = High
3 = Medium
2 = Low
1 = Very Low

4.4.2 Maize plant height

The results of maize plant height, taken at 4 weeks after planting (WAP) and after flowering, are presented in Tables 4.4.2-4. Maize plant height was in the following decreasing order: control < GML alone < 30N and 60N supplementation. In plots with GML residue alone, assessment carried out at the 4 WAP period indicated that maize plant heights in mucuna or crotalaria treatments were significantly greater than those of the control plots. This observation was the same for each of the five cropping seasons. For example, the five seasons' average maize height for the 4 WAP assessment in mucuna plots indicates that maize heights in the residue alone plots were 14 cm or 25% taller than those of the control while those of the lablab plots were 6 cm or 11% taller than those of the control. In lablab plots, the GML residue alone treated plots were significantly taller than those of the control only during LR 2003, SR 2003 and LR 2005 seasons. There were no positive interactions except for the overall seasonal average of the crotalaria residue plots where the fertilizer by density interactions were positive.

A comparison of maize height performance across the three different GML residue sources shows that lablab residue treated plots were shorter than those of the other two legumes. The ability of the GML residues to influence maize plant height early in the season is an indication that these decomposing residues avail N to the maize seedlings within the initial first or second week after germination. This was confirmed by a separate litter bag study (section 4.5.12 in this study) that showed that mucuna GML residue had a half life of about one week only. Similar results were obtained by Mucheru (2003), in the central Kenya division of Chuka, who recorded increased maize plant height above the control in the 4 and 8 week assessments in treatments where crotalaria or mucuna residues alone were applied. Likewise, in the forest-savanna region of Ghana, Boateng (1997) also reported a significant

increase in maize plant height (assessed 7 WAP) in residue incorporated treatments against those of the control. In the derived savanna zone of West Africa, Carsky *et al*. (1999) reported a significant maize height gain (42 days after planting) in treatments with mucuna and crotalaria but not in lablab or natural fallow treatments. Low height gain in lablab treated plots was attributed to the low biomass generated *in situ* and applied.

As expected, mineral N application at planting had a significant positive influence on maize plant height. Thus, maize height in all mineral N treated plots was significantly higher than the rest where only GML residue was used. The initial rapid maize elongation under the influence of mineral N when compared to the legume residue plots could mainly be attributed to the lag period of about one week (section 4.5.12 in this study) that the plant residues require before they release their N to the growing maize crop. However, the trend where maize in mineral N supplemented plots was taller than those under the legume residues alone reversed later in the season. Thus, during the final height assessment (after tasselling), maize plants in the residue alone plots had attained a similar height to those that were supplemented with mineral N. For instance, during the final height assessment, the five seasons' average maize plant height in lablab plots was 40 cm or 36% taller than the control. This was an indication that these GML residues provided adequate N for maize growth resulting in compensatory height attainment by the GML residue alone plants. This was further confirmed by the performance of maize in the lablab residue alone treatments whereby the latter registered a significantly lower height than the mineral N supplemented plots during the drier LR and SR 2004 cropping seasons when low residue biomass was generated (Table 3.6.2). Thus, N from decomposing legume residues became available to the maize plants during the rapid growth phase when the N requirements for the crop is high. In the weather pattern typical to the central highlands of Kenya, this growth phase occurs 4-10 weeks after

planting maize (Mugendi *et al*., 1997).

A comparison of the performance of maize height among different GM residue sources shows that lablab performed poorer than mucuna or crotalaria though the latter tended to have deeper green leaves than the others. This observation was more pronounced during the SR 2003 season when plots after crotalaria residues attained significantly taller maize plants than both mucuna or lablab residue treatments. Edmeades and Lafitte (1993) have stated that increased maize plant height is related to the final grain yield because the stem of maize can serve as a reservoir of labile nonstructural carbohydrates which are mobilized as sugars and translocated to the filling grains during postflowering period. The stem reserves also serve a role in maintaining the rate of grain filling against longer-term effects of persistent postflowering stress such as drought. In the current study, this phenomenon was observed during the drier seasons of LR and SR 2004 when the comparatively shorter maize plants in the control and lablab plots seemed to produce very small or no maize cobs.

Table 4.4 2: Plant height of maize (taken at 4 WAP and at harvest) as affected by different levels of mineral N supplementation to mucuna green manure for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest
0 N	67 b	158 a	77 b	166 a	74 c	128 a	53 b	119 b	76 b	160 a	70 c	147 a
30 N	74 a	160 a	81 ab	163 a	81 b	132 a	66 a	141 a	82 ab	163 a	77 b	153 a
60 N	78 a	174 a	82 ab	158 a	86 a	133 a	69 a	141 a	83 a	174 a	80 a	156 a
Control	54 c	109 b	56 c	124 b	64 d	95 b	45 c	100 c	62 c	118 b	56 d	109 b
CV (%)	7	12	7	8	4	10	8	11	8	15	3.4	7.9
$LSD_{0.05}$	4.7	9.8	5.4	12	3.3	12	4	15	6.1	24.3	2.0	10.1

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 3: Plant height of maize (taken at 4 WAP and at harvest) as affected by different levels of mineral N supplementation to crotalaria green manure for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest
0 N	64 c	144 b	82 b	186 a	70 b	126 a	57 b	122 ab	77 a	147 ab	70 c	145 a
30 N	71 b	150 b	92 a	188 a	85 a	134 a	64 a	143 a	82 a	154 ab	79 b	155 a
60 N	81 a	175 a	93 a	184 a	86 b	121 a	68 a	134 a	82 a	155 a	82 a	152 a
Control	54 d	109 c	56 c	123 b	64 c	95 b	45 c	100 b	62 b	118 b	56 d	109 b
CV (%)	7	15	8	17	7	21	6	19	10	24	3.4	8
$LSD_{0.05}$	4.5	20	6.5	18	6	26	3.6	24.7	8.4	36	2.5	11.4

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 4: Plant height of maize (taken at 4 WAP and at harvest) as affected by different levels of mineral N supplementation to lablab green manure for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest
0 N	66 b	143 b	62 c	155 b	67 b	121 b	46 c	95 b	69 bc	126	62 b	129 b
30 N	72 a	161 a	80 a	160 b	87 a	143 a	59 b	127 a	78 a	146	75 a	148 a
60 N	75 a	148 ab	75 b	178 a	85 a	139 ab	65 a	124 a	73 ab	151	75 a	149 a
Control	54 c	123 c	56 d	109 c	64 b	95 c	46 c	100 b	62 c	118	56 c	109 c
CV (%)	9	10	5	12	5	16	7	19	9	29	4	13
$LSD_{0.05}$	5.4	15	3.6	16	4	20	4	21	7	NS	3	18

Means with same letter in each column are not statistically different at P<0.05

4.4.3 Maize Flowering

The data on number of days to 50% flowering (tasselling and silking) of maize (Table 4.4.5-7) show that N availability to the growing maize plants had an influence on their time to flowering. Maize in mucuna and crotalaria residue treated plots (without mineral N) flowered 1-3 days earlier than those in control plot. The flowering period was, however, significantly different during all seasons other than SR 2004 and LR 2005 seasons. Lablab residue treated plots gave a significantly shorter flowering period only during the two seasons of 2003 (Table 4.4.7) probably due to the higher biomass quantities raised from the wetter preceding seasons (Table 3.6.2).

When compared against residue alone plots, mineral N supplemented treatments gave a significant reduction to maize flowering period in all seasons other than LR 2005. High variability due to the occurrence of an early season moisture stress was probably responsible for the large data variations during LR 2005 cropping season. Nonetheless, it was evident that N stress resulted in delayed maize tasselling and silking in all the affected plots. These findings confirm work by Jacob and Pearson (1991) and Uhart and Andrade (1995) who carried out a study to investigate the effect of N availability on maize crop development and found that N deficiencies produced a delay in crop phenology relative to the control. In the current study, a higher planting density of the legume did not affect the time to flowering probably due to small difference of legume dry matter production, and hence N supply, within the two legume densities (Table 4.4.17-19).

Table 4.4 5: Effect of mineral N supplementation to mucuna green manure on days to 50% flowering of maize for different cropping seasons in Embu, Kenya

Mineral N Rate (Kg ha^{-1})	Days to 50% flowering of maize					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	MEAN
0 N	73 b	72 b	68 a	76 a	79 a	74 b
30 N	69 c	70 bc	65 b	71 b	76 b	71 c
60 N	68 c	69 c	66 b	71 b	76 b	70 c
Control	75 a	75 a	69 a	77 a	80 a	76 a
CV (%)	1.8	2.4	1.5	2.2	2.7	2.1
$LSD_{0.05}$	1.1	1.8	1.0	1.9	2.2	0.9

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 6: Effect of mineral N supplementation to crotalaria green manure on days to 50% flowering of maize for different cropping seasons in Embu, Kenya

Mineral N Rate (Kg ha^{-1})	Days to 50% flowering of maize					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	MEAN
0 N	75 a	71 b	69 a	74 b	77 ab	73 b
30 N	72 b	68 c	64 b	72 c	77 ab	70 c
60 N	67 c	67 c	64 b	72 bc	76 b	70 c
Control	75 a	75 a	69 a	77 a	80 a	76 a
CV (%)	2.0	3.3	2.6	3.5	4.1	2.1
$LSD_{0.05}$	1.5	2.4	1.8	3.0	3.3	1.6

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 7: Effect of mineral N supplementation to lablab green manure on days to 50% flowering of maize for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Days to 50% flowering of maize					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	MEAN
0 N	72 b	73 b	69 a	78 a	81	75 a
30 N	69 c	68 c	63 b	73 b	77	70 b
60 N	69 c	68 c	64 b	73 b	78	71 b
Control	75 a	75 a	69 a	77 a	80	76 a
CV (%)	1.8	1.7	1.9	3.5	6.0	1.5
$LSD_{0.05}$	0.9	1.2	1.3	3	NS	1.1

Means with same letter in each column are not statistically different at P<0.05

4.4.4 Maize stover yield

The responses of maize stover as influenced by N from GML residues with or without inorganic fertilizer are presented in Tables 4.4.8-10. There were no positive interactions except for the overall seasonal average in the crotalaria residue plots where the fertilizer by density interactions were positive. Results of the overall mean for the five seasons show that mucuna and crotalaria plots yielded significantly more stover than the control. The performance of lablab residue plots was comparable to those of the control (Table 4.4.10) which was attributable to the low lablab biomass production (< 1.0 Mg ha^{-1}) and hence low N content (Table 3.6.2) that was released for maize crop nutrition. Similar results on the benefits rendered by incorporation of similar GML residues on maize biomass yield have been reported in East Africa (Wortman *et al.,* 2000; Baijukya, 2004; Mureithi *et al.,* 2005; Nyambati *et al.*, 2006) and West Africa (Carsky *et al.*, 1999).

Mineral N supplementation to the GM residues resulted to 18 and 36% increase in stover yields for the combined mucuna/crotalaria and lablab plots, respectively. This increase in stover yield due to mineral N supplementation could be a pointer that GML residue of slightly above 2.0 Mg ha^{-1} may be required to optimize maize biomass production. Uhart and Andrade (1995) noted that the effect of N deficiency in a maize crop is normally less severe to stover than grain yields because the N stress is associated with interference of dry matter partitioning to reproductive sinks at flowering.

In the current study, a higher planting density of the legume did not result in increased stover production probably due to small difference of legume dry matter production among the two legume densities (Table 4.4.17-19).

Table 4.4 8: Effect of mineral N supplementation to mucuna green manure on maize stover yield for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Stover yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	MEAN
0 N	2.89 b	4.98 a	5.37 b	5.72 b	3.12	4.42 b
30 N	3.12 ab	4.51 a	5.83 ab	7.72 a	3.64	5.00 ab
60 N	3.95 a	4.52 a	6.41 a	7.65 a	3.54	5.22 a
Control	1.65 c	3.07 b	3.96 c	5.28 b	2.53	3.30 c
CV (%)	34	21	16	15	43	11
$LSD_{0.05}$	0.91	0.94	0.92	1.02	NS	0.61

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 9: Effect of mineral N supplementation to crotalaria green manure on maize stover yield for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Stover yield (Mg ha$^{-1)}$					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	MEAN
0 N	2.78 b	5.98 a	4.33 b	6.85 b	3.16	4.60 b
30 N	3.44 ab	5.91 a	5.88 a	7.78 ab	3.99	5.40 a
60 N	3.94 a	5.60 a	4.78 ab	8.38 a	2.90	5.11 a
Control	1.64 c	3.07 b	3.96 b	5.28 c	2.53	3.30 c
CV (%)	30	13	27	17	51	11
$LSD_{0.05}$	0.94	0.71	1.3	1.25	NS	0.52

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 10: Effect of mineral N supplementation to lablab green manure on maize stover yield for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Stover yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	MEAN
0 N	3.16 b	3.69 ab	4.39 b	4.69 b	2.09	3.66 b
30 N	3.41 b	4.29 a	6.65 a	6.58 b	3.22	4.87 a
60 N	4.30 a	4.14 a	5.69 a	7.17 a	3.39	4.99 a
Control	1.65 c	3.07 b	3.97 b	5.28 b	2.52	3.30 b
CV (%)	26	16	20	21	58	17
$LSD_{0.05}$	0.75	0.63	1.06	1.29	NS	0.77

Means with same letter in each column are not statistically different at P<0.05

4.4.5 Maize grain yield

Results of maize grain yield (Tables 4.4.11-13) show that yields were in the order lowest to highest in the following treatments; control < GML residue alone < mineral N supplementation at 30 kg ha^{-1} and mineral N supplementation at 60 kg ha^{-1}. The legume by mineral N or legume by density interactions were not significant for all the three legumes in all the five cropping seasons. Averaged over the five cropping seasons, plots with GML residue alone produced 2.5, 2.3 and 1.6 times more grain than the control for mucuna, crotalaria and lablab treatments, respectively. The maize yields from the GML residue alone plots differed significantly from the control in the mucuna and crotalaria treatments. Increased maize grain yield due to application of GML residues generated *in situ* is an indication that decomposing legume residues form a feasible source of N for growth and development of maize. Increased maize grain yields due to the use of mucuna or crotalaria legume residues as a source of N have been reported in the central Kenya highlands (Mucheru, 2003; Mureithi et al., 2005) as well as other parts of East Africa (Kullaya *et al*., 1998; Fischler *et al*., 1999; Baijukya, 2004). Elsewhere, Carsky *et al*. (2001) and Ibewiro *et al*. (2002b) also observed significant higher maize yields through the use of mucuna residues in the derived savanna of West Africa.

In the present study, the poor performance of lablab as a source of N for the maize crop fertilization was attributable to the low quantities of biomass (< 1.0 Mg ha^{-1}) and hence N release that was realized (Table 3.6.2). In areas where this legume is able to produce adequate biomass, high maize grain yield due to N provision from decomposing lablab residues has been reported (Wortman *et al*., 2000; Ibewiro *et al*., 2000b; Nyambati *et al*., 2006). This phenomenon, where lablab consistently recorded low biomass yields, was mainly attributable to the prevailing soil conditions. Low N status in the experimental field appear to

have caused yellowing of lablab seedlings due to a root rot condition similar to that of the common beans (Ampofo, 1993). In northwestern Kenya, Nyambati (2002) recorded low biomass yields of lablab in farmers' fields that were characterized by impoverished soils but the reverse was true at the on-station site where the soil was relatively fertile. In the northern Tanzanian District of Bukoba, Baijukya (2004) conducted a study to screen different leguminous species and recorded low biomass yields for lablab in soils with low N. The author attributed the poor performance of lablab to attack by bean fly (*Ophyiyomyia phaseoli*) that retarded its growth and establishment. Elsewhere in the savanna zone of West Africa, Carsky *et al*. (1999) also reported substantially low biomass yield in lablab relative to mucuna and crotalaria (at 91 days after planting) as a result of foliar disease and insect damage suffered by this legume.

The results of maize grain yield obtained with the three GML residues, in the present study, also suggest that the efficiency of N released by any of the three GML residues, is comparable to that of the inorganic N sources. These results confirm the findings by Kimetu (2002) who, working in a site within the central highlands of Kenya at Kabete, compared inorganic N versus organic sources of N and observed that substituting 30 kg N ha^{-1} inorganic N sourced from urea with an equivalent amount of N added in form of three different green manures resulted in similar maize grain yields. The green manures used in his study were *Tithonia diversifolia, Senna spectabilis* and *Calliandra calothyrsus* and the fertilizer equivalencies obtained were 130, 68 and 72%, respectively.

Supplementing mineral N for GML residues resulted in significant maize grain increase only in the lablab treated plots (Tables 4.4.13). Increasing the amount of mineral N applied from 30 to 60 kg N ha^{-1} did not result in a significant yield gain in any of the three GML treatments. Slight maize grain increase was observed only during the LR 2003 season.

This lack of response to higher fertilizer dosage was mainly attributable to the ability of the legume residue to supply any balance of N above the 30 kg N ha^{-1} that was applied. Furthermore, the rainfall pattern typical of this region does not allow for a prolonged wet season for an efficient nutrient translocation beyond the initial 6-8 weeks after the onset of rains (Figure 3.2). Nonetheless, the efficiency of N provision by these decomposing legume residues is still comparable to that of the inorganic N sources. Further, these results suggest that in an area with the weather pattern typical of the central highlands of Kenya (where maize plants take about 10 weeks to reach the reproductive growth phase) it is not advisable to fertilize the crop in excess of 60 kg N ha^{-1} since the extra amounts may not be utilized by the crop. In a similar bi-modal rainfall pattern environment of western Kenya, Mureithi *et al*. (2003) reported that application of 15 kg N ha^{-1} to the mucuna or crotalaria green manure plots increased maize grain yields by 38%, but doubling the N only increased the yields by an additional 3%. Likewise, in the wetter windward side of Bukoba District in northern Tanzania, Baijukya (2004) applied residues of mucuna, crotalaria and other leguminous residues and recorded significant maize yield gains above the control but concluded that addition of these residues above 2.0 Mg ha^{-1} does not result in any corresponding maize yield gains. Similarly, in Ibadan-Nigeria, Akobundu *et al.* (2000) conducted some studies on mineral N supplementation to mucuna residue and concluded that applying a low fertilizer rate (30 kg N ha^{-1}) after mucuna residues was more beneficial to maize and more economical than the conventionally recommended rate of 90 kg N ha^{-1} used in that agro-ecological zone. Similarly, in the West African savanna conditions, Carsky *et al.*(1999) found that increasing mineral N supplementation to mucuna, crotalaria or lablab residues from 30 to 60 kg ha^{-1} N did not result in any maize yield gain at both Kaduna and Bauchi sites of northern Nigeria.

In the present study, a higher planting density of the legume did not lead to higher maize grain yield in any of the three GM legumes except for mucuna during SR 2004 cropping season (Tables 4.4.17-19). A comparison of maize grain yield performance across the three different GM species shows that lablab residue treated plots were consistently lower than the rest.

Table 4.4 11: Effect of mineral N supplementation to mucuna green manure on maize grain yield for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Maize grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	MEAN
0 N	2.70 a	2.93 a	1.38	1.55 b	1.86 a	2.25 a
30 N	2.81 a	2.69 a	1.35	2.98 a	1.88 a	2.58 a
60 N	3.46 a	2.50 a	1.52	3.37 a	2.07 a	2.63 a
Control	0.50 b	0.77 b	0.73	0.66 c	0.91 b	0.91 b
CV (%)	49	38	62	30	46	31
$LSD_{0.05}$	1.07	0.88	NS	0.66	0.80	0.62

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 12: Effect of mineral N supplementation to crotalaria green manure on maize grain yield for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Maize grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	MEAN
0 N	1.40 b	3.77 a	1.05	1.86 a	2.10 a	2.12 a
30 N	2.53 a	3.47 a	1.16	2.20 a	2.11 a	2.58 a
60 N	2.85 a	3.17 a	1.08	2.23 a	1.71 ab	2.23 a
Control	0.50 b	0.76 b	0.73	0.67 b	0.91 b	0.91 b
CV (%)	65	33	75	57	50	31
$LSD_{0.05}$	1.08	0.95	NS	1.03	0.90	0.64

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 13: Effect of mineral N supplementation to lablab green manure on maize grain yield for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Maize grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	MEAN
0 N	2.47 b	1.43 ab	0.70	0.70 b	0.93	1.43 bc
30 N	2.87 ab	2.13 a	1.39	1.74 a	1.49	2.06 ab
60 N	3.63 a	1.70 ab	1.33	1.80 a	1.60	2.25 a
Control	0.50 c	0.74 b	0.73	0.66 b	0.91	0.91 c
CV (%)	44	46	79	63	85	38
$LSD_{0.05}$	0.97	0.72	NS	0.81	NS	0.66

Means with same letter in each column are not statistically different at P<0.05

4.4.6 Maize harvest index

The results of maize harvest index are presented in Tables 4.4.14-16. Maize harvest index was higher in wetter seasons of 2003 than during the drier seasons of 2004 (Figures 3.2). Generally, mineral N supplementation to the GML residues did not appear to affect the harvest index of maize but the control treatment tended to result in significantly lower harvest index. The legume by mineral N supplementation interactions were also not significant. Low harvest index in drier seasons and in plots with N stress is mainly attributed to reduced production and translocation of assimilates to the developing kernels (Edmeades and Lafitte, 1993; Schusser and Westgate, 1995).

Table 4.4 14: Effect of mineral N supplementation to mucuna green manure on maize harvest index for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Harvest index				
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005
0 N	0.51 a	0.38 a	0.19	0.20 b	0.37 ab
30 N	0.49 a	0.40 a	0.18	0.27 a	0.41 a
60 N	0.49 a	0.36 a	0.18	0.26 a	0.35 ab
Control	0.31 b	0.24 b	0.14	0.10 c	0.24 b
CV (%)	23	15	40	20	40
$LSD_{0.05}$	0.11	0.05	NS	0.04	0.14

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 15: Effect of mineral N supplementation to crotalaria green manure on maize harvest index for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Harvest index				
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005
0 N	0.32 ab	0.40 a	0.16	0.18 a	0.43 a
30 N	0.46 ab	0.40 a	0.13	0.20 a	0.39 ab
60 N	0.38 ab	0.38 a	0.12	0.20 a	0.39 ab
Control	0.31 b	0.24 b	0.13	0.10 b	0.24 b
CV (%)	37	16	50	40	44
$LSD_{0.05}$	0.14	0.05	NS	0.07	0.16

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 16: Effect of mineral N supplementation to lablab green manure on maize harvest index for different cropping seasons in Embu, Kenya

Mineral N Rate (kg ha^{-1})	Harvest index				
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005
0 N	0.47 ab	0.31 a	0.13	0.13 ab	0.35 a
30 N	0.43 ab	0.36 a	0.16	0.19 a	0.32 ab
60 N	0.47 a	0.33 a	0.17	0.19 a	0.30 ab
Control	0.31 b	0.24 b	0.13	0.11 b	0.24 b
CV (%)	29	20	55	46	33
$LSD_{0.05}$	0.12	0.06	NS	0.07	0.10

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 17: Effect of mucuna planting density on maize seedling vigour, maize grain and stover yields, plant height and days to flowering for different cropping seasons in Embu, Kenya

Cropping Season	Legume Density	Biomass Incorporated (Mg ha^{-1})	Maize Seedling vigour	Grain yield (Mg ha^{-1})	Stover yield (Mg ha^{-1})	Plant height (cm)	Days to 50% flowering
	Low density	2.72 a	-	2.82	3.15	163	70
LR 2003	High density	4.15 b	-	3.16	3.48	164	70
	CV (%)	13	-	42	26	12	1.8
	$LSD_{0.05}$	NS	-	NS	NS	NS	NS
	Low density	2.3	-	2.67	4.89	163	70
SR 2003	High density	2.7	-	2.73	4.45	162	70
	CV (%)	14	-	39	20	7	2.5
	$LSD_{0.05}$	0.32	-	NS	NS	NS	NS
	Low density	4.17 a	1.9	1.31	5.99	129	66
LR 2004	High density	4.84 b	2.2	1.52	5.79	132	66
	CV (%)	12	26	63	16	9	1.7
	$LSD_{0.05}$	0.50	NS	NS	NS	NS	NS
	Low density	2.20 a	4.3	2.15 b	6.94	61	73
SR 2004	High density	3.23 b	4.5	3.11 a	7.12	64	73
	CV (%)	27	8.6	28	13	10	1.8
	$LSD_{0.05}$	0.42	NS	0.64	NS	NS	NS
LR 2005	Low density	0.78	3.3	1.80	3.64	166	76
	High density	1.28	3.4	2.08	3.22	164	77
	CV (%)	52	32	42	45	11	3.2
	$LSD_{0.05}$	0.46	NS	NS	NS	NS	NS
	Low density	-	3.8	2.33	4.95	152	71
MEAN	High density	-	3.9	2.64	4.82	151	72
	CV (%)	-	17	27	13	7	1.3
	$LSD_{0.05}$	-	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 18: Effect of crotalaria planting density on maize seedling vigour, maize grain and stover yields, plant height and days to flowering for different cropping seasons in Embu, Kenya

Cropping Season	Legume Density	Biomass Incorporated (Mg ha^{-1})	Maize Seedling vigour	Grain yield (Mg ha^{-1})	Stover yield (Mg ha^{-1})	Plant height (cm)	Days to 50% flowering
	Low density	1.75 b	-	2.37	3.63	155	69
LR 2003	High density	2.33 a	-	2.13	3.15	158	68
	CV (%)	14	-	53	30	15	3.7
	$LSD_{0.05}$	0.43	-	NS	NS	NS	NS
	Low density	3.02 b	-	3.01 a	5.64	176 b	69
SR 2003	High density	4.03 a	-	3.94 b	6.03	192 a	68
	CV (%)	66	-	30	13	9	3.7
	$LSD_{0.05}$	NS	-	0.64	NS	13	NS
	Low density	0.51	1.6 b	0.53 a	4.59	119	66
LR 2004	High density	0.71	2.3 a	1.30 b	5.39	135	65
	CV (%)	36	29	77	30	22	2.8
	$LSD_{0.05}$	NS	0.4	0.61	NS	NS	NS
	Low density	0.76	4.3	1.56 b	7.29	129	73
SR 2004	High density	0.93	4.5	2.63 a	8.05	137	72
	CV (%)	42	10	54	16	19	19
	$LSD_{0.05}$	NS	NS	0.98	NS	NS	NS
	Low density	0.33	3.0	1.77	3.30	145	77
LR 2005	High density	0.67	2.9	2.17	3.40	158	76
	CV (%)	95	36	45	48	20	4.4
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
	Low density	-	3.8	2.09	4.85	144 b	72
MEAN	High density	-	5.0	2.52	5.22	156 a	70
	CV (%)	-	61	28	11	6	2.4
	$LSD_{0.05}$	-	NS	NS	NS	8	NS

Means with same letter in each column are not statistically different at P<0.05

Table 4.4 19: Effect of lablab planting density on maize seedling vigour, maize grain and stover yields, plant height and days to flowering for different cropping seasons in Embu, Kenya

Cropping Season	Legume Density	Biomass Incorporated (Mg ha^{-1})	Maize Seedling vigour	Grain yield (Mg ha^{-1})	Stover yield (Mg ha^{-1})	Plant height (cm)	Days to 50% flowering
	Low density	0.34	-	2.36	3.33	156	70
LR 2003	High density	0.69	-	2.82	3.10	159	70
	CV (%)	64	-	52	24	11	1.8
	$LSD_{0.05}$	NS	-	NS	NS	NS	NS
	Low density	0.1	-	1.90	4.81	149	69
SR 2003	High density	0.1	-	1.61	3.90	151	70
	CV (%)	34	-	47	16	11	3.2
	$LSD_{0.05}$	NS	-	NS	NS	NS	NS
	Low density	0.14	3.7	1.05	5.43	135	66
LR 2004	High density	0.18	3.8	1.23	5.72	133	65
	CV (%)	92	11	84	20	16	1.9
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
	Low density	0.27	4.1	1.52	6.59	120	75
SR 2004	High density	0.6	4.0	1.36	5.70	110	73
	CV (%)	121	11	64	20	19	3.7
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
LR 2005	Low density	0.29	2.6	1.27	2.52	134	79
	High density	0.60	2.8	1.41	3.28	149	77
	CV (%)	156	33	88	63	29	7.1
	$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
	Low density	-	3.5	1.91	4.55	142	72
MEAN	High density	-	3.7	1.92	4.46	142	72
	CV (%)	-	11	38	19	14	1.6
	$LSD_{0.05}$	-	NS	NS	NS	NS	NS

Means with same letter in each column are not statistically different at P<0.05

4.4.7 Nitrogen Mineralization

Mineral N content in the 0 to 20 cm soil depth ranged from 40 to 128 kg ha^{-1} for both SR 2004 and LR 2005 cropping seasons (Tables 4.4.20-22). The ratio of NH_4^+-N and NO_3^--N contents of the mineralized N was almost equal but there were large fluctuations from one sampling period to another, as expected. There were slight differences in the mineralization patterns of the two seasons during the three sampling periods of each season. In the drier SR 2004, peak N mineralization was observed between 4 and 8 weeks after planting (WAP) and declined until harvest (19 WAP). In the more moist LR 2005 season, highest mineral-N content was registered at 4 WAP sampling and declined up to the 8 WAP before picking up again until harvest (23 WAP). These results are consistent with those of other workers in the region (Mugendi *et al*., 2000; Mucheru, 2003) who reported peak mineral N levels in decomposing legume residues at 4 WAP sampling date. Likewise in northwestern Kenya (where maize grows for a longer season of 27 weeks), Nyambati (2002) also observed peak N-mineralization at 4 WAP and towards the end of the season with lowest N content occurring 10 WAP after incorporating mucuna and lablab GM residues. The general trend in mineral-N decrease between 4 and 8 WAP, observed in the current study, could partly be due to rapid N uptake by maize as reported by Tian *et al*. (1993) and Franzluebbers *et al*. (1994) coupled with leaching (Hartermink *et al*., 1996 and Hogervorst, 1999) which may result from the excess downpours of rain that occur in this region (Figures 3.2).

In the present study, treatments where legume residues were applied mineralized greater amounts of N than the control although the differences were not significant. Throughout the period from 4 WAP to harvest, there were no differences among the treatments in soil mineral N at any sampling date. The fertilizer by density interactions were also not significant except for lablab NO_3^--N in the last sampling date of SR 2004 season. There was a tendency for crotalaria

residues to exhibit higher contents of NH_4^+-N and NO_3^--N when compared against mucuna, lablab or the control treatments, particularly during the more moist LR 2005 cropping season (Table 4.4.21). High levels of available N in all treatments including those where no mineral N was applied was possibly due to the ability of these GM residues to supply adequate N coupled with the fact that during sampling, soils are taken within and between rows with fewer chances of encountering the N fertilizer which was applied in a hole with only a small radius. Nitrogen losses through volatilization of available N could be ruled out since the soil pH (5.4) was not high enough to facilitate this process (Myers *et al*., 1994; Mugendi *et al*., 2000).

Table 4.4 20: Amount of NH^{+}_{4}-N and NO^{-}_{3}-N mineralized in the 0-20 cm soil depth of mucuna residue incorporated plots at different sampling dates of SR 2004 and LR 2005 cropping season at Embu, Kenya

Rate of mineral N (kg ha^{-1}) applied	Period after planting											
	4 weeks				8 weeks				At harvest			
	SR 2004		LR 2005		SR 2004		LR 2005		SR 2004		LR 2005	
	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N
	----------kg ha^{-1}----------											
0 N	41	55	51	34	65	34	30	25	62	19	60	48
30 N	47	60	60	47	64	36	33	22	52	21	59	50
60 N	36	56	51	55	79	48	24	25	58	19	58	63
Control	39	50	46	27	76	32	23	17	51	18	59	23
SE	6.3	5.4	7.2	6.4	8.3	4.6	8.2	4.0	8.7	3.1	8.2	11.6
Effects	----------P value----------											
Fertilizer (F)	0.534	0.776	0.566	0.214.	0.422	0.11	0.753	0.857	0.752	0.857	0.980	0.632
Density (D)	0.264	0.273	0.310	0.407	0.151	0.887	0.125	0.417	0.375	0.417	0.768	0.910
F X D	0.803	0.459	0.220	0.120	0.888	0.284	0.720	0.580	0.479	0.580	0.694	0.765

Table 4.4 21: Amount of NH^{+}_{4}-N and NO^{-}_{3}-N mineralized in the 0-20 cm soil depth of crotalaria residue incorporated plots at different sampling dates of SR 2004 and LR 2005 cropping season at Embu, Kenya

Rate of mineral N (kg ha^{-1}) applied	Period after planting											
	4 weeks				8 weeks				At harvest			
	SR 2004		LR 2005		SR 2004		LR 2005		SR 2004		LR 2005	
	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N
	----------kg ha^{-1}----------											
0 N	37	59	55	47	59	39	37	41	64	23	71	46
30 N	43	55	62	67	80	35	25	42	65	18	64	50
60 N	37	50	50	63	54	34	29	27	61	18	72	57
Control	39	50	46	27	76	32	23	17	51	18	49	23
SE	3.1	5.4	7.0	7.5	8.5	5.2	8.7	10.0	2.7	1.5	11.9	17.3
Effects	----------P value----------											
Fertilizer (F)	0.316	0.512	0.535	0.198.	0.127	0. 818	0.631	0.511	0.659	0.052	0.902	0.911
Density (D)	0.636	0.423	0.781	0.619	0.206	0.272	0.685	0.992	0.524	0.104	0.571	0.905
F X D	0.752	0.107	0.886	0.409	0.655	0.732	0.346	0.918	0.261	0.931	0.930	0.712

Table 4.4 22: Amount of NH_4^+-N and NO^-_3-N mineralized in the 0-20 cm soil depth of lablab residue incorporated plots at different sampling dates of SR 2004 and LR 2005 cropping season at Embu, Kenya

Rate of mineral N (kg ha^{-1}) applied	Period after planting											
	4 weeks				8 weeks				At harvest			
	SR 2004		LR 2005		SR 2004		LR 2005		SR 2004		LR 2005	
	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N
	kg ha^{-1}											
0 N	35	49	43	38	52	36	28	22	52	17	55	47
30 N	36	55	54	39	62	44	34	21	65	16	56	37
60 N	45	46	46	45	53	53	32	23	62	21	48	32
Control	39	50	46	27	76	32	23	17	51	18	49	23
SE	3.3	6.8	4.4	7.5	8.8	7.1	7.3	5.1	301	1.7	10.5	12.7
Effects	P value											
Fertilizer (F)	0.120	0.627	0.234	0.778	0.670	0.284	0.816	0.957	0.042	0.155	0.830	0.714
Density (D)	0.757	0.826	0.073	0.337	0.063	0.346	0.731	0.211	0.059	0.027	0.770	0.353
F X D	0.809	0.962	0.793	0.747	0.518	0.227	0.443	0.416	0.735	0.025	0.739	0.843

4.4.8 Nitrogen uptake by maize

The results of N uptake by maize for the SR 2004 and LR 2005 cropping seasons (when this parameter was assessed) are presented in Tables 4.4.23-25. Nitrogen uptake by maize following mucuna or crotalaria GM treatments were significantly higher than those of lablab or control in all samplings of both seasons except for the third sampling of SR 2004 and 4 WAP in LR 2005. Application of mucuna or crotalaria GML (with or without mineral N) resulted in significantly higher N uptake compared to the control (Tables 4.4.23 and 4.4.24). In contrast, only mineral N fertilized lablab plots gave higher N uptake than the control (Table 4.4.25) implying that N uptake was a function of available N either from inorganic or organic sources. Similar results were obtained in the sub-humid highlands of northwestern Kenya by Nyambati (2002) after incorporating mucuna and lablab GM residues. He attributed enhanced N uptake in GML treated plots, compared to the natural fallow, to N mineralization from the GML residues. Likewise, Mucheru (2003), working in the central Kenya division of Chuka, reported higher N concentration in mucuna, crotalaria and mineral N treatments compared to those of the unfertilized control. In northern Tanzania, Baijukya (2004) also observed significant N uptake by maize in plots following mucuna or crotalaria as well as other legume residues. In the present study, mineral N supplementation resulted in higher N uptake in the lablab but not mucuna or crotalaria treatments. Overall, there were no significant N uptake interactions (legume by fertilizer, legume by density, fertilizer by density or legume by fertilizer by density) that were observed in any of the three GML treatments.

Table 4.4 23: Nitrogen taken up by maize in plots with mucuna residues under various levels of mineral N at different sampling dates of SR 2004 and LR 2005 cropping season at Embu, Kenya

Rate of mineral N (kg ha^{-1}) applied	Period after planting					
	4 weeks		8 weeks		At harvest	
	SR 2004	LR 2005	SR 2004	LR 2005	SR 2004	LR 2005
	----------kg ha^{-1}----------					
0 N	16	18	158	93	106	125
30 N	32	19	162	118	120	144
60 N	33	21	191	131	154	134
Control	6	7	94	46	90	92
SE	4.9	2.3	19.4	12.0	9.3	13.6
Effects	----------P values----------					
Fertilizer	0.015	0.578	0.381	0.084	0.003	0.742
Density	0.546	0.194	0.839	0.589	0.510	0.073
F X D	0.780	0.204	0.637	0.853	0.521	0.913

Table 4.4 24: Nitrogen taken up by maize in plots with crotalaria residues under various levels of mineral N at different sampling dates of SR 2004 and LR 2005 cropping season at Embu, Kenya

Rate of mineral N (kg ha^{-1}) applied	Period after planting					
	4 weeks		8 weeks		At harvest	
	SR 2004	LR 2005	SR 2004	LR 2005	SR 2004	LR 2005
	----------kg ha^{-1}----------					
0 N	20	16	110	135	129	160
30 N	26	19	134	145	148	185
60 N	32	19	154	147	204	192
Control	6	7	91	46	95	92
SE	5.0	2.1	12.6	19.4	18.4	25.3
Effects	----------P values----------					
Fertilizer	0.169	0.309	<0.001	0.876	0.149	0.642
Density	0.097	0.598	0.051	0.631	0.598	0.080
F X D	0.972	0.225	0.069	0.972	0.170	0.977

Table 4.4 25: Nitrogen taken up by maize in plots with lablab residues under various levels of mineral N at different sampling dates of SR 2004 and LR 2005 cropping season at Embu, Kenya

Rate of mineral N (kg ha^{-1}) applied	Period after planting					
	4 weeks		8 weeks		At harvest	
	SR 2004	LR 2005	SR 2004	LR 2005	SR 2004	LR 2005
	----------kg ha^{-1}----------					
0 N	7	12	92	68	98	85
30 N	16	17	125	108	143	116
60 N	28	17	128	120	149	128
Control	6	7	91	46	94	92
SE	3.7	2.2	12.5	11.4	15.2	17.9
Effects	----------P values----------					
Fertilizer	0.001	0.11	0.021	0.006	0.050	0.235
Density	0.939	0.967	0.906	0.411	0.417	0.288
F X D	0.997	0.682	0.991	0.575	0.794	0.795

4.4.9 Soil chemical characteristics

Table 4.4.26 presents the results of soil total N and pH status (for the 0-20 cm depth) sampled in the various treatments at the end of the experiment in October 2005. Due to the large number of plots and financial constraints, only two soil parameters were assessed at the end of the study. Measurement of potassium was not considered due to the abundance of this element in the local soils while phosphorus was left out because it was applied uniformly to all the plots in each of the growing seasons.

The results of the two soil chemical properties assessed show that soils were modestly affected by the incorporation of GML residues over the 3-year period. Total N levels in the crotalaria residue treated plots showed significantly higher N (Table 4.4.26) than the lablab or control treatments. Application of mineral N (to supplement the green manures) did not influence either the total N or the pH of the soils in the various treatments. There was no significant fertilizer by density or fertilizer by density by residue interactions that were observed for any of the two chemical properties assessed. The findings of this study concur with those of Waswa (2004) who, working in the same site here in Embu, observed a significant increase in total N, above the control, in plots where leguminous tree residues were incorporated into the soils. In the slightly more acidic soils within central Kenya, Mucheru (2003) also observed more total N in mucuna or crotalaria incorporated plots compared to the control plot although there was a slight decline over the two year period when compared to the original site characterization results. Similarly, Njunie (2002) did not detect any change in soil pH after incorporating lablab and clitoria residues over a two year period in a sandy loam soil at the coastal lowlands of Kenya.

Table 4.4 26: Soil chemical properties (0 – 20 cm depth) as influenced by different green manure legume residues applied under different levels of mineral N supplementation at Embu, Kenya

Rate of mineral N (kg N ha^{-1}) applied	Chemical characteristic					
	Mucuna		Crotalaria		Lablab	
	Nitrogen (%)	pH (water)	Nitrogen (%)	pH (water)	Nitrogen (%)	pH (water)
0 N	0.35	5.8	0.37	5.6	0.33	5.6
30 N	0.36	5.6	0.36	5.7	0.34	5.6
60 N	0.35	5.6	0.36	5.7	0.32	5.6
Control	0.32	5.6	0.32	5.6	0.32	5.6
SE	0.017	0.043	0.012	0.035	0.015	0.057
Effects	----------P values----------					
Fertilizer (F)	0.896	0.171	0.904	0.245	0.332	0.576
Density (D)	0.264	0.279	0.398	0.882	0.099	0.132
F X D	0.758	0.962	0.997	0.658	0.982	0.771

4.4.10 Soil physical characteristics - bulk density

The results (Table 4.4.27) show that mineral N supplementation to green manure residues did not affect the bulk density of the soil within the three (3) year period of the study. When compared across different GML irrespective of mineral N supplementation, crotalaria, mucuna, lablab and control plots registered bulk density values of 1.025, 1.035, 1.042 and 1.044 g cm^{-3}, respectively. Thus, there was a slight reduction (0.9-1.8%) in soil bulk density for plots where mucuna or crotalaria residues were incorporated when compared to the control (no residues). Other workers, conducting similar work in a neighbouring farm also never recorded any change in soil bulk density as a result of incorporating calliandra or leucaena agroforestry tree prunings (Mugendi *et al*., 1997; Waswa, 2004). The authors attributed their results to the short duration of experimentation. In the forest savanna of southwestern Nigeria, Carsky *et al*. (2001) reported increased porosity and infiltration when the amount of mucuna residues applied were increased from 3.8 to 8.5 Mg ha^{-1}. In the present study, the small reduction in soil bulk density was probably attributable to the small quantities of residues applied (Table 3.6.2) as well as the relatively short duration of experimentation.

Table 4.4 27: The influence of mineral N supplementation to green manure legumes on soil bulk density in Embu, Kenya

Mineral N	Soil bulk density (g cm^{-3})		
Rate (Kg ha^{-1})	Mucuna	Crotalaria	Lablab
0 N	1.036	1.028	1.061
30 N	1.027	1.021	1.027
60 N	1.043	1.026	1.068
Control	1.044	1.044	1.044
CV (%)	3.2	3.1	3.7
$LSD_{0.05}$	NS	NS	NS

4.4.11 Nodulation in GML species

Nodulation assessment was carried out by measuring the fresh weight of nodules per plant in each of the three GML species used in the study. Mucuna nodules were few but very big while crotalaria had very many small nodules. Lablab formed few nodules of average size. Among the three GML species, mucuna had the highest root nodulation (0.24 g plant^{-1}) followed by crotalaria (0.09 g plant^{-1}) and lablab (0.008 g plant^{-1}). These weights were significantly different from each other (Table 4.4.28). Similar nodulation results in mucuna and lablab have been reported by Ibewiro *et al*. (2000a).

Effect of N fertilizer on nodulation

As expected, application of inorganic N fertilizer had a negative effect on the legume root nodulation (Table 4.4.28). Overall, N application depressed nodulation by between 1.5 and 3 times in the three GML species. The reduction was, however, significant only in mucuna. The legume nodulation by mineral N interaction was significant (P = 0.012) implying that nodulation in different GM legumes was affected by N fertilizer application differently. These results corroborate the findings of Cheminingw'a *et al.* (2004) who worked in similar type of soils at Kabete, Kenya and found that application of 30 kg N ha^{-1} resulted in a reduction of the number as well as the dry weight of mucuna, crotalaria and lablab nodules assessed 8 weeks after emergence. Likewise, Sanginga *et al*. (1996) found that nodulation of mucuna was significantly reduced by N fertilizer applied at the rate of 90 kg N ha^{-1} in a field experiment conducted at Ibadan, Nigeria.

Table 4.4 28: Effect of mineral N supplementation to green manure legumes on nodule fresh weight in Embu, Kenya

Mineral N Rate (Kg ha^{-1})	Nodule fresh weight (g $plant^{-1}$)		
	Mucuna	Crotalaria	Lablab
0 N	0.37 a	0.12	0.003
30 N	0.25 ab	0.08	0.002
60 N	0.11 b	0.07	0.002
CV (%)	71	51	47
$LSD_{0.05}$	0.18	NS	NS

Means with same letter in each column are not statistically different at P<0.05

4.5 EXPERIMENT FOUR

Title: The use of low quality residues in slowing down the rate of fast-decomposing green manure legume residues to improve N synchrony for maize performance

4.5.1 Maize seedling vigour

Maize seedling vigour, taken 3 weeks after emergence, was high in treatments where GML residues were present either alone or in combination with medium (3.0 Mg ha^{-1}) or high (6.0 Mg ha^{-1}) amounts of low quantity residues (Tables 4.5.1). Maize seedlings in the two controls (absolute control with no residues and control with stover alone) had normal germination but the plants thereafter appeared stunted with yellowish or light green colouration indicating low vigour. However, maize vigour in the stover alone treatment registered the lowest visual score rating. The visual scores of maize in the two controls were significantly different from those of the other treatments during last three seasons (LR 2004 - LR 2005) when the scoring was done. Low seedling vigour in the control plots is an indication that there was N stress in the plots where GML residues were absent (Uhart and Andrade, 1995). There was an occurrence of an early season moisture deficit period during LR 2005 season which stressed maize seedlings in all the plots resulting in low seedling vigour of maize for all the treatments and eventually resulted in high coefficient of variability (CV) for all parameters measured thus rendering the statistical comparisons less sensitive. A comparison of the three GML

sources, irrespective of the amount of low quality residues added, showed that maize seedling vigour across different GML was similar.

Table 4.5 1: Maize seedling vigour as influenced by low quality (stover) residues added to different green manure legumes for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Early seedling vigour (visual rating)											
	LR 2004			SR 2004			LR 2005			MEAN		
	Mucuna	Lablab	Crotalaria	Mucuna	Lablab	Crotalaria	Mucuna	Lablab	Crotalaria	Mucuna	Lablab	Crotalaria
None	4.0 a	3.8 a	4.0 a	5.0 a	3.1 b	4.0 a	2.5	3.0	2.8	3.7 a	2.8 b	3.5 a
Three	3.5 a	2.8 b	3.0 b	4.5 a	4.2 a	4.5 a	2.5	3.1	2.5	3.5 ab	3.8 a	3.0 ab
Six	3.0 a	3.2 b	3.0 b	5.0 a	4.5 a	4.5 a	3.0	3.0	2.5	3.2 ab	3.9 a	3.0 ab
Stover only	2.0 b	2.0 c	2.0 c	3.0 b	3.0 b	3.0 b	2.5	2.5	2.5	2.2 c	2.2 c	2.3 b
Control	3.0 a	2.8 b	3.0 b	3.0 b	3.0 b	3.0 b	2.5	2.8	2.5	2.8 bc	2.8 b	2.8 ab
CV (%)	8	11	8	10	11	10	21	32	33	18	13	18
$LSD_{0.05}$	0.60	0.43	0.52	0.50	0.43	0.61	NS	NS	NS	0.86	0.48	0.80

Means with same letter in each column are not statistically different at P<0.05

Key for the visual scores of the seedling vigour
5 = Very high
4 = High
3 = Medium
2 = Low
1 = Very Low

4.5.2 Maize plant height

The results of maize plant height are presented in Tables 4.5.2-4. Seasonal effects were evident whereby maize height attained during the wetter 2003 seasons was higher than those of the drier 2004 seasons. For example, tallest maize plants were achieved during SR 2004 with a height of 130 cm compared to 212 cm for the LR 2003 season.

The results of maize plant height (Tables 4.5.2-4) show that the height of plants attained in plots that had different quantities of the low quality residues (stover) added to any of the three GML residues was similar to that of the treatment where no low quality residues were added. The results of the initial three seasons show that maize height, taken one month after planting, ranged between 66 and 72 cm for the three GML treatments with or without the low quality residues. These heights were significantly higher than those of the two control plots (absolute control and stover alone control). The stover alone treated plot registered the lowest early season heights that was about 5 cm lower than that of the absolute control. However, these observations were restricted to the initial three cropping seasons (LR 2003 - LR 2004). These results are a pointer that as was the case in grain and stover yields, N availability was not curtailed by the presence of the low quality residues in these mixtures. Contrariwise, these low quality residues acted like catalysts toward the release and retention of N from the decomposing GML residues for enhanced uptake by the maize crop (Martin *et al*., 1989; Karlen *et al*., 1994; Bunyasi, 1997).

In the final two seasons of experimentation (SR 2004 and LR 2005), early seasonal height (4 WAP assessment) for the stover alone control was lower than that of the GML residue plots but significantly higher than that of the absolute control (Table 4.5.2-4). The final maize plant heights, taken after tasselling, followed a similar trend to that of the early season assessments. Maize plant height for the final two seasons of the trial indicated that all residue treated plots (including stover alone control) produced maize plants that were significantly taller than the absolute control. It would thus appear that maize plants in the stover only plots grew

relatively faster than those of the other treatments during the latter (after 4 weeks) stages of vegetative phase of growth. The low quality by high quality residues interaction were not significant for the early or final maize plant height. These results suggest that the presence of low quality residues mixed with the GML residues did not negatively influence N availability from their decomposition process. The response of mucuna, crotalaria or lablab GM residues in determining the final maize plant height was similar. These results confirm work by Nandwa (1995) who, working in similar type of soils within the central highlands of Kenya at Kabete, registered increased maize height in stover incorporated plots when compared to the removal treatments during the final two out of the six consecutive seasons of experimentation. Singh and Singh (1994) have argued that the function of these low quality residues is to enhance N mineralization rate and increase nutrient supply to the crop during the periods when N supply from other sources is not feasible due to unsuitable conditions that may be prevailing in the soil.

Table 4.5 2: Maize plant height (taken at 4 WAP and at harvest) as influenced by low quality (stover) residues added to mucuna green manure for different cropping seasons in Embu, Kenya

Amount of stover added ($Mg\ ha^{-1}$)	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest
None	70 a	199 a	84 a	204 a	73 a	159 a	48 a	120 a	80 a	171 a	72 a	171 a
Three	72 a	212 a	81 a	203 a	73 a	159 a	48 a	127 a	68 ab	189 a	69 a	179 a
Six	69 a	191 a	78 a	185 a	75 a	158 a	50 a	131 a	75 a	198 a	70 a	173 a
Stover only	50 b	147 a	53 b	147 b	55 b	132 ab	43 b	130 a	60 b	163 ab	52 b	144 b
Control	54 b	142 b	55 b	146 b	55 b	117 b	38 c	79 b	43 c	125 b	50 b	123 c
CV (%)	11	13	9	9	7	12	5	13	12	15	5	6
$LSD_{0.05}$	9	31	9	24	7	27	3.5	23	12	39	4.8	14

Means with same letter in each column are not statistically different at $P<0.05$

Table 4.5 3: Maize plant height (taken at 4 WAP and at harvest) as influenced by low quality (stover) residues added to crotalaria green manure for different cropping seasons in Embu, Kenya

Amount of stover added	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
(Mg ha^{-1})	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest
None	67 a	191 a	80 a	192 a	77 a	152 ab	51 a	123 a	74 ab	161 ab	71 a	162 a
Three	69 a	202 a	85 a	203 a	72 a	150 ab	49 a	119 a	77 a	168 a	71 a	168 a
Six	70 a	192 a	86 a	205 a	73 a	153 a	53 a	119 a	76 a	189 a	72 a	173 a
Stover only	50 b	147 b	53 b	147 b	55 b	132 ab	43 b	130 a	60 b	163 a	53 b	144 b
Control	55 b	143 b	55 b	146 b	55 b	117 b	38c	79 b	43 c	125 b	50 b	123 c
CV (%)	10	16	6	9	9	16	6.3	13	14	18	4.4	7.2
$LSD_{0.05}$	8.8	38	9	26	9	35	4.5	24	14	40	4.2	17

Means with same letter in each column are not statistically different at P<0.05

Table 4.5 4: Maize plant height (taken at 4 WAP and at harvest) as influenced by low quality (stover) residues added to lablab green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Maize plant height (cm)											
	LR 2003		SR 2003		LR 2004		SR 2004		LR 2005		MEAN	
	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest	4 week	Harvest
None	66 a	193 a	77 a	190 a	74 a	150 a	49 a	121 a	73 a	172 a	68 a	165 a
Three	66 a	191 a	68 a	180 a	73 a	149 ab	50 a	132 a	70 a	171 a	66 a	165 a
Six	66 a	188 a	70 a	192 a	71 a	150 a	51 a	138 a	60 a	179 a	64 a	171 a
Stover only	50 b	147 b	53 b	147 b	55 b	132 bc	43 b	130 a	60 a	163 a	53 b	144 b
Control	55 b	143 b	55 b	146 b	55 b	117 c	38 c	79 b	43 b	125 b	50 b	123 c
CV (%)	11	15	9	7	7	8	7	11	15	12	5	4
$LSD_{0.05}$	9	36	9	20		17	5	20	14	30	4	10

Means with same letter in each column are not statistically different at P<0.05

4.5.3 Maize flowering

Maize flowering (tasselling and silking) ranged between 70 to 83 days from planting but was dependent upon the individual seasonal weather conditions (Tables 4.5.5-7). Relative to the two controls (absolute and stover alone), maize in the GML residue treatments with or without low quality residues flowered 3-5 days earlier, except during SR 2004 when no treatment differences were detected. This tendency to flower early was an indication of lack of N stress in these treatments implying that net N mineralization of the GML residues was not affected by the presence of the low quality residues that tend to immobilize this nutrient. Maize flowering in mucuna, crotalaria or lablab treatments was similar and significantly differed from the two controls, except during the final two seasons of experimentation. The ability of maize to flower early in plots with mixed low and high quality residues was an indication of lack of N stress in these plots. These findings confirm work by Jacob and Pearson (1991) and Uhart and Andrade (1995) who carried out a study to investigate the effect of N availability on crop development and found that N deficiencies delayed tasselling and silking of the maize crop relative to the control.

Table 4.5 5: Days to 50% flowering as influenced by low quality (stover) residues added to mucuna green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Days to 50% flowering					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
None	70 b	71 b	71 ab	80 a	82 ab	77 a
Three	70 b	71 b	71 ab	80 a	81 ab	76 a
Six	70 b	72 ab	71 ab	70 b	78 b	73 b
Stover only	75 a	74 a	73 ab	79 ab	82 ab	75 ab
Control	75 b	74 a	74 a	82 a	84 a	77 a
CV (%)	6	2	2	9	3.6	2.6
$LSD_{0.05}$	2.3	2.2	2.4	9.5	4.5	3.0

Means with same letter in each column are not statistically different at $P<0.05$

Table 4.5 6: Days to 50% flowering as influenced by low quality (stover) residues added to crotalaria green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Days to 50% flowering					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
None	71 ab	71 b	70 b	79	80	74 b
Three	70 b	70 b	71 ab	80	81	73 b
Six	70 b	70 b	70 b	79	81	73 b
Stover only	73 ab	74 a	73 ab	79	82	75 b
Control	75 a	74 a	74 a	83	84	77 a
CV (%)	3	22	2.5	3.2	5.1	1.8
$LSD_{0.05}$	2.2	2.3	2.7	NS	NS	2.1

Means with same letter in each column are not statistically different at P<0.05

Table 4.5 7: Days to 50% flowering as influenced by low quality (stover) residues added to lablab green manure for different cropping seasons in embu, kenya

Amount of stover added (Mg ha^{-1})	Days to 50% flowering					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
None	71 b	70 b	71 b	78 b	80	73 b
Three	72 b	72 ab	72 b	77 b	81	74 b
Six	72 b	72 ab	72 b	78 b	81	74 b
Stover only	74 a	74 a	73 a	79 b	82	75 b
Control	75 a	74 a	74 a	81 a	84	77 a
CV (%)	2	2	2	3	3.9	1.7
$LSD_{0.05}$	1.9	2.2	1.8	3.1	NS	1.9

Means with same letter in each column are not statistically different at P<0.05

4.5.4 Maize stover yields

The results of maize stover yields for each of five seasons are presented in Tables 4.5.8-10. These results show that the production of maize stover was not affected by the seasonal variability as much as the maize grain yields. On average, maize stover yields ranged between 4-6 Mg ha^{-1}. In the majority of the seasons, rainfall tended to taper off after the sixth week, when maize plants were already advanced in vegetative growth. In general, GML residues with or without low quality (stover) residues gave 1.5 to 2.1 times more stover when compared to the two controls (absolute or stover alone) plots. This observation was however restricted to the

initial three seasons of experimentation (LR 2003 to LR 2004). During these initial three seasons, GML residue plots produced significantly higher stover yields than the two controls (except during SR 2003 when the differences were not significant). Similar results were reported by Rutunga (2000) who added low quality maize stover (2.0 Mg ha^{-1}) to an equivalent amount of high quality residues of *Tithonia diversifolia* or *Tephrosia vogelii* residues, in similar type of soils within the central highlands of Kenya at Kabete, and observed no reduction in maize dry matter yield. Research with other types of residues has also been reported by Bunyasi (1997) who conducted pot experiments to investigate the effect of mixing low quality rice straw residues with high quality *Croton macrostachyus* on the performance of maize dry matter and found that mixing the two residues in equal proportions gave similar performance to that of pure *C. macrostachyus* residues alone. Likewise, Martin *et al*. (1989) found that mixing low quality millet residues did not alter the performance of the high quality *Gliricidia sepium* residues in a field of maize. The authors attributed their observation to the occurrence of N_2-fixing bacteria in maize rhizosphere that are activated by the presence of these low quality residues. These bacteria enhance the microbial activity at the maize rhizosphere thereby causing a higher turnover with corresponding increased mineral N for uptake by the maize plants.

In the current study, the performance of maize dry matter yields in the stover alone treatment was similar to that of the other treatments during the final two seasons (SR 2004 and LR 2005) and this was probably attributable to an accumulation of microbial bound N which was released in latter seasons thus offsetting any further N immobilization that could have occurred during the preceding three seasons. Nandwa (1995), working in similar type of soils within the central highlands of Kenya at Kabete, obtained similar maize stover yields (after the first season) in stover incorporated plots (4.0 Mg ha^{-1}) when compared to those recorded in the inorganic N fertilized treatment applied at 50 kg N ha^{-1}.

Table 4.5 8: Stover yield as influenced by low quality (stover) residues added to mucuna green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Maize stover yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
None	4.58 a	6.97 a	5.32 a	5.71	2.98 c	5.14 ab
Three	4.74 a	6.92 a	5.22 a	5.92	4.46 ab	4.47 ab
Six	4.77 a	6.25 ab	5.23 a	7.40	5.47 a	5.85 a
Stover only	3.06 b	4.67 ab	3.57 b	6.90	4.17 b	4.49 b
Control	2.57 b	3.73 b	3.42 b	5.31	1.97 c	3.30 c
CV (%)	25	31	14	23	18	14
$LSD_{0.05}$	1.34	2.74	0.87	NS	1.17	1.07

Means with same letter in each column are not statistically different at P<0.05

Table 4.5 9: Stover yield as influenced by low quality (stover) residues added to crotalaria green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Stover grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
None	5.38 a	6.97 ab	5.98 a	6.20	2.86 bc	5.38 ab
Three	5.27 a	7.37 a	6.11 a	6.78	4.16 bc	5.93 a
Six	4.78 ab	7.17ab	5.47 a	6.32	6.22 a	5.95 a
Stover only	3.06 bc	4.67bc	3.57 b	6.90	4.17 b	4.50 b
Control	2.57 c	3.73c	3.42 b	5.32	1.97 c	3.30 c
CV (%)	32	28	21	21	30	13
$LSD_{0.05}$	1.84	2.60	1.63	NS	1.82	1.03

Means with same letter in each column are not statistically different at P<0.05

Table 4.5 10: Stover yield as influenced by low quality (stover) residues added to lablab green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Stover grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
None	6.78 a	5.55	5.58 a	6.31 ab	3.64 ab	5.73 a
Three	4.71 a	5.57	4.96 a	7.28 a	3.90 a	5.34 a
Six	4.66 ab	5.92	5.15 a	7.43 a	4.11 a	5.53 a
Stover only	3.06 b	4.67	3.57 b	6.90 a	4.17 a	4.50 b
Control	2.57 b	3.72	3.42 b	5.32 b	1.97 b	3.30 c
CV (%)	43	30	18	15	32	11
$LSD_{0.05}$	2.51	NS	1.28	1.54	1.75	0.80

Means with same letter in each column are not statistically different at P<0.05

4.5.5 Maize grain yield

Generally, maize grain yield was higher during the wetter season of 2003 compared to that of the drier 2004 cropping seasons. The results (Tables 4.5.11-13) show that maize grain yield in the initial three seasons of the study were different from those of the final two seasons. During the initial three seasons of experimentation, treatments where GML residues were present produced significantly higher maize grain yield than the two controls (absolute control and stover alone control). This increase in maize yield was irrespective of whether the low quality residues were present or absent.

In the initial 3 seasons of experimentation, maize grain yields in the stover alone or the absolute control plots were similar and never exceeded 2.0 Mg ha^{-1}. The GML residue by low quality (stover) residues interactions were not significant. These results suggest that during these initial three seasons, the addition of low quality (stover) residues did not cause any net immobilization of N released by the decomposing GML residues but rather there was a net mineralization of N in all plots with GML residues. These results are in agreement with those of several workers who have investigated the effect of mixing high quality with low quality residues on maize yields. For example, Rutunga (2000), working with a similar Nitisol type of soil in

central Kenya highlands, investigated the effect of adding maize stover (2.0 Mg ha^{-1}) to an equivalent amount of high quality residues of *Tithonia* or *Tephrosia* and observed no reduction in maize grain yield. Myers *et al.* (1997) also concluded that mixing *Gliricidia* residues with rice straw led to a short delay in N release but the total amount of N mineralized was not altered. In the present study, the highest proportion of stover residues mixed with the various GML residues was about two thirds (67%) but this did not affect the final maize grain yield. In contrast, Handayanto *et al.* (1997) concluded that in a mixture of high quality *Gliricidia* and low quality *Peltophurum* residues, the latter should not exceed 50% so as to avoid a reduction in the amount of N recovered by maize. However, these authors also noted that *Peltophurum* exhibits strong protein binding effect, which effectively protects the *Gliricidia* N from release for uptake by maize.

In the current study, there was a reversal in the performance of maize grain yield in the stover alone treated plots during the last two seasons of experimentation (SR 2004 and LR 2005). In SR 2004 cropping season, highest maize grain yield was recorded in the stover alone treated plots. These yields were, however, not significantly different from those of the other treatments but the absolute control still registered the lowest maize yields. Low maize yield recorded during that season (<2.0 Mg ha^{-1}) in all the treatments was exacerbated by moisture deficit during the critical silking and grain filling stages of the maize crop (Figure 3.2). For example, the last day of rainfall was December 10, 2004 when the crop was only 51 days old whereas silking and anthesis occurred 80 days after planting.

These observations where the initial and the final phases of experimentation produced contrasting results were rather difficult to explain but it could be speculated that the continual addition of high quantities of stover residues may have led to an accumulation of soil microbial population whose immobilized N was remineralized in later seasons as confirmed by section 4.5.7 of this study. The high performance of the stover alone residue treatment in SR 2004 was

initially thought to have been due to the occurrence of moisture conserving effects by these residues but the repeated good performance in the subsequent and normal LR 2005 season was an indication that this observation was due to the treatment effects. Such contrasting seasonal performances due to incorporation of maize stover in the soil has also been reported by other workers. For example, Nandwa (1995), working in a similar type of soil at Kabete, investigated the effect of incorporating stover (4.0 Mg ha^{-1}) on maize growth and reported that maize grain yield suppression due to stover application occurred only during the first season but the performance reversed in the subsequent five seasons when these plots registered similar maize grain yields to that of the inorganic N fertilized treatment (50 kg N ha^{-1}) which was also significantly higher than that of the removal or mulched plots. In the present study, the increased maize yields due to stover addition into the soil could mainly be attributed to N availability. Despite the presence of some literature indicating low or decreased N content from low quality residue additions into the soil, Karlen *et al*. (1994) pinpointed that in hot climates, addition of low quality residues may result in short-term N immobilization but longer-term additions result in increased build up of C and N contents in the soil.

Table 4.5 11: Maize grain yield as influenced by low quality (stover) residues added to mucuna green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Maize grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
None	4.26 a	4.02 a	2.58 a	1.29 ab	2.21 c	2.89 a
Three	3.75 a	3.50 a	2.28 ab	1.27 ab	3.14 d	3.01 a
Six	4.51 a	3.85 a	2.10 ab	1.76 a	4.15 a	3.37 a
Stover only	1.76 b	2.03 b	1.27 bc	1.77 a	3.44 ab	2.04 b
Control	1.56 b	1.75 b	0.92 c	0.70 b	0.71 d	1.15 c
CV (%)	32	25	37	39	20	14
$LSD_{0.05}$	1.36	1.18	1.0	0.82	0.77	0.55

Means with same letter in each column are not statistically different at P<0.05

Table 4.5 12: Maize grain yield as influenced by low quality (stover) residues added to crotalaria green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Maize grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
None	3.80 a	3.62 a	2.86 a	1.17	1.95 b	2.62 ab
Three	4.11 a	4.30 a	2.67 a	1.37	3.11 a	3.01 a
Six	3.98 a	4.50 a		1.49	4.12 a	3.13 a
Stover only	1.76 b	2.03 b	1.72 b	1.77	3.44 a	2.04 b
Control	1.68 b	1.75 b	1.27 b	0.70	0.71 c	1.15 c
CV (%)	45	23	47	55	25	21
$LSD_{0.05}$	1.86	1.14	1.37	NS	1.03	0.8

Means with same letter in each column are not statistically different at P<0.05

Table 4.5 13: Maize grain yield as influenced by low quality (stover) residues added to lablab green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Maize grain yield (Mg ha^{-1})					
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005	Mean
None	3.67 a	3.25 a	2.07 a	1.13 a	2.62 a	2.61 a
Three	3.46 a	2.80 b	1.47 ab	1.45 ab	3.10 a	2.50 ab
Six	3.00 ab	3.55 a	1.47 ab	1.71 a	3.03 a	2.59 a
Stover only	176 b	2.03 c	1.27 b	1.77a	3.44 a	2.04 b
Control	1.68	1.75 c	0.92 b	0.70 b	0.71 b	1.15 c
CV (%)	43	10	27	42	27	16
$LSD_{0.05}$	1.58	0.41	0.61	0.87	1.11	0.53

Means with same letter in each column are not statistically different at P<0.05

4.5.6 Maize harvest Index

Maize harvest index was higher in wetter seasons of 2003 than during the drier seasons of 2004 (Tables 4.5.14-16). Generally, addition of low quality residues to the GML residues did not appear to influence the harvest index of maize. The legume by low quality residue interactions were also not significant. Low harvest index in drier seasons and in plots with N stress is mainly attributed to reduced production and translocation of assimilates to the developing kernels (Nandwa, 1995; Schusser and Westgate, 1995).

Table 4.5 14: Harvest index as influenced by low quality (stover) residues added to mucuna green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Harvest index				
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005
None	0.48 a	0.36	0.31	0.18 a	0.43 a
Three	0.49 a	0.34	0.31	0.16 ab	0.41 a
Six	0.50 a	0.38	0.28	0.18 a	0.43 a
Stover only	0.34 b	0.34	0.26	0.19 a	0.45 a
Control	0.35 b	0.32	0.22	0.10 b	0.29 b
CV (%)	18	22	24	28	11
$LSD_{0.05}$	0.12	NS	NS	0.07	0.07

Means with same letter in each column are not statistically different at P<0.05

Table 4.5 15: Harvest index as influenced by low quality (stover) residues added to crotalaria green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Harvest index				
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005
None	0.36	0.31	0.32 a	0.14 ab	0.45
Three	0.43	0.37	0.26 ab	0.11 ab	0.45
Six	0.47	0.38	0.24 ab	0.13 ab	0.40
Stover only	0.34	0.34	0.26 ab	0.19 a	0.45
Control	0.35	0.32	0.22 b	0.10 b	0.29
CV (%)	27	20	25	39	26
$LSD_{0.05}$	NS	NS	0.10	0.08	NS

Means with same letter in each column are not statistically different at P<0.05

Table 4.5 16: Harvest index as influenced by low quality (stover) residues added to lablab green manure for different cropping seasons in Embu, Kenya

Amount of stover added (Mg ha^{-1})	Harvest index				
	LR 2003	SR 2003	LR 2004	SR 2004	LR 2005
None	0.35	0.36	0.27	0.15 ab	0.43 ab
Three	0.41	0.33	0.23	0.16 ab	0.43 ab
Six	0.39	0.38	0.22	0.18 a	0.43 ab
Stover only	0.35	0.34	0.26	0.19 a	0.45 a
Control	0.35	0.32	0.22	0.10 b	0.29 b
CV (%)	20	21	30	30	23
$LSD_{0.05}$	NS	NS	NS	0.07	0.14

Means with same letter in each column are not statistically different at P<0.05

4.5.7 Nitrogen Mineralization

The results of N mineralization for the various treatments are presented in Tables 4.5.17-19. Total mineral-N content in the 0 to 20 cm soil depth ranged from 38 kg ha^{-1} in the absolute control to 98 kg ha^{-1} in stover alone plots. There were slight differences in mineralization patterns of the two seasons possibly due to seasonal moisture regimes of the seasons (Figures 3.2). Mineral N content was highest during the 4 WAP and gradually declined up to 8 WAP before peaking again until the last sampling date at harvest (23 WAP). All treatments showed similar amounts of mineral N irrespective of the type of residue applied. However, these residue treated plots had consistently higher mineral N than the absolute control in most of the sampling periods during the LR 2005 season. The ratios of NH_4^+-N and NO_3^--N contents were almost equal in most of the seasons but there were fluctuations from one sampling period to another in both seasons.

Throughout the sampling period from 4 WAP to harvest, there were no differences among the treatments in soil mineral N at any sampling date. The legume residue by stover interactions were also not significant. Thus, contrary to the expectation that mixing high quality residues with low quality ones would lead to lower availability of mineral N, the reverse was true in this study indicating that N dynamics in the soil are more complex. These results corroborate the findings of Bunyasi (1997) who worked in glasshouse conditions with similar Nitisol type of soil and found that soil mineral N content in pots where *Croton macrostachyus* and *Oryza sativa* were mixed in equal proportions recorded as much mineral N as those of *C. macrostachyus* alone between the 4 and 6 weeks after incorporation. In the present study, stover alone treated plots also gave correspondingly high levels of mineral N which was probably attributable to the possible remineralization of N that had been immobilized in the preceding three seasons (Nandwa, 1995).

Table 4.5 17: Amount of NH_4^+-N and NO^-_3-N mineralized in the 0-20 cm soil depth of mucuna green manure incorporated plots (with or without low quality residues) at different sampling dates of SR 2004 and LR 2005 cropping seasons at Embu, Kenya

Stover applied (Mg ha^{-1})	Period after planting											
	4 weeks				8 weeks				At harvest			
	SR 2004		LR 2005		SR 2004		LR 2005		SR 2004		LR 2005	
	kg ha^{-1}											
	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N
	kg ha^{-1}											
Zero	35	49	32	9	24	18	31	8	46	16	41	15
Three	35	56	45	14	34	28	40	10	61	19	33	24
Six	46	50	44	16	33	22	49	13	59	24	31	16
Stover alone	67	50	39	19	33	23	39	8	50	13	34	63
Control	44	52	31	9	34	25	26	11	58	18	25	14
SE	11.0	3.2	8.3	1.5	3.8	4.5	5.4	4.1	5.2	2.8	3.7	3.7
Effects	P value											
Stover	0.311	0.672	0.656	0.006	0.407	0.625	0.112	0.916	0.278	0.185	0.450	0.450

Table 4.5 18: Amount of NH^{+}_{4}-N and NO^{-}_{3}-N mineralized in the 0-20 cm soil depth of crotalaria green manure incorporated plots (with or without various levels of stover residues) at different sampling dates of SR 2004 and LR 2005 cropping seasons at Embu, Kenya

Stover applied (Mg ha^{-1})	Period after planting											
	4 weeks				8 weeks				At harvest			
	SR 2004		LR 2005		SR 2004		LR 2005		SR 2004		LR 2005	
	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N
	----------kg ha^{-1}----------											
Zero	41	55	37	21	28	22	45	13	68	17	27	21
Three	41	56	38	18	29	19	33	15	65	22	27	15
Six	41	55	42	16	28	18	40	12	65	20	29	17
Stover alone	67	50	39	19	33	23	39	8	50	13	34	63
Control	44	52	31	9	34	25	26	11	58	18	25	14
SE	9.7	4.6	9.9	3.7	2.8	2.6	8.4	2.0	3.1	3.8	11.4	2.5
Effects	----------P value----------											
Stover	0.308	0.915	0.946	0.224	0.524	0.398	0.567	0.222	0.018	0.519	0.987	0.401

Table 4.5 19: Amount of NH^{+}_{4}-N and NO^{-}_{3}-N mineralized in the 0-20 cm soil depth of lablab green manure residues plots (with or without various levels of stover residues) at different sampling dates of SR 2004 and LR 2005 cropping seasons at Embu, Kenya

Stover applied (Mg ha^{-1})	Period after planting											
	4 weeks				8 weeks				At harvest			
	SR 2004		LR 2005		SR 2004		LR 2005		SR 2004		LR 2005	
	kg ha^{-1}											
	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N
	kg ha^{-1}											
Zero	36	58	35	8	32	24	35	9	56	18	34	14
Three	42	52	35	22	32	22	35	12	64	15	33	23
Six	46	55	43	22	28	18	43	8	61	19	33	17
Stover alone	67	50	39	19	33	23	39	8	50	13	34	63
Control	44	52	31	9	34	25	26	11	58	18	25	14
SE	12.6	2.9	9.8	3.3	2.7	3.1	6.3	2.8	3.1	3.0	9.5	3.2
Effects	P value											
Stover	0.514	0.452	0.913	0.031	0.567	0.519	0.344	0.718	0.089	0.644	0.970	0.300

4.5.8 N uptake by maize

Tables 4.5.20-22 present the results of N uptake by maize as influenced by various low quality residues additions to GM legume residues. Nitrogen uptake was proportionately low in the 4 WAP sampling and rapidly increased between the 4 and 8 WAP growth periods. All residue treated plots achieved significantly higher N uptake than the absolute control with no residues. The amount of N taken up by maize plants was not greatly influenced by the amount of low quality (stover) residues added to the GML residue. Furthermore, N uptake by maize in plots with stover was similar to that of GM legume residues alone. The three GML residues seem to have responded in a similar manner to addition of these low quality residues. Other types of low quality (rice) and high quality (*Croton macrostachyus*) residues have yielded similar N uptake results (to those obtained in the current study) when the two residues were mixed in equal ratios in a similar type of soil (Bunyasi, 1997).

Surprisingly, the stover alone treatment achieved N uptake quantities similar to those of the plots with high quality residues. This suggests that there was adequate N build up which could be remineralized to become available in N pools of the rhizosphere in the fourth successive season when N uptake was assessed. These findings concur with those of Nandwa (1995) who also obtained large mineralization values in stover incorporated plots during the fourth successive season of experimentation in the central highlands of Kenya site at Kabete. This author observed some immobilization of N only during the first season of experimentation.

Table 4.5 20: Nitrogen taken up by maize in plots with mucuna residues under various levels of stover residues at different sampling dates of SR 2004 and LR 2005 cropping seasons at Embu, Kenya

Stover applied (Mg ha^{-1})	Period after planting					
	4 weeks		8 weeks		At harvest	
	SR 2004	LR 2005	SR 2004	LR 2005	SR 2004	LR 2005
	kg ha^{-1}					
Zero	16	18	137	161	141	165
Three	15	12	139	157	186	226
Six	18	14	142	202	190	303
Stover alone	14	9	145	166	159	190
Control	5	5	117	127	149	141
SE	1.6	1.1	5.5	25.6	18.6	29.2
Effects	P values					
Stover	0.006	< 0.001	0.444	0.422	0.313	0.031

Table 4.5 21: : Nitrogen taken up by maize in plots with crotalaria residues under various levels of stover residues at different sampling dates of SR 2004 and LR 2005 cropping seasons at Embu, Kenya

Stover applied (Mg ha^{-1})	Period after planting					
	4 weeks		8 weeks		At harvest	
	SR 2004	LR 2005	SR 2004	LR 2005	SR 2004	LR 2005
	kg ha^{-1}					
Zero	20	12	146	226	219	195
Three	19	12	134	244	213	266
Six	18	20	136	260	232	300
Stover alone	14	9	145	166	159	190
Control	5	5	117	127	150	141
SE	2.2	2.4	9.8	23.7	21.3	20.9
Effects	P values					
Stover	0.008	0.025	0.311	0.018	0.082	< 0.001

Table 4.5 22: : Nitrogen taken up by maize in plots with lablab residues under various levels of stover residues at different sampling dates of SR 2004 and LR 2005 cropping seasons at Embu, Kenya

Stover applied (Mg ha^{-1})	Period after planting					
	4 weeks		8 weeks		At harvest	
	SR 2004	LR 2005	SR 2004	LR 2005	SR 2004	LR 2005
	----------kg ha^{-1}----------					
Zero	12	10	149	146	187	261
Three	16	11	165	141	192	242
Six	15	10	147	143	159	190
Stover alone	14	9	145	166	159	190
Control	5	5	117	127	149	141
SE	1.2	1.4	8.3	33.9	16.1	30.0
Effects	----------P values----------					
Stover	0.001	0.134	0.042	0.947	0.034	0.105

4.5.9 Soil chemical properties

Tables 4.5.23 present the results of total N, organic carbon and pH (water) measured at the end of the experiment in October 2005. These results show that addition of low quality residues (maize stover) to GM legume residues had a more significant impact on the soil organic carbon (SOC) than either total N or the soil pH. When compared against the absolute control (no residues added), all residue treated plots registered slight increases in total N and soil pH, suggesting that a longer duration of residue addition into the soil could have a major impact in nutrient gains of the soil's chemical properties. Overall, the highest improvements on soil properties appear to have been on the SOC. These gains were also reflected in the corresponding decrease in the soil bulk density (section 4.5.10 of this study). Thus, improving the soil organic matter is key to regulating crop production and influencing soil-based environmental services (Vanlauwe, 2004) due to improvement in the soil nutrient supply, water availability, soil structure as well as the soil buffering capacity (Smith, 1994; Barrios *et al*., 1996). Similar gains in soil improvement after addition of leguminous tree residues (in a site located in a neighbouring farm) were reported by Waswa (2004) who concluded that continued application of organic residues results in the improvement of SOC and the related soil chemical properties.

Table 4.5 23: Soil chemical properties (0 – 20 cm depth) as influenced by low quality residue (stover) added to different green manure legume residues at Embu, Kenya

Rate of stover (Mg ha^{-1}) applied	Soil chemical parameter								
	Mucuna			Crotalaria			Lablab		
	Nitrogen (%)	Carbon (%)	pH (water)	Nitrogen (%)	Carbon (%)	pH (water)	Nitrogen (%)	Carbon (%)	pH (water)
Zero	0.35	2.72	5.6	0.32	2.71	5.8	0.31	2.77	5.8
Three	0.32	2.88	5.8	0.34	2.88	5.9	0.35	2.94	5.7
Six	0.34	3.11	5.8	0.32	2.78	5.9	0.35	2.90	5.8
Stover alone	0.31	2.72	5.6	0.31	2.77	5.6	0.31	2.86	5.6
Control	0.30	2.70	5.6	0.30	2.70	5.6	0.30	2.70	5.6
SE	0.020	0.096	0.089	0.014	0.106	0.98	0.019	0.036	0.116
Effects ----------P values----------									
Stover	0.298	0.060	0.249	0.592	0.861	0.168	0.223	0.003	0.519

4.5.10 Soil physical properties - bulk density

Table 4.5.24 presents the results of soil bulk density in different low and high carbon residue treatments. Inclusion of low quality residues (stover) had a positive effect in the reduction of soil bulk density than the pure GML residues. For example, plots where 6.0 Mg ha^{-1} of stover was incorporated into the soil for the five successive cropping seasons achieved 8.3% reduction of soil bulk density when compared to the absolute control (no residues added). When compared across the different herbaceous legumes (irrespective of the amount of stover residues added) soil bulk density reduction was in the order highest to lowest in stover < crotalaria < mucuna < lablab < control. These results support work by Nandwa (1995) who recorded a reduction in soil bulk density after addition of maize stover residues (4.0 Mg ha^{-1}) for six successive seasons in a similar type of soil at Kabete, Kenya.

Table 4.5 24: Effect of low quality (stover) residues added to green manure residues on soil bulk density at Embu, Kenya

Stover added Rate (Mg ha^{-1})	Soil bulk density (g cm^{-3})		
	Mucuna	Crotalaria	Lablab
None	1.054 a	1.031 ab	1.068 ab
Three	1.038 ab	1.022 ab	1.054 ab
Six	1.006 b	1.005 ab	1.036 ab
Stover only	1.002 b	1.002 b	1.046 b
Control	1.085 a	1.085 a	1.085 a
CV (%)	5.1	5.5	3.9
$LSD_{0.05}$	0.06	0.08	0.06

Means with same letter in each column are not statistically different at P<0.05

4.5.11 Effect of low quality residues on nodulation of legumes

Nodulation was assessed by sampling the fresh weight of the nodules sampled from six plants per plot in each of the treatments. The results indicated that nodulation in mucuna was significantly higher than that of lablab or crotalaria irrespective of the type and/or amount of residue present in the plot. On the average, the nodule fresh weight per plant was 1.24, 0.13 and

0.11g for mucuna, crotalaria and lablab, respectively. Table 4.5.25 shows that the mixing of low quality (stover) residues with the high quality GML residues did not affect the nodulation of any of the three GML used in the study. The stover by legume residue interactions on nodulation were also not significant. The inability of these low quality residues to influence nodulation in GML was a pointer that N immobilization was minimal in these plots (Sanginga *et al*., 1996; Cheminingw'a *et al*., 2004).

Table 4.5 25: Effect of low quality (stover) residues added to green manure residues on nodule fresh weight at Embu, Kenya

Stover added	Nodule fresh weight (g plant^{-1})		
Rate (Mg ha^{-1})	Mucuna	Crotalaria	Lablab
None	1.08	0.12	0.21
Three	1.36	0.16	0.07
Six	1.28	0.12	0.05
CV (%)	44	47	86
$LSD_{0.05}$	NS	NS	NS

4.5.12 Decomposition rate and pattern for different residues

Figures 4.5.1 and 4.5.2 present the residue decomposition curves for some of the residues used in experiment four while the data on decomposition rate constants (k) values as well as the days taken for 50% of residue to decompose (t_{50}) for the different residues is presented in Table 4.5.26. In SR 2004 cropping season, the decomposition rate constant (k) values and their respective t_{50} values for the different residues were in the order: mucuna alone > 2:3 mucuna:stove >1:3 mucuna:stover > stover alone. The differences in the rate constants and (t_{50}) were, however, not significantly different for the various residues and their mixtures. A similar decomposition pattern was found during LR 2005 though less uniform, possibly due to the uneven weather pattern (Figure 3.2) that persisted during the initial three weeks of the season. These results are consistent with those of other researchers who have carried out litter

bag studies with different types of plant residues. For instance, Ibewiro *et al*. (2000b) conducted litter bag studies in west Africa and found that mucuna and lablab residues lost more than half of their dry weight within 28 days thereby releasing more than half of their N. Similarly, faster decomposition (2 weeks) of lablab residues was reported by Njunie (2002) in the coastal lowlands of Kenya. Mwangi *et al.* (2004), working in a neighbouring farm here in Embu, used litter bags to investigate the rate of decomposition of leucaena and calliandra agroforestry leaf prunnings and reported similar decomposition patterns and rates particularly during the wetter short rains 2002 cropping season. In the present, there was no significant dry matter loss between the high N (mucuna) or low N (stover) residues (Figures 4.6.1 and 2). This observation is in agreement with the conclusions made by Mugendi *et al.* (1997) and Vanlauwe *et al*. (2004) that the general assumption that decomposition of plant residues in a given region is determined predominantly by plant quality factors may not be true because factors such as rainfall and temperature are strongly correlated with decomposition rate whilst in certain cases soil macrofauna (especially termites) are also important (Schroth *et al*., 1992; Nandwa, 1995; Mwangi *et al.,* 2004).

Table 4.5 26: Decomposition rate constant (k) and t_{50} values of residues for different cropping seasons in Embu, Kenya

Residue composition	k values		t_{50} values	
	SR 2004	LR 2005	SR 2004	LR 2005
Mucuna alone	0.80	0.63	6.0	7.7
Mucuna:Stover at 2:3 ratio	0.81	0.52	6.0	9.3
Mucuna:Stover at 1:3 ratio	0.57	0.31	8.6	15
Stover alone	0.47	0.51	10.2	9.5

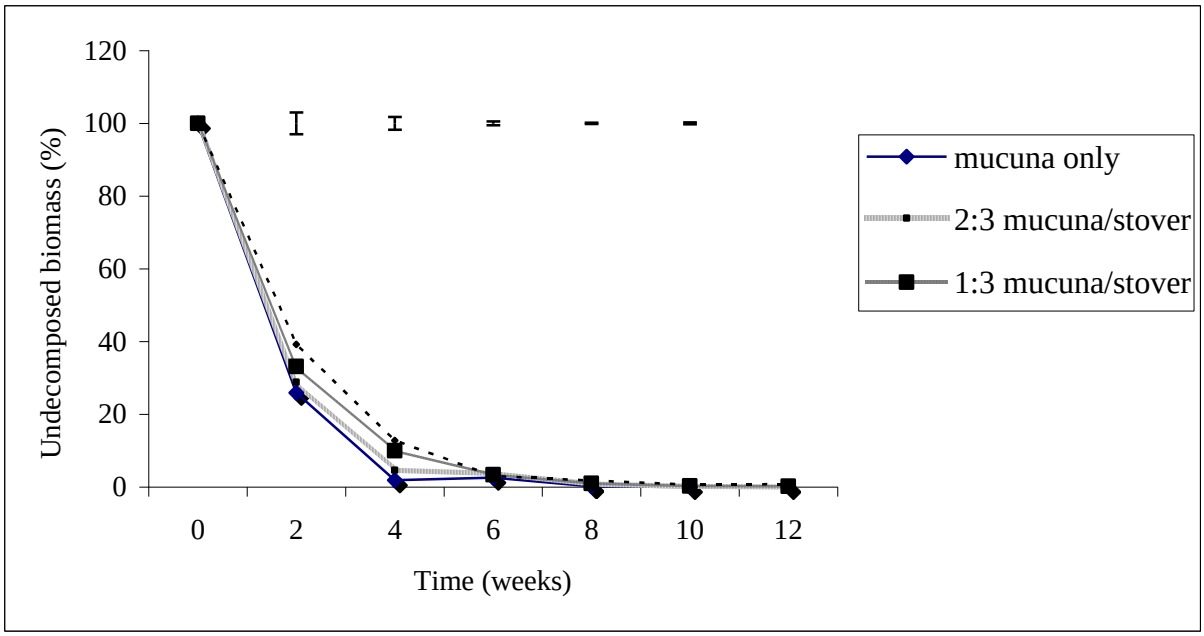


Figure 4.5. 1: Percentage of initial dry matter remaining in different residue litterbags as a function of time after burying in the field during the short rains (SR) 2004 cropping season at Embu, Kenya. Least Significance Difference ($LSD_{0.05}$) bars shown

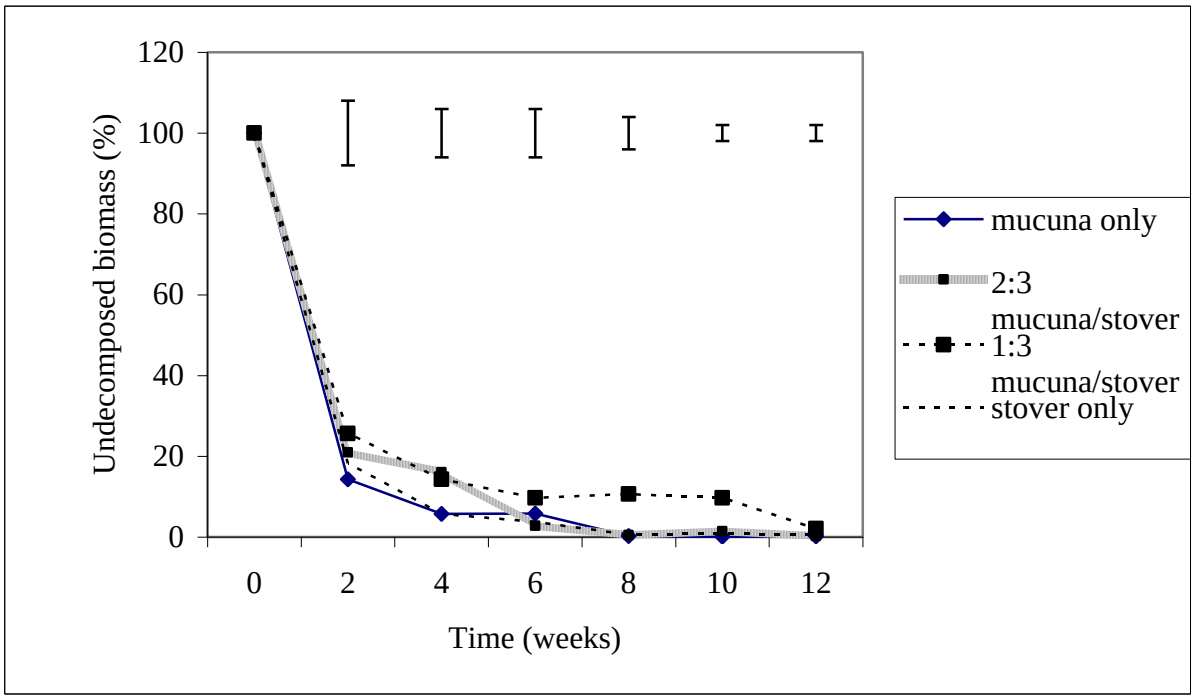


Figure 4.5. 2: Percentage of initial dry matter remaining in different residue litterbags as a function of time after burying in the field during the long rains (LR) 2005 cropping season in Embu, Kenya. Least Significance Difference ($LSD_{0.05}$) bars shown

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The overall objectives of the study were to: 1) gain some understanding on farmers' knowledge on soil fertility management, 2) assess the performance of maize and three herbaceous legumes under intercropping situation, 3) determine the most appropriate legume residue management techniques and levels of mineral N supplementation, and 4) investigate the role of low quality residues in regulating N release by decomposing legume residues. The findings of the study are presented in five major parts found in sections 4.1 through 4.5 of the dissertation.

Section 4.1 reports on the survey while the four field experiments that were conducted are reported in sections 4.2, 4.3, 4.4 and 4.5 of the results and discussion chapter. The survey (section 4.1), that was conducted at the beginning of the study, clearly showed that farmers are knowledgeable in issues of soil fertility. The farmers gave soil colour, soil structure and the occurrence of certain weed flora as their main soil fertility assessment indicators. The most pronounced and elaborate local soil fertility indicator was the dominance of certain weed flora. The most prevalent high soil fertility indicator weeds were: *Commelina benghalensis, Bidens pilosa, Galinsoga parviflora* and *Amaranthus* spp. whereas *Rhynchelytrum repens, Richardia scabra, Alternanthera philoxeroides* and *Pteridium equilinum* were the most prevalent low soil fertility indicator weed species. Laboratory analysis of the soils indicated that soil pH and exchangeable bases (Ca^{++} and Mg^{++}) are the most sensitive soil parameters that corroborate farmers' perceptions and knowledge of soil fertility indicators. The pH of soils collected from infertile and fertile farm sections were 4.8 and 5.4, respectively, for the cooler, wetter agro-ecological zones while that of the lower,

warmer zones were 6.0 and 6.9 for infertile and fertile sections, respectively. The concentration of exchangeable bases in the fertile fields was 5-9 times higher than that of the infertile fields.

The study established that the farmers' perceptions and knowledge are well corroborated by scientific laboratory measurements. Most of the indicators mentioned for fertile and infertile farm fields matched with the quantitative scientific measurements. Moreover, variation in data sets for samples collected from similar categories of different farms was high implying that such results could only be applied locally within a given farm. This means that one farmer's fertile field may be another farmer's infertile field. Nonetheless, the results of this study present a strong case for not disregarding farmers' ideas and knowledge. Such knowledge may be useful for making provisional recommendations particularly in situations where scientific soil analysis is inaccessible or is not economically feasible.

The second part of the study consisted of four on-station trials. The trials investigated different aspects of maize-herbaceous legumes intercrops. The experiments were conducted for five consequtive cropping seasons between March 2003 and October 2005.

Section 4.2 reports the effect of intercropping herbaceous legumes with maize at varying densities and relay-cropping intervals. The three herbaceous legumes were: mucuna [*Mucuna pruriens* (L.) DC. Var. utilis (Wright) Bruck], crotalaria [*Crotalaria ochroleuca* G. Don] and lablab [*Lablab purpureus* (L) Sweet cv. Rongai]. The study established that neither the intercropping density nor the period to relaying the legumes affected the performance of maize. However, a high density of crotalaria planted at the same time with maize affected the performance of maize particularly in seasons when soil moisture was inadequate. Relay-cropping the legumes later than the second week after the emergence of maize greatly affected their performance by depressing the biomass production possibly due to competition

for growth resources, in particular light, where less that one third of the total incoming solar radiation is intercepted.

Section 4.3 reports on suitability of surface mulching versus soil incorporation as methods of legume residue placement. Maize grain and stover yields were similar under either muching or incorporation treatment. There was a two-fold increase in maize grain yield above the control (no residues applied) in both mucuna or crotalaria treated plots. The exception was lablab whose poor performance was attributed to the low quantities of residues generated *in situ* and applied. Rapid breakdown of surface mulched residues was greatly aided by the high intensity of early seasonal rains together with the presence of certain macrofauna, particularly termites (*Macrotermes* spp.). The results of this study therefore indicate that under the rainfall and temperature regime patterns typical of the sub-humid central highlands of Kenya, the decomposition and nutrient availability from mucuna, crotalaria or lablab residues is similar whether placed on the surface or incorporated into the soil.

Section 4.4 reports on N contribution of relay-cropped mucuna, crotalaria and lablab (raised *in situ*) to the succeeding maize crop with or without mineral N supplementation at 30 or 60 kg N ha^{-1}. There were large seasonal variations in legume biomass generation. On average, mucuna or crotalaria produced about 2.0-4.5 Mg ha^{-1} of legume herbage contributing 30-80 kg N ha^{-1} while lablab biomass was low (<1.0 Mg ha^{-1}). These seasonal legume herbage quantities had some implication on maize responses for the individual cropping seasons. The effect of legume residue incorporation on maize growth was evident throughout the entire growth cycle of the maize crop. Plots with none or low quantities of legume residues where no mineral N was supplemented gave low grain and stover yields indicating the effectiveness of these residues as a source of N. Averaged across the five cropping seasons, plots with legume residues alone (no mineral N) produced 2.5, 2.3 and 1.6

times more grain than the unamended control for mucuna, crotalaria and lablab, respectively. The study established that biomass quantities in excess of 2.0 Mg ha^{-1} may not require any mineral N supplementation. Furthermore, the rainfall data recorded at the site for the six consecutive seasons of experimentation showed that only two out of the six seasons could be considered as having adequate and well distributed rainfall. This has great implication on N use efficiency. Mineralization of soil N and maize N uptake information generated revealed that there is a slight mismatch between the two although this does not greatly hinder seasonal N utilization due to the length of the growing season typical of this study region where normal seasonal rainfall distribution hardly exceeds two months. On the other hand, commonly grown mid altitude maize cultivars (PHB 3253 and H 513) take 70-74 days to reach 50% tasselling and silking.

The final part of the study (section 4.5) investigated the effect of adding low quality (high carbon) residues to the legume residues as a method of slowing down their decomposition to maximize N synchrony. The inclusion of these high carbon residues did not affect N availabity from legume residues. Maize N uptake and the resultant grain and stover yields were similar in both pure and mixed residue treatments. In general, grain and stover yields from the treatments with mixed residues were slightly higher suggesting that the presence of these low quality residues was somehow synergistic. For instance, the five seasons' average maize grain yields in plots with legume residues (2.0 Mg ha^{-1}) mixed with 6.0 Mg ha^{-1} of stover were 3.37, 3.13 and 2.59 Mg ha^{-1} for mucuna, crotalaria and lablab while the corresponding yields in pure legume treated plots were 2.89, 2.62 and 2.61 Mg ha^{-1} for mucuna, crotalaria and lablab, respectively. To gain a greater understanding of these mixed residues, a separate litter bag study was conducted alongside the main experiment to evaluate the decomposition patterns. The mass loss results of this experiment showed that mixed maize:mucuna residues in a ratio of 2:3 (w/w) had a decomposition half life (t_{50}) of 7.7

days compared to 6.9 days for the pure mucuna residues. Overall, these two simultaneous studies point to the complexity of decomposition patterns in such mixtures. This is probably attributable to the nature of mineralization-immobilization patterns in such situations. It is clear from the results of this study that these low quality residues have a role in soil quality improvement particularly the soil physical characteristics. For a period of three years, when this study was undertaken, the inclusion of high carbon residues (6.0 Mg ha^{-1}) significantly increased the soil organic carbon by 13% and also led to a decrease in the soil bulk density by 8.3% when compared to the absolute control with no residues added.

5.2 Recommendations and guidelines for future research

- Use the existing farmers' knowledge on soil fertility to provide an insight on crop nutrition requirements where scientific measurements are not available.
- Conduct a more focused study to relate crop yields from fertile and infertile farm sections to quantitative laboratory soil measurements.
- Advice farmers on what constitutes good and poor plant residues for soil fertility enhancement.
- Intercropping maize with high densities of herbaceous legumes is not desirable in the mid altitude areas of the central highlands of Kenya.
- Mucuna, lablab and crotalaria should not be relay-cropped with maize later than the second week after maize emergence.
- The suitability of lablab as a green manure is location specific.
- Farmers should be advised to plant maize (or other appropriate crops) and then mulch the legume residues so as to save on labour costs.
- A single dose of basal N application (30 kg N ha^{-1}) could be used to supplement green manure legume residues if adequate (>2.0 Mg ha^{-1}) quantities were not generated.

- The use of low quality, high carbon residues (with or without GML residues) by farmers should be encouraged. More studies should be conducted to ascertain their full benefits.

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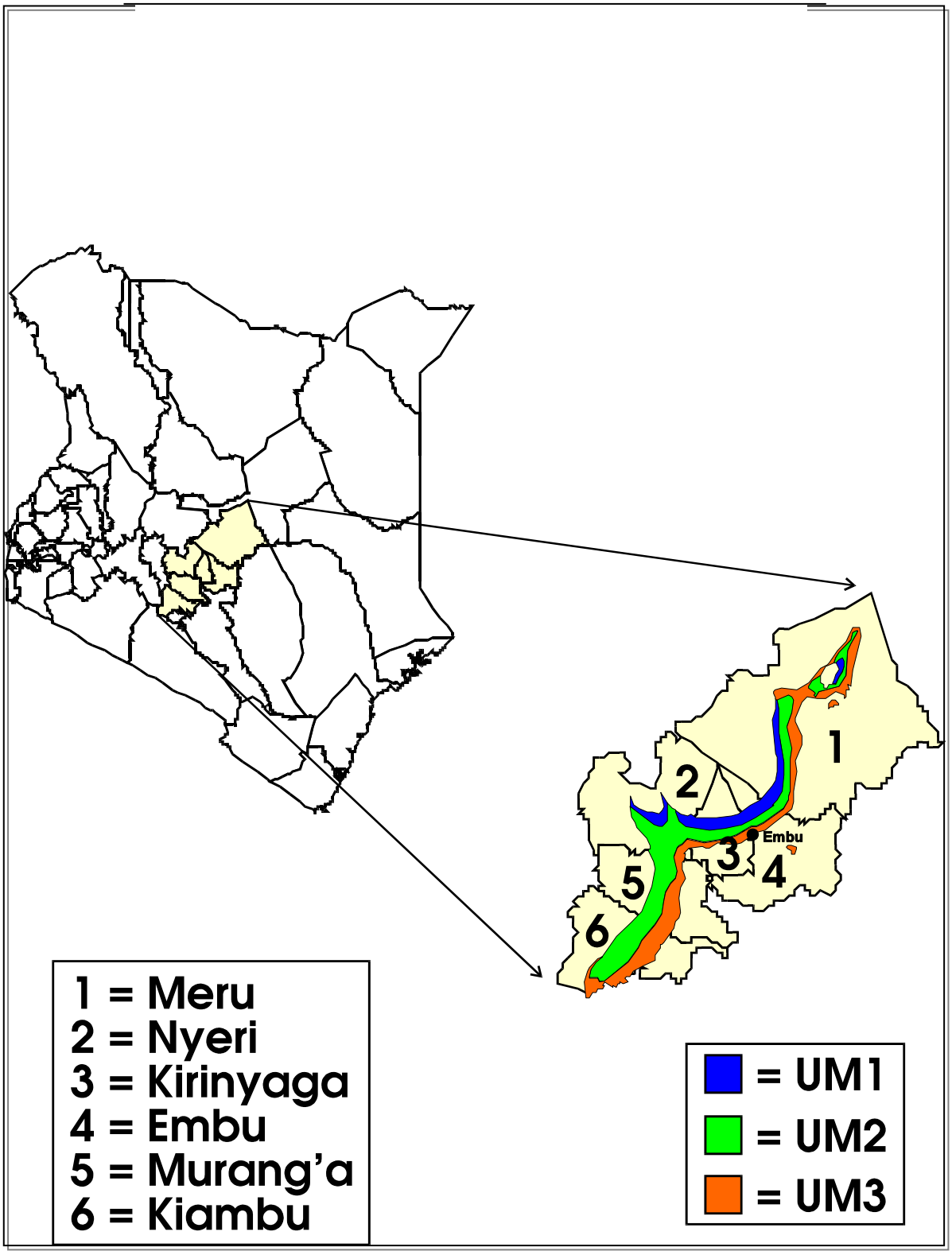
APPENDICES

Appendix 1: Map of Kenya showing the position of the maize-based land use system within the central highlands region and the location of the study.



Appendix 2. 1: Treatment details for experiment one at Embu, Kenya

Treatment	Legume	No. of rows	Weeks after maize emergence
1	Mucuna	One – Row	0
2	"	"	1
3	"	"	2
4	"	"	3
5	"	"	4
6	Mucuna	Two – Row	0
7	"	"	1
8	"	"	2
9	"	"	3
10	"	"	4
11	Crotalaria	One – Row	0
12	"	"	1
13	"	"	2
14	"	"	3
15	"	"	4
16	Crotalaria	Two – Row	0
17	"	"	1
18	"	"	2
19	"	"	3
20	"	"	4
21	Lablab	One –Row	0
22	"	"	1
23	"	"	2
24	"	"	3
25	"	"	4
26	Lablab	Two – Row	0
27	"	"	1
28	"	"	2
29	"	"	3
30	"	"	4
31	Maize only	-	0
32	Mucuna only	One –Row	0
33	"	Two – Row	0
34	Crotalaria only	One –Row	0
35	"	Two – Row	0
36	Lablab only	One –Row	0
37	"	Two – Row	0

Appendix 2. 2: Randomisation and field plan for experiment one at Embu, Kenya

7 M2 1w	12 C1 1w	25 L1 4w	4 M1 3w	16 C2 0w	31 -	14 C1 3w	33 M2 0w	27 L2 1w	2 M1 1w	21 L1 0w	35 C2 0w	5 M1 4w	23 L1 2w	29 L2 3w	3 M1 2w	19 C2 3w	10 M2 4w	17 C2 1w	REP 3
28 L2 2w	15 C1 4w	22 L1 1w	18 C2 2w	1 M1 0w	34 C1 0w	11 C1 0w	37 L2 0w	8 M2 2w	20 C2 4w	36 L1 0w	26 L2 0w	9 M2 3w	30 L2 4w	32 M1 0w	13 C1 2w	6 M2 0w	24 L1 3w	38 blank	REP 3
21 L1 0w	29 L2 3w	5 M1 4w	13 C1 2w	7 M2 1w	9 M2 3w	19 C2 3w	4 M1 3w	23 L1 2w	34 C1 0w	15 C1 4w	33 M2 0w	17 C2 1w	31 -	2 M1 1w	25 L1 4w	11 C1 0w	27 L2 1w	36 L1 0w	REP 2
24 L1 3w	35 C2 0w	32 M1 0w	3 M1 2w	10 M2 4w	38 blank	28 L2 2w	30 L2 4w	26 L2 0w	37 L2 0w	12 C1 1w	22 L1 1w	6 M2 0w	14 C1 3w	20 C2 4w	8 M2 2w	18 C2 2w	16 C2 0w	1 M1 0w	REP 2
17 C2 1w	11 C1 0w	27 L2 1w	31 -	2 M1 1w	36 L1 0w	25 L1 4w	33 M2 0w	13 C1 2w	38 blank	29 L2 3w	7 M2 1w	4 M1 3w	21 L1 0w	19 C2 3w	9 M2 3w	23 L1 2w	15 C1 4w	5 M1 4w	REP 1
37 L2 0w	6 M2 0w	20 C2 4w	34 C1 0w	14 C1 3w	8 M2 2w	22 L1 1w	24 L1 3w	18 C2 2w	1 M1 0w	35 C2 0w	16 C2 0w	32 M1 0w	10 M2 4w	28 L2 2w	3 M1 2w	30 L2 4w	26 L2 0w	12 C1 1w	REP 1

Length of plot = 6.0 m; Width of plot = 4.5 m; Width of paths = 1.0 m

Appendix 3.1: Treatment details for experiment two at Embu, Kenya

TREATMENT No.	FIRST SEASON TRT.	OTHER SEASONS TRT.
1	Mucuna-one row	Mucuna one row-Incorp.
2	Mucuna-one row	Mucuna-one row-Mulch
3	Mucuna-Two row	Mucuna-Two row-Incop.
4	Mucuna-Two row	Mucuna-Two row-Mulch
5	Crot.-one row	Crot. one row-Incorp.
6	Crot.-one row	Crot.-one row-Mulch
7	Crot.-Two row	Crot.-Two row-Incop.
8	Crot.-Two row	Crot.-Two row-Mulch
9	Lablab-one row	Lablab-one row-Incorp.
10	Lablab-one row	Lablab-one row-Mulch
11	Lablab-Two row	Lablab-Two row-Incop.
12	Lablab-Two row	Lablab-Two row-Mulch
13	Maize only, control	Maize only, control

Appendix 3. 2: Randomisation and field plan of experiment two at Embu, Kenya

10 L 1r-M	4 2r-m	5 C 1r – I	6 C 1r - M	9 L 1r - I	12 L 2r - M	8 C 2r-M							REP 4
13 contr.	11 L 2r-I	1 M 1r – I	3 M 2r - I	7 C 2r - I	Blank	2 M 1r – m							REP 4
9 L 1r – I	1 M 1r – I	10 L 1r – M	13 contr.	12 L 2r - M	2 M 1r - M	8 C 2r – M	11 L 2r- I	6 C 1r – M	3 M 2r - I	7 C 2r - I	5 C 1r - I	4 M 2r – M	REP 3
2 M 1r – M	7 C 2r – I	9 L 1r – I	11 L 2r- I	6 C 1r-M	10 L 1r -I	12 L 2r – M	1 M 1r – I	5 C 1r - I	8 C 2r - M	4 M 2r - M	3 M 2r - I	control	REP 2
12 L 2r – I	3 M 2r – I	7 C 2r – I	13 contr.	10 L 1r-M	4 M 2r - M	5 C 1r - I	11 L 2r- I	8 C 2r - M	9 L 1r - I	6 C 1r – M	1 M 1r – I	2 M 1r – M	REP 1

Length of plot = 6.0 m; Width of plot = 4.5 m; Width of paths = 1.0 m

Appendix 4. 1: Treatment details for experiment three at Embu, Kenya

TREATMENT No.	FIRST SEASON TRT.	OTHER SEASONS TRT.
1	Mucuna-One row	Mucuna-One row-0N
2	Mucuna-One row	Mucuna-One row-30N
3	Mucuna-One row	Mucuna-One row-60N
4	Mucuna-Two row	Mucuna-Two row-0N
5	Mucuna-Two row	Mucuna-Two row-30N
6	Mucuna-Two row	Mucuna-Two row-60N
7	Crot.- One row	Crot.-One row-0N
8	Crot.- One row	Crot.-One row-30N
9	Crot.- One row	Crot.-One row-60N
10	Crot. - Two row	Crot. Two row-0N
11	Crot. - Two row	Crot.-Two row-30N
12	Crot. - Two row	Crot.-Two row-60N
13	Lablab - One row	Lablab-One row-0N
14	Lablab - One row	Lablab-One row-30N
15	Lablab - One row	Lablab-One row-60N
16	Lablab - Two row	Lablab-Two row-0N
17	Lablab - Two row	Lablab-Two row-30N
18	Lablab - Two row	Lablab-Two row-60N
19	Maize only - Control	Maize only – control

Appendix 4. 2: Randomisation and field plan for experiment three at Embu, Kenya

12 60N C2	19 contr	9 60N C1	15 60N L1	2 30N M1	16 0N L2	11 30N C2	0N C1	13 0N L1	1 0N M1	10 0N C2	6 60N M2	14 30N L1	4 0N M2	17 30N L2	8 30N C1	3 60N M1	18 60N L2	5 30N M2	REP 4
4 0N M2	14 30N L1	18 60N L2	13 0N L1	1 0N M1	16 0N L2	7 0N C1	19 contr	6 60N M2	2 30N M1	8 30N C1	15 60N L1	3 60N M1	9 60N C1	17 30N L2	5 30N M2	11 30N C2	12 60N C2	10 0N C2	REP 3
5 30N M2	7 0N C1	13 0N L1	11 30N C2	19 contr	15 60N L1	12 60N C2	3 60N M1	14 30N L1	10 0N C2	16 0N L2	1 0N M1	18 60N L2	9 60N C1	4 0N M2	17 30N L2	6 60N M2	2 30N M1	8 0N C1	REP2
10 0N C2	16 0N L2	12 60N C2	6 60N M2	7 0N C1	4 0N M2	13 0N L1	2 30N M1	18 60N L2	1 0N M1	15 60N L1	11 30N C2	17 30N L2	8 30N C1	19 contr	9 60N C1	5 30N M2	14 30N L1	3 60N M1	REP 1

Length of plot = 6.0 m; Width of plot = 4.5 m; Width of paths = 1.0 m

Appendix 5. 1: Treatment details for experiment four at Embu, Kenya

Treatment no.	First season trt.	Other seasons trt.
1	Mucuna	Mucuna-0 Mg ha^{-1} -Stover
2	Mucuna	Mucuna-3 Mg ha^{-1} -Stover
3	Mucuna	Mucuna-6 Mg ha^{-1} - Stover
4	Lablab	Lablab-0 Mg ha^{-1} -Stover
5	Lablab	Lablab-3 Mg ha^{-1} - Stover
6	Lablab	Lablab-6 Mg ha^{-1} -Stover
7	Crotalaria	Crotalaria -0 Mg ha^{-}1-Stover
8	Crot.	Crotalaria -3 Mg ha^{-1}-Stover
9	Crot.	Crotalaria -6 Mg ha^{-1}-Stover
10	Maize only- control	Maize only – control
11	Maize only	Maize with 6 Mg ha^{-1}-Stover

Appendix 5. 2: Randomisation and field plan for experiment four at Embu, Kenya

2 M 3t	4 L 0t	11 stove r	1 M 0t	9 C 6t	3 M 6t	6 L 6t	5 L 3t	7 C 0t	10 contr ol	8 C 3t	Rep4
8 C 3t	1 M 0t	7 C 0t	10 contr ol	4 L 0t	5 L 3t	2 M 3t	9 C 6t	6 L 6t	3 M 6t	11 stove r	Rep 3
6 L 6t	8 C 3t	4 L 0t	9 C 6t	10 contr ol	2 M 3t	1 M 0t	11 stove r	5 L 3t	7 C 0t	3 M 6t	Rep 2
5 L 3t	1 M 0t	2 M 3t	7 C 0t	6 L 6t	4 L 0t	3 M 6t	9 C 6t	10 contr ol	8 C 3t	11 stov. 6t	Rep 1

Length of plot = 6.0 m; Width of plot = 4.5 m; Width of paths = 1.0 m

Appendix 6 1: Questionnaire on inventory of soil fertility indicators and use of plant residues for improvement of soil fertility used in Embu District, Kenya

1.1 SECTION A: GENERAL INFORMATION

Questionnaire No…… Date of interview…… Starting Time ……..…

District…….
Division……..…….…….

Location…… Sub-location……..……..

Village……
A.E.Z…….

Name of Enumerator…….……...…..

Name of respondent:…….…….. Sex respondent: Male = 1, Female = 0

1.2 SECTION B: HOUSEHOLD CHARACTERISTICS ……..…N.B……..
[preferably to be asked towards the ……...end…of the questionnaire]

N.B/ Underline (_____) as appropriate

i) Characteristics of the Respondent

1.2.1 Position of respondent in household: 1=Head, 2=Husband, 3=wife, 4=Son, 5=Daughter

1.2.2 Level of Education of respondent: 1=None, 2=Primary, 3=Secondary, 4=Tertiary, 5=Others (specify)

ii) Characteristics of the Decision maker (wife & husband….where applicable)

1.2.3 Who is the main decision maker of what is to be done in the farm? 1=Husband, 2=Wife, 3= Son/Daughter

1.2.4 When were you born? (Decision maker)…….(……years)
Age bracket of decision maker 01=<20 years, 02=21-30 yrs, 03=31-40 yrs, 41-50 yrs, 51-60 yrs, >60 yrs

1.2.5 Household type: 01=Male headed with spouse, 02=Male headed single, 03=Male headed husband away, 04=Female headed single, 05=Widow.

1.2.6 Level of Education of wife: 01=None, 02=Primary, 03=Secondary, 04=Tertiary, 05=others (specify).

1.2.7 Occupation of wife: 1=Full time farmer, 0=employment…… (Specify)

1.2.8 Level of Education of husband: 01=None, 02=Primary, 03=Secondary, 04=Tertiary, 05=Others (specify)

1.2.9 Occupation of husband: 1=Full time farmer, 0=Employment……. (Specify)

iii) Characteristics of the Farm

1.2.10 Type of living house: 1=Permanent, 2=Semi-permanent, 3=Mud

1.2.11 What are the sizes of land parcels (acres) you cultivate?
Owned:
1……..…..…,2……3……..……..
Hired:
1……..….,,2……..,,3…….……..…
For hired indicate the distance (km) away from the household

1.2.12 What is the general topography of the farm? (should add up to 100%)

Topography	**Flat (0 –5%)**	**Gentle (5-10%)**	**Hilly (>10%)**
Proportion of the farm (%)			

1.2.13 Make a sketch of the farm below:

2.1 **CROPS GROWN AND ACREAGE**

CROPS GROWN	**MAJOR SEASON**		**CROPS GROWN**	**MINOR SEASON**	
Crops	**Area (acres)**	**Yields**	**Crops**	**Area in acres**	**Yields**
Food crops					
1.					
2					
3.					
4.					
5.					
Cash crops (specify)					
1.					
2.					
3.					
Fodder crops					
1.					
2.					
3.					
Others (specify)					
TOTAL AREA			TOTAL AREA		

2.2.1 TYPE OF LIVESTOCK KEPT AND NUMBERS

Type of Livestock	No. of mature stock	No. of young stock	Total	Milk (Tree Top bottles per day)	Milk (Liters per ….).
Cattle					
Sheep					
Goats					
Pigs					
Poultry					
Draft bull					
Others (specify)					

2.2.2 Method of grazing (3 Tick as appropriate)

1. Zero grazing (concrete)
2. Zero grazing (earth)
3. Semi-Zero grazing
4. Extensive / tethering

3.1 SECTION C: ON-FARM FERTILITY IMPROVEMENT RESOURCES INVENTORY

3.1.0 Do you use any soil fertility improvement inputs in your farm? Yes=1, No=0

If No. Why ?

If yes, list all the soil fertility improvement resources used in the farm, amount generated per year, application rates to various crops area cover and frequency of application:

Soil fertility amendment resource	Amount generated or bought per year	Crops benefiting and	Rate of application (in local units) per hill or stem	Area covered in acres	Frequency of application (yearly or seasonally)
1. Fertilizer					
2. manure					
Resting or fallowing					

3.2 SECTION D: SOIL FERTILITY MANAGEMENT

Is low soil fertility a major constraint in your farm? ……..Yes=1, No=0

If yes, which part of the farm?, Indicate crops , indicate area affected (acres)
(3 Tick as appropriate)

1. Near homestead
2. Far from homestead
(indicate approximate distance from homestead)
3. Whole farm
4. Steep slope (conseved)
5. Steep slope (unconserved area)
6. Other (specify)

Indicate area (in acres) affected

3.2.1 What are the main causes of soil INFERTILITY in your farm ?

1) Soil erosion
2) Over cultivation
3) No amendments used
4. Soil type
5. Type of trees in the farm
6. Other (specify)

3.2.2 Have you put in place soil and water conservation structures in your farm?
……Yes=1, No=0

If yes, list them.

If No, why (3 Tick as appropriate)

1. Land is flat
2. Lack resources
3. Lack knowledge
4. Other (specify)

4.0 SECTION E: SOIL FERTILITY INDICATORS

4.1.1 What are the **inherently** HIGH soil fertility indicators? (3 Tick as appropriate)

1. Crop performance
(Describe)……
……
2. Type of weed (name them)
……
……

3. Colour of soil (specify
……
……

4. Any other (specify)
……
……

4.1.2 What are the **inherently** LOW soil fertility indicators? (3 Tick as appropriate)

1. Crop performance
(Describe)……
……

2. Type of weed (name them)
……
……

3. Colour of soil (specify)
……
……

4. Any other (specify)
……
……

4.1.3 Do you know any wild or domesticated plants that are used to improve soil fertility?
……Yes=1, No=0

If yes List them.

For each soil fertility indicator in each farm 2 plants from each category will be sampled and preserved for identification. Remember to pick **extreme** indicators on each side and label the following information:

Name of
interviewer:…….
Name of
farmer:…….
Location &
village…….
Place sampled in the
farm……..
Sampling
date:……...
English name if
known:…….

In each AEZ, soil sample from a fertile and on infertile area will be taken from THREE (3) representative farms.
Depth of sampling = 20 cm

N.B The sampling will be in 3 farms per zone, 2 (samples per farm) x 5 AEZ = 30 SAMPLES.

5.0 SECTION F: USE OF PLANT RESIDUES FOR SOIL FERTILITY IMPROVEMENT

5.1.1 List crop, tree or weeds types of plant residues that are there in your farm which lead to GOOD or POOR crop performance (3 Tick as appropriate)

RESIDUE SOURCE FOR **GOOD** PERFORMANCE

1. Crop
……
……
2. Tree
……..…….……..

3. Herbs/weeds
……..……..**.....**
……..

RESIDUE SOURCE FOR **POOR** PERFORMANCE

2. Crop
……..
……..
2. Tree
……..…….……..

3. Herbs/weeds
……..……..**.....**
……

5.2.2 What are the perceived reasons for good or poor performance

RESIDUE	REASON FOR **GOOD** PERFORMANCE
1…….1	……..
2…….2.	……
3…….3.	……

RESIDUE	REASON FOR **POOR** PERFORMANCE
1…….1	……..**...**
2…….2.	……
3…….3.	……

5.2.3 Do you intend to increase the area under these plant residues and if yes how?
1. Plant more
2. Biomass transfer
3. Leave residues already in farm to incorporate
5. Other (specify)

5.3 Would you be interested in introducing NEW plants whose residues improve soil fertility? Yes=1, No=0

Appendix 6 2: Summary of sampling scheme followed in selecting and interviewing farmers during the survey in Embu District, Kenya

Agro-Ecological Zone	Division	Location	Sub-location	Village	Date of Interview
Lower Highland 1	Kathanjuri Runyenjes	Kyeni north Kagaari north	Kiangungi Kanja	Kavururi Gichegeni/Munyutu	July 3, 2002 July 9, 2002
Upper Midland 1	Kathanjuri Runyenjes	Kyeni north Kagaari north	Kiangungi Gitare	Kithangariri Ngui	July 10, 2002
Upper Midland 2	Runyenjes	Runyenjes township	Gichiche	Gaciari	July 17, 2002
Upper Midland 3/4	Runyenjes	Kagaari south	Gichiche Gichera	Kamisha Ithatha	July 18, 2002
Lower Midland 3	Runyenjes	Kagaari south	Kiringa	Nguruka	July 19, 2002

Appendix 6 3: Crop species found in the transect area during the survey in Embu District, Kenya

Common name	**Botanical name**
Tea	*Camellina sinensis*
Maize	*Zea mays*
Beans	*Phaseolus vulgalis*
Yams	*Dioscorea* spp.
Coffee	Coffea arabica
Napier grass	*Pennisetum purpureum*
Bananas	*Musa acuminata/balbisiana* Colla
Potatoes (Irish)	*Solanum tuberosum*
Arrow roots	*Maranta arundinacea*
Kales	*Brassica Oleracea* var., acaphala
Cassava	*Manihot esculenta*
Sugar cane	*Saccharum cvs*
Sweet potato	*Ipomoea batatas*
Macadamia	*Macadamia integrifolia*
Cow peas	*Vigna unguiculata*
Sorghum	*Sorghum bicolor*
Pigeon pea	*Cajanus cajan*
Tomatoes	*Lycopersicon esculentum*
Onions	*Allium cepa*
Cabbages	*Brassica oleracea* var., *capitata*
Pumpkins	*Cucurbita moschata*
Miraa	*Cartha edulis*
Mangoes	*Mangifera indica*
Tobacco	*Nicotiana tabacum*
Pawpaw	*Carica papaya*
Sunflower	*Helianthus annuus*
Avocado	*Persea americana*
Foxtail millet	*Setaria italica*
Pearl millet	*Pennisetum glaucum*
Finger millet	*Eleusine coracana*

Appendix 6 4: Tree species found in the transect area during the survey in Embu District, Kenya

Vernacular (Kiembu) name	**Common name**	**Scientific name**
Mukima	Grevillea	Grevillea robusta
Mukondovia	Avocado	*Persea americana*
Muvuru	Meru oak	*Vitex keniensis*
Mukinduri	Croton	*Croton megalocarpus*
Mutundu	Croton (broadened)	*Croton macrostachyus*
Mururi	Conmiphora	*Commiphora zimmermanii*
Muembe	Mango	*Mangifera indica*
Mukandamia	Macadamia	*Macadamia integrifolia /tetraphylla* spp.
Muu	Marchamia	*Markhamia lutea*
Mugaa	Acacia	*Acasia spp.*
Mugumo	Fig tree	*Ficus thonningii*
Munyuamai/Muringamu	Blue gum	*Eucalyptus saligna*
Mutoo	Dombeya	*Dombeya goetzenii*
Muvuti	Flame tree	*Erythrina abyssinica*
Mukwego	Bridelia	*Bridelia micrantha*
Muvevu	Pigeon wood	*Trema orientallis*
Mucuca	Loquat	*Eriobotrya japonica*
Muringa	Cordia (large leaved)	*Cordia africana*
Muthanduku	Wattle tree	*Acacia mearnsii*
Mutarakwa	Mexican cypress	*Cupressus lusitanica*
Mwiria	Red stinkwood	*Prunus africana*
Mucavavinduki	Nandi flame	*Spathodea campanulate*
Mukuu	Sycamore tree	*Ficus sycomorus*
Matunda wa Nthakame	Tree tomato	*Cyphomandra betacea*
Murangi	Bamboo	Arundinaing alpina
Muthata	-	*Olea europea* spp. *africana*
Mukurwe	-	*Albizia gummifera*
Mukarara	-	*Margaritaria discoide*
Mukura	-	*Combretum molle*
Murama	-	*Piliostigua thonningii*
Muvevu	-	*Trema orlentalis*
Mucovo	-	-
Mwenjeu	-	-
Mwanjati	-	-

Appendix 6 5: Weed species found in the transect area during the survey in Embu District, Kenya

Vernacular (Kiembu) name	**Common name**	**Scientific name**
Ruoga	Pigweed	*Amaranthus* spp.
Mukevui	Itch grass or guineafowl grass	*Rottboellia cochinchinensis*
Mukengeria	Wandering jew	*Commelina benghalensis*
Mucege	Black jack	*Bidens pilosa*
Ndaugu	Double thorn	*Oxygonum sinuatum*
Mung'ei	Gallant soldier	*Galinsoga parviflora*
Managu	Black nightshade	*Solanum nigrum*
Gitima	Kikuyu grass	*Pennisetum clandestinum*
Muthunga	Wild lettuce	*Launaea cornuta*
Mwaraciau	Mexican clover	*Richardia scabra*
Ntheru	Oxalis	*Oxalis latifolia*
Muvangi	Mexican marigold	*Tagetas minuta*
Kirurite	Tithonia	*Tithonia diversifollia*
Mucimoro	Lantana /Tickberry	*Lantana camara*
Muguku	-	*Digitaria velutina*
-	Yellow sorrel	*Oxalis corniculata* L.
Mbuinjeru / Karerevui	Red-top grass	*Rhynchelytrum repens*
Nthangari	Coach grass	Digitaria scalarum
Ruthiru	Bracken fern	*Pteridium equilinum*
-	Dwarf marigold	*Schluria spinnata*
Gikothe / Kigatu	Sedge	*Cyperus spp*
-	Kidney weed	*Dichondra repens*
-	-	*Andropogon spp.*
Muria	-	*Euphorbia heterophylla*
Kathenge	Goat weed	*Ageratum conyzoides*
-	Asthma weed	*Euphorbia hirta*
Kimore	-	*Cimmelina diffusa*
Mukwakuru	Upright starbur	*Acanthospernum hispidum*
Matatu	Starbur	-
Muvuva ndundi	Fleabane	*Conyza bonariensis*
Maviuviu	Sow thistle	*Sonchus oleraceus*
Matatu	Starbur	-
Muvuva ndundi	Fleabane	*Conyza bonariensis*
Mucuki	-	-
Maviuviu	Sow thistle	*Sonchus oleraceus*
Mukiranthongo	-	*Alternanthera philoxeroides*
Mutindie	Love grass	*Setaria verticillata*
Mugico	-	*Triufetta macrophylla*
Mwogoya	-	*Plectranthus barbatus*
Mwirinda ngurwe	-	*Triufetta rhomboidea*
-	Devils horsewhip	*Achyranthes aspera* L
-	Cat's ear	*Hypochroeris glabra* L.
Ndongu	Sodom apple	*Solanum incanum*

Vernacular (Kiembu) name	Common name	Scientific name
Runjure	-	-
Rwindu	-	-
Mucivivi	Bobbin weed	*Leucas martinicensis*
Mucatha	-	*Chromolana odorata*
Thuuri	-	-
Muthatha	-	-
Mukorivu	-	-
-	Star grass	*Cynodon dactylon*
-	Guinea grass	*Panicum maximum*
Mwathathi	-	-
Mukevui	Itch grass or guineafowl grass	*Rottboellia cochinchinensis*

Appendix 7. 1: Summary of the soil physical and chemical characteristics of the experimental site at Embu, Kenya

Depth (cm)	0-20	20-40	40-70	70-102	102-150
Bulk density (g cm^{-3})	1.02	1.00	1.04	1.04	0.95
Sand (%)	18	16	14	10	8
Silt (%)	18	18	14	14	6
Clay (%)	64	66	72	76	86
pH - H_20 (1:2:5)	5.8	6.1	6.1	6.2	6.2
C (%)	2.59	1.95	1.49	0.91	0.69
N (%)	0.26	0.18	0.13	0.10	0.07
C/N ratio	10.0	10.8	11.5	9.1	9.9
P-Olsen (ppm)	6.50	2.00	nd	nd	nd
CEC (cmol kg^{-1})	25.9	23.8	21.1	18.7	16.6
Ca (cmol kg^{-1})	4.00	3.50	2.90	2.10	2.20
Mg (cmol kg^{-1})	2.10	2.00	1.20	1.50	1.40
K (cmol kg^{-1})	1.35	0.68	0.48	.26	0.09
Na (cmol kg^{-1})	0.26	0.25	0.28	0.21	0.65
Base saturation (%)	29.8	27.1	23.0	21.8	26.1

Source: Kihanda, 1996

Appendix 7.2: Summary of the soil physical and chemical characteristics for experiment one in Embu, Kenya

Treatment	Legume	No. of Rows	WAP	pH water	pH KCl	N (%)	C (%)	p (ppm)	Ca (c mol/kg)	Mg (c mol/kg)	K (c mol/kg)	CEC (c mol/kg)	Sand (%)	Silt (%)	Clay (%)
1	Mucuna	One	0	5.97	4.30	0.34	2.94	22.50	4.75	2.50	6.67	12.00	26.33	38.00	35.67
2	“	“	1	5.53	4.20	0.32	3.12	21.67	4.42	2.53	9.00	10.07	27.67	38.00	34.33
3	“	“	2	5.97	4.30	0.34	2.94	22.50	4.75	2.50	6.67	12.00	26.33	38.00	35.67
4	“	“	3	5.50	4.13	0.39	2.97	16.67	4.83	2.53	9.67	13.60	26.33	38.67	35.00
5	“	“	4	5.50	4.13	0.39	2.97	16.67	4.83	2.53	9.67	13.60	26.33	38.67	35.00
6	Mucuna	Two	0	5.70	4.37	0.35	2.97	27.50	4.75	2.60	6.67	10.33	27.67	38.00	34.33
7	“	“	1	5.77	4.07	0.30	2.94	11.67	4.83	2.43	9.67	15.27	25.00	38.67	36.33
8	“	“	2	5.70	4.37	0.35	2.97	27.50	4.75	2.60	6.67	10.33	27.67	38.00	34.33
9	“	“	3	5.50	4.13	0.32	2.97	16.67	4.83	2.53	9.67	13.60	26.33	38.67	35.00
10	“	“	4	5.97	4.30	0.34	2.94	22.50	4.75	2.50	6.67	12.00	26.33	38.00	35.67
11	Crotalaria	One	0	5.80	4.13	0.32	3.08	16.67	4.42	2.43	9.00	11.73	26.33	38.00	35.67
12	“	“	1	5.67	4.30	0.32	2.83	22.50	5.17	2.60	7.33	13.87	26.33	38.67	35.00
13	“	“	2	5.80	4.13	0.32	3.08	16.67	4.42	2.43	9.00	11.73	26.33	38.00	35.67
14	“	“	3	5.67	4.30	0.32	2.83	22.50	5.17	2.60	7.33	13.87	26.33	38.67	35.00
15	“	“	4	5.50	4.13	0.39	2.97	16.67	4.83	2.53	9.67	13.60	26.33	38.67	35.00
16	Crotalaria	Two	0	5.97	4.30	0.34	2.94	22.50	4.75	2.50	6.67	12.00	26.33	38.00	35.67
17	“	“	1	5.53	4.20	0.32	3.12	21.67	4.42	2.53	9.00	10.07	27.67	38.00	34.33
18	“	“	2	5.97	4.30	0.34	2.94	22.50	4.75	2.50	6.67	12.00	26.33	38.00	35.67
19	“	“	3	5.80	4.13	0.42	3.08	16.67	4.42	2.43	9.00	11.73	26.33	38.00	35.67
20	“	“	4	5.70	4.37	0.35	2.97	27.50	4.75	2.60	6.67	10.33	27.67	38.00	34.33
21	Lablab	One	0	5.50	4.13	0.35	2.97	16.67	4.83	2.53	9.67	13.60	26.33	38.67	35.00
22	“	“	1	5.67	4.30	0.32	2.83	22.50	5.17	2.60	7.33	13.87	26.33	38.67	35.00
23	“	“	2	5.23	4.20	0.35	3.01	21.67	4.83	2.63	9.67	11.93	27.67	38.67	33.67
24	“	“	3	5.97	4.30	0.34	2.94	22.50	4.75	2.50	6.67	12.00	26.33	38.00	35.67

Treatment	Legume	No. of Rows	WAP	pH water	pH KCl	N (%)	C (%)	p (ppm)	Ca (c mol/kg)	Mg (c mol/kg)	K (c mol/kg)	CEC (c mol/kg)	Sand (%)	Silt (%)	Clay (%)
25	“	“	4	5.80	4.13	0.32	3.08	16.67	4.42	2.43	9.00	11.73	26.33	38.00	35.67
26	Lablab	Two	0	5.40	4.37	0.29	2.86	27.50	5.17	2.70	7.33	12.20	27.67	38.67	33.67
27	“	“	1	5.53	4.20	0.32	3.12	21.67	4.42	2.53	9.00	10.07	27.67	38.00	34.33
28	“	“	2	5.93	4.23	0.32	2.79	17.50	5.17	2.50	7.33	15.53	25.00	38.67	36.33
29	“	“	3	5.80	4.13	0.32	3.08	16.67	4.42	2.43	9.00	11.73	26.33	38.00	35.67
30	“	“	4	5.40	4.37	0.31	2.86	27.50	5.17	2.70	7.33	12.20	27.67	38.67	33.67
31	Maize only	-	0	5.50	4.13	0.36	2.97	16.67	4.83	2.53	9.67	13.60	26.33	38.67	35.00
32	Mucuna only	One	0	5.97	4.30	0.34	2.94	22.50	4.75	2.50	6.67	12.00	26.33	38.00	35.67
33	“	Two	0	5.23	4.20	0.35	3.01	21.67	4.83	2.63	9.67	11.93	27.67	38.67	33.67
34	Crotalaria only	One	0	5.67	4.30	0.32	2.83	22.50	5.17	2.60	7.33	13.87	26.33	38.67	35.00
35	“	Two	0	5.67	4.30	0.38	2.83	22.50	5.17	2.60	7.33	13.87	26.33	38.67	35.00
36	Lablab only	One	0	5.53	4.20	0.36	3.12	21.67	4.42	2.53	9.00	10.07	27.67	38.00	34.33
37	“	Two	0	5.40	4.37	0.33	2.86	27.50	5.17	2.70	7.33	12.20	27.67	38.67	33.67

Appendix 7.3: Summary of the soil physical and chemical characteristics for experiment two in Embu, Kenya

TRT	SEASON ONE TRT.	pH water	pH KCl	N (%)	C (%)	p (ppm)	Ca (c mol/kg)	Mg (c mol/kg)	K (c mol/kg)	CEC (c mol/kg)	Sand (%)	Silt (%)	Clay (%)
	Mucuna-one row	5.28	3.93	0.27	2.52	12.75	3.94	2.28	2.00	9.55	28.00	41.50	30.50
2	Mucuna-one row	5.28	3.93	0.27	2.52	12.75	3.94	2.28	2.00	9.55	28.00	40.00	32.00
3	Mucuna-Two row	5.38	4.00	0.34	2.58	15.25	4.00	2.23	2.00	10.10	27.00	41.50	31.50
4	Mucuna-Two row	5.38	4.00	0.34	2.58	15.25	4.00	2.23	2.00	10.10	27.00	41.50	31.50
5	Crot.-one row	5.35	4.00	0.34	2.59	13.75	4.00	2.25	2.00	10.10	27.50	41.50	31.00
6	Crot.-one row	5.35	4.00	0.33	2.59	13.75	4.00	2.25	2.00	10.10	27.50	41.50	31.00
7	Crot.-Two row	5.30	3.93	0.33	2.51	14.25	3.94	2.25	2.00	9.55	27.50	40.00	32.50
8	Crot.-Two row	5.35	4.00	0.38	2.59	13.75	4.00	2.25	2.00	10.10	27.50	41.50	31.00
9	Lablab-one row	5.23	3.85	0.33	2.44	13.25	3.88	2.28	2.00	9.00	28.00	38.50	33.50

Trt	Season One Trt.	pH water	pH KCl	N (%)	C (%)	p (ppm)	Ca (c mol/kg)	Mg (c mol/kg)	K (c mol/kg)	CEC (c mol/kg)	Sand (%)	Silt (%)	Clay (%)
10	Lablab-one row	5.28	3.93	0.34	2.52	12.75	3.94	2.28	2.00	9.55	28.00	40.00	32.00
11	Lablab-Two row	5.28	3.93	0.33	2.52	12.75	3.94	2.28	2.00	9.55	28.00	40.00	32.00
12	Lablab-Two row	5.28	3.93	0.35	2.52	12.75	3.94	2.28	2.00	9.55	28.00	40.00	32.00
13	Maize only, control	5.28	3.93	0.33	2.52	12.75	3.94	2.28	2.00	9.55	28.00	38.50	33.50

Appendix 7. 4: Summary of the soil physical and chemical characteristics for experiment three in Embu, Kenya

TRT	SEASON ONE TRT.	**pH water**	**pH KCl**	**N (%)**	**C (%)**	**p** (ppm)	**Ca (c mol/kg)**	**Mg (c mol/kg)**	**K (c mol/kg)**	**CEC (c mol/kg)**	**Sand (%)**	**Silt (%)**	**Clay (%)**
1	Mucuna-One row	5.33	4.05	0.36	2.81	19.13	3.63	2.63	2.00	13.70	27.00	35.50	37.50
2	Mucuna-One row	5.28	4.03	0.33	2.83	14.13	3.63	2.70	2.00	14.55	27.50	38.50	34.00
3	Mucuna-One row	5.18	3.95	0.32	3.02	17.13	3.81	2.70	1.75	15.20	25.50	35.00	39.50
4	Mucuna-Two row	5.38	4.00	0.33	3.10	21.88	4.00	2.68	2.50	15.20	25.50	34.00	40.50
5	Mucuna-Two row	5.25	3.93	0.30	3.18	16.25	3.88	2.75	2.25	16.25	25.50	37.00	37.50
6	Mucuna-Two row	5.40	4.03	0.36	2.96	19.50	3.81	2.75	2.25	14.25	26.00	35.50	38.50
7	Crot.-One row	5.38	4.00	0.35	3.02	21.38	3.44	2.53	2.50	14.60	27.00	36.50	36.50
8	Crot.-One row	5.30	3.95	0.36	3.15	22.50	4.00	2.75	2.00	14.90	24.00	32.00	44.00
9	Crot.-One row	5.35	3.98	0.37	3.14	26.25	3.88	2.60	2.25	14.55	24.50	31.00	44.50
10	Crot. Two row	5.23	3.98	0.33	3.01	20.88	3.69	2.55	2.00	14.85	26.00	34.00	40.00
11	Crot. Two row	5.40	4.03	0.36	2.96	19.50	3.81	2.75	2.25	14.25	26.00	35.50	38.50
12	Crot-Two row	5.23	3.98	0.31	3.02	19.63	3.56	2.48	2.25	15.35	27.00	36.00	37.00
13	Lablab-One row	5.33	4.05	0.34	2.82	17.88	3.50	2.55	2.25	14.20	28.00	37.50	34.50
14	Lablab-One row	5.23	3.98	0.33	3.01	20.88	3.69	2.55	2.00	14.85	26.00	34.00	40.00
15	Lablab-One row	5.33	4.05	0.32	2.90	18.38	4.06	2.70	2.25	14.80	26.50	35.00	38.50
16	Lablab-Two row	5.33	4.05	0.30	2.91	17.13	3.94	2.63	2.50	15.30	27.50	37.00	35.50
17	Lablab-Two row	5.25	3.93	0.32	3.17	17.50	4.00	2.83	2.00	15.75	24.50	35.00	40.50
18	Lablab-Two row	5.23	3.98	0.33	3.01	20.88	3.69	2.55	2.00	14.85	26.00	34.00	40.00
19	Maize only – control	5.50	4.10	0.36	2.77	16.50	3.63	2.75	2.50	13.60	28.00	39.00	33.00

Appendix 7. 5: Summary of the soil physical and chemical characteristics for experiment four in Embu, Kenya

TRT	SEASON ONE TRT.	SEASON TWO TRT.	pH water	pH KCl	N (%)	C (%)	p (ppm)	Ca (c mol/kg)	Mg (c mol/kg)	K (c mol/kg)	CEC (c mol/kg)	Sand (%)	Silt (%)	Clay (%)
1	Mucuna	Mucuna-0 Mg ha^{-1} Stover	5.88	4.42	0.38	2.68	21.70	4.65	2.62	4.20	10.36	23.00	44.80	32.20
2	Mucuna	Mucuna-3.0 Mg ha^{-1} Stover	5.88	4.42	0. 38	2.68	21.70	4.65	2.62	4.20	10.36	23.00	44.80	32.20
3	Mucuna	Mucuna-6.0 Mg ha^{-1} Stover	5.70	4.28	0. 35	2.71	18.40	4.30	2.60	3.20	11.76	23.00	41.60	35.40
4	Lablab	Lablab-0 Mg ha^{-1} Stover	5.90	4.44	0. 37	2.70	19.10	4.80	2.60	5.00	11.72	23.00	43.20	33.80
5	Lablab	Lablab-3.0 Mg ha^{-1} Stover	5.74	4.32	0. 33	2.75	13.20	4.60	2.56	4.80	14.48	23.00	38.40	38.60
6	Lablab	Lablab-6.0 Mg ha^{-1} Stover	5.72	4.30	0. 34	2.73	15.80	4.45	2.58	4.00	13.12	23.00	40.00	37.00
7	Crot.	Crot. -0 Mg ha^{-1} Stover	5.72	4.28	0. 34	2.67	18.60	4.35	2.60	3.40	11.12	23.00	43.20	33.80
8	Crot.	Crot. -3.0 Mg ha^{-1} Stover	5.78	4.30	0. 31	2.59	10.50	4.40	2.50	4.00	11.96	23.00	41.60	35.40
9	Crot.	Crot. -6.0 Mg ha^{-1} Stover	5.72	4.30	0. 34	2.73	15.80	4.45	2.58	4.00	13.12	23.00	40.00	37.00
10	Maize only-control	Maize only – control	5.64	4.22	0. 32	2.68	12.70	4.15	2.54	3.00	12.88	23.00	39.20	37.80
11	Maize only	6.0 Mg ha^{-1} Strover	5.50	4.10	0.36	2.70	7.00	4.00	2.50	3.00	15.00	23.00	36.00	41.00