USE OF *CALLIANDRA CALOTHYRSUS* AND *LEUCAENA TRICANDRA* TREE SPECIES FOR SOIL NUTRIENT ENHANCEMENT IN CHUKA DIVISION, CENTRAL HIGHLANDS OF KENYA

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DECLARATIONS

CANDIDATE'S DECLARATION

This thesis is my original work and has not been presented for any other award. No part of this thesis may be reproduced without prior permission from the researcher.

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To my children to be; my grandfather Samuel M' Imwara who encouraged me to go for higher education; to the farmers of Chuka Division on whose farms this study was carried and to all the beneficiaries of this thesis.

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ABSTRACT

The central highlands of Kenya are characterized by high soil and nutrient losses through soil erosion and leaching. Research has reported positive results from the use of appropriate vegetative contour hedges since they are able to hold topsoil while simultaneously capturing and pumping up leached nutrients. It has also been shown that farmers' adoption of new technologies is dependent on their perception of those technologies. Against this background, an on farm trial involving use of *Calliandra*, *Leucaena* and napier contour hedges was started in farmers fields of Chuka Division to evaluate the feasibility of these technologies in the control of soil and nutrient losses.

The trial farmers were recruited on the basis of gender and slope after a Participatory Rural Appraisal (PRA). The slopes were categorized as 5-10, 10-20, 20-30 and > 30% slope. Treatments were laid down on these slope categories along the contours in a zig-zag manner with an inter-row spacing of 0.25 m, intra-row spacing of 0.5 m and a variable inter-hedge spacing depending on the slope. Soils were sampled at the start and 20 months after establishment of the trials at 0-30, 30-90 and 90-150 cm depths. Soils from 0-30 cm depth were analysed for pH, Ca, Mg, K, C, N, P, and inorganic N, while soils from 30-90 and 90-150 cm depth were analysed for inorganic N only. Farmers' perceptions of these technologies were determined by use of questionnaires.

Treatments that had trees either as sole or combination hedges registered a significant ($P<0.05$) increment in pH, Ca, Mg, P and K as compared to those that were either under sole napier hedge or control after 20 months of experimentation. During the first sampling, all the plots had more mineral-N beyond 0-30 cm depth. During the second sampling inorganic N in the 0-30 cm depth was significantly higher for *Leucaena* than the control and napier. *Leucaena* plots also had higher concentration ($P<0.05$) of inorganic-N than sole napier plots. The other treatments did not show any significant difference at this depth. Inorganic N at 30-90 cm depth was lower ($P<0.05$) in *Calliandra*, *Leucaena* and *Leucaena* + napier than the control plot. On the other hand at 90-150 cm depth, *Leucaena*,

Leucaena + napier and *Calliandra* significantly reduced (P<0.05) inorganic-N accumulation in comparison with the control and napier.

The first season registered higher soil losses than second season for treatments with hedges and vice versa for the control. Soil losses during the first season and second season were lower (P<0.05) in hedge plots for 10-20, 20-30 and >30% slope categories in comparison to the control. However, soil loss on 10-20% slope category during the second season was significantly lower (P<0.05) for napier hedges than for all the other treatments. *Calliandra* + napier and *Leucaena* + napier plots lost significantly lower (P<0.05) amount of soil than *Calliandra*, *Leucaena* and control at this slope category.

Farmers perceptions of appropriate hedgerow species showed that farmers would favor species that would provide quality and quantity fodder, improve crop production, enhance soil fertility, control soil erosion and provide cash income on sale of their products.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CIAT	International Centre for Tropical Agriculture
ERDU	Division of Ecosystem Research and Development Bureau
FAO	Food Agriculture Organization of the United Nations
IBSRAM	International Board for Soil Research and Management
ICRAF	International Centre for Research in Agroforestry
PRA	Participatory Rural Appraisal
TSBF	Tropical Soil Biology and Fertility
NDF	Neutral detergent fibre (a measure of hemicellulose, cellulose, and lignin, which represent the fibrous bulk of forage)
WaNuLCAS	Water, Nutrient and Light Capture in Agroforestry Systems

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CHAPTER 1

INTRODUCTION

1.1 Background information

The sub-Saharan Africa is undergoing extensive environmental degradation for various reasons (Lal et al., 1995). This has manifested itself through rapid deforestation, thinning of tree cover in woodland fallow and the creation of grasslands. These changes usually result in decreased soil organic matter (SOM) and losses of organic carbon of 25% to 30% in the topsoil layer in the first five years after conversion to agricultural land (Houghton, 1995; Young, 1997). Mineral nitrogen (N), especially nitrate (NO_3^-), released during decomposition of soil organic matter may be taken up by plants, immobilized by microbes, lost from the soil system through leaching and denitrification or retained in the soil profile (Davidson and Ackerman 1993; Shepherd et al., 2000).

The huge losses of nitrates are causing serious environmental concern due to increased nitrogen concentration in drinking waters at regional scale (Shepherd et al., 2000). Concern arises especially when nitrates accumulate in ground water, because when ingested in high amounts by humans and animals, potential adverse effects may occur. These health effects are reported to include methemoglobinemia and cancer among others (Cast, 1985; Duijvenbooden and Matthijsen, 1987). Apart from health effects, the enhanced N loading can alter nutrient balances and ecological processes in rivers, lakes and estuaries potentially leading to

eutrophication, affecting net phytoplankton productivity and causing increased bottom water hypoxia (Justic et al., 1995).

Agroforestry (an integration of trees into agricultural landscapes) has frequently been cited as one of the natural resource management systems that improve nutrient cycling (Young, 1997). Trees root deep into sub-soil layers beyond the rooting depth of annual crops and are capable of capturing and "pumping up" inaccessible nutrients in these horizons greatly benefiting field crops (Mekonnen et al., 1997). In addition, the deep roots act as "safety net" below the annual crops intercepting the nutrients especially N (Van Noordwijk, 1989, Van Noordwijk et al., 1996) which have a potential of being leached to deeper layers. The captured nutrients can potentially be transferred to the surface soil in the form of litter and prunings. In addition to retrieving sub-soil nutrients, studies in tropical regions have also shown that agroforestry systems are capable of controlling soil erosion. In Ibadan, contour hedgerows of *Leucaena leucocephala* and *Gliricidia sepium* on a 7% slope, reduced both soil and nutrient losses by 85% in comparison to conventional plowing (Young, 1988).

The central highlands of Kenya are characterized by moderate to steep slopes of up to 60% (Minae and Nyamae, 1988). Cultivation on these slopes with little or no soil and water management practices leads to soil nutrient loss through soil erosion and is thus one of the constraints that impede land productivity.The current recommendation of digging cut-off drains on contours is effective but highly labor intensive. Competition for family labor, which is the main source of labor in this

area, is high such that enterprises with immediate returns like coffee and tea harvesting get the first priority leaving little or no time for installation of costly and time consuming physical/mechanical structures for soil conservation. Effective low cost technologies like contour planting of leguminous shrubs and grasses on these slopping landscapes that can also be a source of fodder for livestock have been recommended (Peden et al., 1993). It is also evident that vegetation strips are becoming more and more attractive than terracing due to decreasing farm sizes per person, which leaves no free land for growing fodder.

According to Angima (2000), combinations of *Calliandra* or *Leucaena* and napier on soil erosion control structures have not yet been fully documented. However, since *Calliandra* and *Leucaena* are nitrogen fixing multi-purpose trees, it is expected that napier can establish better due to available N and hence provide a better barrier to runoff. Such a practice of combining napier's soil conserving properties with protein rich hedges of multi-purpose trees would be beneficial in areas where farmers raise livestock because of enhanced quality and yield of napier and the protein supplements. Therefore, napier grass, when mixed with a suitable legume, could play a role in soil conservation when planted along the contours to provide a barrier for soil movement, as well as increasing yields of fodder. The multi-purpose nature and the direct benefits derived from these leguminous species may enhance the adoption of such technologies.

1.2 Statement of the problem

Small-scale farmers in the central highlands of Kenya have limited farm incomes due to their small farm sizes, low crop yields, and lack of high value enterprise options. As a result they cannot afford to purchase sufficient inorganic fertilizer to offset the nutrient depletion occurring through leaching and crop harvest. Moreover, recent studies in central highlands of Kenya have indicated a substantial nitrate build up in the soil early in the season with N supply (mineralization) exceeding maize-crop demand during the first six weeks of each cropping season. Such available N in the soils is subject to loss through leaching, volatilization and denitrification. These losses contribute to decline in soil fertility leading to low land productivity and eventually translating to inadequate food production to meet human demand.

The topography of central highlands is gently to steeply rolling with a medium to high soil erosion hazard (Kassam et al., 1992). Construction of terraces and other physical soil erosion control structures is expensive, laborious and time-consuming leading to their low adoption. This has led to heavy soil losses down the slope leading to accumulation of nutrients in water bodies and increasing the farmer's cost of production (when nutrients from applied soil amendments are washed away by water). On the other hand whereas it is sufficiently documented that incorporation of trees in farming systems can improve nutrient cycling and enhance soil conservation leading to higher productivity, farmers in central highlands of Kenya

have not integrated trees in their farms in sufficient quantities and arrangements to tap these benefits.

1.3 Research questions

The research questions that guided this study were:

i. How effective are *Calliandra calothyrsus* and *Leucaena tricandra* tree species in capturing, recycling and enhancing soil nitrogen?

ii. How effective are *Calliandra calothyrsus*, *Leucaena tricandra* and napier hedges as barriers for soil erosion control on sloping lands in central highlands of Kenya?

iii. What are the farmers' perceptions with respect to adoption of introduced technologies?

1.4 Objectives of the study

The overall objective of this study was to evaluate different approaches of improving soil nutrient management in small-holder cropping systems of central highlands of Kenya and also to determine the farmers perceptions leading to adoption/non-adoption of these introduced technologies. As such, the specific objectives of this study were:

i. To determine the effectiveness of *Calliandra* and *Leucaena* trees in capturing, recycling and enhancing soil nitrogen in smallholder farming systems of central highlands of Kenya.

ii. To establish the effectiveness of *Calliandra*, *Leucaena* and napier hedges as barriers for soil erosion control on sloping lands in central highlands of Kenya.

iii. To determine the farmers' perception in respect to adoption of these introduced technologies.

1.5 Research hypotheses

The working premise of this study was that 'nutrients may be captured, recycled and enhanced by incorporating fast growing trees. If these trees are planted as hedges along contours, they would also aid in soil conservation leading to higher soil productivity. In connection to this the following specific hypotheses were formulated and pursued.

i. *Calliandra* and *Leucaena* tree species are more effective in capturing, recycling and enhancing soil nitrogen than napier grass.

ii. There are no differences between *Calliandra*, *Leucaena* and napier plant species in reducing soil erosion when planted along the slope contours.

iii. Farmers' perceptions are directly linked to adoption of introduced technologies.

1.6 Justification and significance of the study

Smallholder farms in most parts of the country are experiencing declining food production as a result of continuous cropping, crop harvests and losses of nutrients due to soil erosion and leaching. The role of agroforestry in conservation and maintenance of soil fertility has been recognized as an important option for sustainable agriculture. Huge amounts of NO_3^- leached from the crop root zones in the range of 30 kg to 500 kg N ha^{-1} yr^{-1} have been reported in the low and high input agricultural systems of tropics (Wild and Cameron, 1980; Van der Krujis et al., 1988; Hartemink et al., 1996; Mugendi et al., 2003). These huge losses in addition to posing a health hazard to humans and animals due to water pollution also make farmers incur

heavy investment losses due to costs of nutrients from the little fertilizer and manure applied on the croplands. This being the case, this study was set to evaluate the effectiveness of various biological contour hedges in controlling soil loss and nutrient leaching and hence reduce the associated costs.

1.7 Limitations of the study

Data collection was carried out for only two seasons, which may not be necessarily representative of the overall rainfall distribution, crop yield, soil loss and nutrient cycling status of the used species. The research findings could therefore have been influenced by the short period of study.

Erosional pegs are also known to yield variable data. The variability was reduced by use of many farms (33) with enough replications to increase the study population and hence limit the coefficient of variation. Well-calibrated erosional pegs were however very important in enhancing visibility of soil loss to farmers and hence enhancing their perception and the need to want to take action against it.

CHAPTER TWO

LITERATURE REVIEW

2.1 The role of trees in soil improvement and management

Trees (especially leguminous) can potentially improve soils through numerous processes including, maintenance and increase of soil organic matter, biological nitrogen fixation, uptake of nutrients that are beyond reach of annual crop roots, increased water infiltration and storage, reduced loss of nutrients through erosion and leaching, reduced soil acidity and improved soil biological activities (Young, 1997). Most of these roles can be attributed to deep rooting nature of the trees and their ability to form a symbiotic relationship with nitrogen fixing bacteria which converts atmospheric nitrogen into forms that can be used by plants.

2.1.1 Biological nitrogen fixation by trees

Biological nitrogen fixation involves conversion of atmospheric forms of nitrogen into the form that can be utilized by plants. It can be represented by the following equation in which two moles of ammonia are produced from one mole of nitrogen gas at the expense of 16 moles of adenosine triphosphate (ATP) and supply of electrons and protons (hydrogen ions).

$$N_2 + 8H^+ + 8e^- + 16\ ATP = 2\ NH_3 + H_2 + 16\ ADP + 16\ Pi$$

Biological nitrogen fixation takes place through symbiotic and non-symbiotic means. Symbiotic fixation occurs through the association of plant roots with nitrogen fixing bacteria. Many legumes are associated with rhizobium, whilst a few

non-leguminous species are associated with frankia. These symbioses occur in association with soil fungi, which infect roots to form mycorrhizae. According to Young (1988), there is not enough data but it is at least a plausible hypothesis that trees and shrubs can be identified which, when grown in agroforestry systems are capable of fixing nitrogen to the order of 50-100 kg N ha^{-1} yr^{-1}.

2.1.2 Deep capture of nutrients by tree

Trees with deep roots can potentially intercept nutrients leaching down the soil profiles and 'capture' those accumulated below rooting depth of annual crops (Van Noordwijk et al., 1996). Nutrients taken up by trees from below the rooting depth of annual crops become an input when transferred to surface soil in the form of leaf litter, roots and prunings of tree leaves and branches (Schroth, 1995). The lateral extension of tree roots can be considerable particularly in semi-arid areas. The lateral capture and uptake of nutrients from within the rooting zone of crops, however, represents a re-distribution of nutrients within the soil plant system rather than input. Buresh et al. (1995) from a review of literature concluded that the potential of trees to retrieve sub-soil nutrients is generally greatest when (i) trees have deep rooting systems and high demand for nutrients, (ii) water and /or nutrient stress occurs in the surface soil and (iii) considerable reserves of plant available nutrients or weatherable minerals occur in the sub-soil.

In western Kenya, researchers have noted the accumulation of fairly large quantities of nitrate (70-315 kg N ha^{-1}) in acid soils at 50-200 cm depth under unfertilized maize and have attributed this to the formation of nitrate by mineralization of SOM

and the sorption and retention of nitrates by clay minerals (Mekonnen et al., 1997). Fast growing trees such as *Calliandra calothyrsus*, *Sesbania sesban*, *Leucaena leucocephala* and *Eucalyptus grandis* grown in rotation with maize rapidly root into these nitrate-accumulation zones and take up the sorbed nitrate that is inaccessible to maize (Hartemink et al., 1996; Jama et al., 1998; Hartemink et al., 2000; Shepherd et al., 2000). Kindu et al. (1997) reported an increment of total nitrate-N in the maize land use system by 44 kg N ha^{-1} and a reduction of the same by up to 64 kg N ha^{-1} in the *Sesbania* fallow. Jama et al. (1998) further reported that the reduction in soil nitrate in the top 2 m (150 to 200 kg N ha^{-1}) corresponded to large accumulation of N in above-ground biomass for *Sesbania sesban* (336 kg N ha^{-1}) and *Calliandra calothyrsus* (312 kg N ha^{-1}). In areas where the soil is rich in nutrients in the sub-soil and with no chemical and physical barrier to root penetration, nutrient pumping by roots is greater. In acid soils however, nutrient pumping can be affected by chemical barriers to root penetration, such as high aluminium saturation, low level of phosphorus and exchangeable bases and weatherable minerals in the sub-soil (Szott and Palm, 1991). The selection of trees and shrubs that can be adapted to various soil and climatic factors is important for effective nutrient capture and pumping up.

The potential for nutrient uptake from deeper soils is much greater for water-soluble nutrients such as nitrate than for immobile nutrients such as phosphorus (P). Simulations using the water, nutrient and light capture in agroforestry systems (WaNuLCAS) model suggest that tree root length densities in the soil layer beneath

the main crop rooting zone must be substantial if safety net uptake is to occur; recycling efficiencies greater than 50% require a root length density in this 'safety-net zone' of >0.5 cm cm^3 (Cadisch et al., 1997). The role of trees in nutrient uptake from deeper soil layers for nutrients other than N and P is however, generally little studied.

According to Nair (1984), natural forest ecosystems represent a closed and efficient nutrient cycling systems meaning that they have high rates of turnover, and low rates of outputs or losses from the system; hence they are self sustaining. On the other hand, common agricultural (food production) systems are more "leaky" meaning that the nutrient turnover within the system is relatively low and losses (as well as inputs) are comparatively high. Nutrient cycling in agroforestry system falls within these two extremes; more nutrients in the natural forest system are re-used by plants compared to agricultural systems before being lost. The major difference between agroforestry and other land use systems lies in the transfer or turnover of nutrients within the system from one component to another and the possibility of managing the system to obtain a more closed cycling in forest system or its components to facilitate increased rates of turnover without affecting the overall productivity of the system.

Results of long-term alley cropping trial with *Leucaena* hedges on a degraded alfisol in Nigeria showed that despite the general decline in soil fertility status of the soil with continuous cropping, the plots that were alley cropped following five year of intensive cropping showed higher nutrient status than the control (no tree) plot.

Other research results from the International Institute of Tropical Agriculture (IITA) also provide evidence on the role of woody hedgerows in nutrient cycling in alley cropping system. Based on measurement of nutrient levels in soil solution in alley cropped plot, Hauser and Kang (1993) reported that: (i) under hedgerows, the nutrient level in the surface soil was higher than at lower depths, and (ii) in the alleys between the hedgerows with food cropping, the soil surface showed lower nutrient levels than in the sub-soil due to nutrient uptake by shallow rooting food crops.

2.1.3 Reduced leaching

Changes from perennial land use to annual systems generally leads to lower plant N demand and poorer synchrony between plant demand and N mineralization supply, resulting in increased N leaching losses (Van Noordwijk, 1989). Studies in central highlands of Kenya have indicated a substantial NO_3^- build up in the soil early in the season with N supply (mineralization) exceeding maize-crop demand during the first six weeks of each cropping season (Mugendi et al., 1999). Such available N in the soils is subject to losses through leaching, volatilization and denitrification. Nitrate leaching accelerates the downward loss of Ca and Mg, which leads to soil acidification (Cahn et al., 1993).

Plants with active and effective roots reduce losses of leachable nutrients (Van Noordwijk et al., 1996). Van Noordwijk (1989) modelled the rooting depth required to intercept leaching nutrients for different climatic and soil conditions. He concluded that deep root systems in agroforestry systems may be sufficient to

recover all the N that is leached during cropping phases in sub-humid tropics though the high rate of N movement in the humid tropics require a continuous presence of deep root system as part of crop combination on the field for efficient N use. Lesile and Charles (1983) monitored the movement of nitrate (applied at 250 kg N ha^{-1}) under maize and fallow conditions analyzing soil solution samples taken at 48 to 72 hour intervals for 120 days from the 20, 40, 60, 80, 100 and 140 cm depths. They observed leaching of nitrate with percolating water beyond 100 cm depth under maize, and the capture of nitrate by deep fallow roots before it reached 80 cm depth within 65 days. Imbach (1989) measured nutrient concentrations in soil water at 1 m depth from systems of cacao (*Theobroma cacao*) grown below the shade of either *Cordia alliodora* or *Erythrina peoppigiana* and found in both systems low annual leaching losses of N (5 kg ha^{-1}), P (0.5 kg ha^{-1}) and K (1.3 kg ha^{-1}). In Western Kenya, Mekonnen et al. (1997) measured NO_3^--N concentrations to 4 m depth and found 199 kg NO_3^--N ha^{-1} under maize, 42 kg NO_3^--N ha^{-1} under natural fallow and 51 kg NO_3^--N ha^{-1} under *Sesbania* fallow. On the other hand, Jama et al. (1998) found that 11 months old *Calliandra* and *Sesbania* fallows could reduce leaching N in the top 2 m by 150 to 200 kg N ha^{-1}. In central highlands of Kenya, Mugendi et al. (2003) recorded lower N in the 200-300 cm depth on treatments that had *Calliandra* and *Leucaena* hedges in comparison to the control and concluded that trees were capable of reducing nutrient losses through leaching.

2.2 Role of agroforestry in soil erosion control

Soil erosion is regarded as one of the forms of soil degradation, which involve deterioration of physical, chemical and biological properties of soil all of which require attention (FAO, 1978,1979). Accelerated erosion by water is one of the most critical problems of agriculture in central highlands of Kenya (Angima, 2000).

Investigations elsewhere in the world show that erosion is highly related to the slope angle and it causes considerable deterioration of soil fertility and crop yields (Stocking, 1984). Young (1988) found that on relatively gentle slopes of up to about 14%, the barriers could be effective in controlling soil erosion. On steep slopes, barriers have to be closely spaced if they are to reduce soil erosion to torelable levels. When trees are well arranged along the contours with close spacing, they form an effective barrier to soil erosion. In addition to this, over time a natural terrace would be formed up slope the barrier further reducing soil erosion rates (Angima, 2000). *Calliandra calothyrsus* and *Leucaena tricandra* can be used in barrier erosion control. Agronomically, *Calliandra* and *Leucaena* are good colonizers of denuded areas tolerating soils that are heavily compacted and poorly aerated, and can persist in poorly drained soils. Through erosion control and addition of high N green manure or leaf litter *Calliandra* and *Leucaena* can improve soil quality and hence yields of associated crops (Goudreddy, 1992).

The U.S. Soil Conservation Service sets limits of tolerable erosion in the range of 2.2 to 11.2 Mg $ha^{-1}yr^{-1}$ (lower figures for shallow soils over hard rock and higher

figure for deep soils). These limits are based on two notions: (i) erosion is acceptable up to the rate at which soil is renewed by natural processes and (ii) these rates are assumed to be predictable under common farming conditions. However, Young (1988) argues that the capacity of agroforestry practices to supply organic matter and recycle nutrients needs to be integrated with losses through erosion, in order to determine whether a system is viable or not.

All other factors held constant, soil erosion hazard from steep lands can be drastically reduced by use of agroforestry systems. Usefulness of agroforestry systems in erosion control and in stabilizing steep lands has been demonstrated in Kenya (Raintree and Torres, 1986) and Nigeria (Lal et al., 1995) where it has been shown that properly arranged and maintained *Leucaena* hedgerows can effectively reduce runoff and control soil erosion in manual and motorized systems of soil and crop management. According to Lal (1990) agroforestry systems decrease runoff and soil erosion by one or all of the following mechanisms:

1. Reducing runoff amount by creating a barrier formed by a closely spaced hedge of shrubs,

2. Decreasing runoff amount by allowing more time for water to infiltrate into the soil,

3. Minimizing rain-drop impact and sheet erosion due to protective ground cover provided by shrub canopy and mulch available from leaf-fall and prunings

Establishment of contour hedgerows in Nigeria led to formation of natural terraces due to the entrapment of washed off soil behind the hedges (Lal, 1989). Development of natural terraces however is indicative of both strength and

weakness of the system. According to Lal et al. (1995), trapping sediments is indicative of the conservation effectiveness of contour hedgerows. On the other hand the fact that sediments originated and moved (prior to being trapped) is indicative of vulnerability of the ecosystem as a whole to forces and agents of erosion.

2.3 Effects of tree prunings on crop yields

When leguminous prunings are incorporated into the soil, they improve the soil fertility upon decomposition, which translates into improved crop production. Apart from improving the soil nutrient status the prunings may also increase the organic matter content of the soil (Yemoah et al., 1986). This in turn improves the physical properties of the soil, creating favorable conditions for plant growth. In alley cropping of nine leguminous trees with maize in Hawaii, Rosecrane et al. (1992) reported an increase in maize yields with addition of tree pruning mulches. For every kilogram of nitrogen applied in form of mulch, approximately 12 kg of maize grain yield was produced. This shows that addition of prunings from leguminous plants into farmlands can play an important role in improvement of the soil and hence enhancing its productivity.

2.3 Role of Calliandra and Leucaena in animal diet

Identification of multi-purpose tree and shrubs with potential for maintaining soil fertility and providing high quality fodder for livestock is a major focus of agroforestry research. Napier grass is suitable for providing the basic ration, while

trees and shrubs have a significant potential as high protein supplements to conventional animal feeds (Kibet, 1994). The quality of animal feed is highly related to its digestibility (Nyaata, 1998). The digestibility of plant material in the rumen is determined by lignification of plant cell walls (Neutral detergent fiber-NDF). Tree forages are generally low in NDF content (23-55%) and degrade fairly well and rapidly in the rumen, supplying carbohydrates and fermentable nitrogen. Tree legume fodders also undergo post rumenal digestion, often at higher rate than tropical grasses improving the intake and digestibility of the latter (Smith, 1992). Reviews made by a number of authors (Devendra, 1990; Norton, 1994; Palmer and Ibrahim, 1996) indicate consistent increases in live weight gain and milk production by cattle, sheep and goats supplemented with tree legume fodder. Bamualim et al. (1984) reported that *Leucaena* supplements at a rate of 0.6% live-weight (16%) in dry matter was effective in converting sheep and cattle weight loss to significant weight gain. In Indonesia, Yates and Panggabean (1985) supplemented thirty goats feeding on napier with various levels of *Leucaena* and commercial concentrate. Animals on 100% napier grass lost weight at the rate of 19 g day^{-1}. As the intake of concentrate and *Leucaena* increased there were positive responses in live weight gain. Maximum live-weight gains were 76 and 43 g day^{-1} for concentrate and *Leucaena* respectively at ad libitum intakes. In one of the examples cited by Devendra (1990), supplementation of *Chloris gayana* hay with 200 to 300 g of dried *Leucaena* leaves given to goats in Tanzania significantly increased organic matter intake, crude protein intake and daily growth rate compared with the control group. In this study *Leucaena* supplementation increased total dry matter intake

from 42.3 kg $W^{0.75}$ in the control group to 77.9 kg $W^{0.75}$ in hay with *Leucaena* fed ad libitum. Palmer et al. (1994) in review of *Calliandra calothyrsus,* concluded that this species is potentially a very valuable forage species despite some few reports of low palatability. They noted that both large and small ruminants readily eat *Calliandra*. Work by Palmer and Schlink (1992) has shown that *Calliandra* forage value is high when fed fresh but the intake and digestibility of wilted or dried material is markedly depressed. In a feeding trial with sheep using several rates of inclusions of fresh *Calliandra* to basal diets of buffel grass (*Cenchrus ciliaris)* hay, Ibrahim (1994) showed increasing wool production with increasing levels of *Calliandra* intake. He noted that with inclusion of 35% fresh *Calliandra* into the diet, wool production increased to 106 from 53 mg/100 cm^2/day on sheep fed on hay supplemented with 16% fresh *Calliandra*.

In central highlands of Kenya, Paterson et al. (1996) noted that 3 kg of *Calliandra* was able to achieve the same amount of milk yield from a cow as 1 kg of concentrate. The butterfat content of the milk however, increased from 4.0 to 4.5% after addition of *Calliandra* into the animal diet. From these results Paterson et al. (1996) observed that for milk yields, *Calliandra* performed as though it was interchangeable with commercial dairy meal. The consistent improvement in butterfat content however implied that *Calliandra* fodder was superior to concentrate in terms of milk quality. The same study demonstrated the potential of *Calliandra* and *Leucaena* as supplement for both heifers and lactating cows. Five dairy heifers with an average age of 9 months achieved an acceptable average

liveweight gain of 29.4 kg over 105 days in which they fed on fresh napier grass supplemented with either fodder from *Calliandra calothyrsus, Leucaena tricandra, Manhot glasiovii, Morus alb*a tree species and commercial concentrate (16% crude protein).

2.5 Farmers' perceptions and adoption

The role of agroforestry in reducing soil erosion losses has widely been recognized in the scientific literature (Scroth et al., 1995; Breman and Kessler, 1997). Studies have also shown that agroforestry practices can improve food production simultaneously with soil erosion control (Sanchez et al., 1997). However, like any other agricultural technology, the adoption of agroforestry technologies by farmers depend to a large extent on perception of the potential benefits accruing to them (Avilla, 1990).

Farmers' perceptions of soil erosion and their subsequent conservation behavior have however sometimes shown mixed results in different parts of the world. Some studies have shown no substantial relationship between soil erosion perception and farmers conservation behavior while others have shown a strong direct link between the two. For instance, the perception of erosion was found to be important to adoption behavior of soil and water conservation structures in Philippines (Cramb, et al., 1999) and at Andit Tid, Ethiopia (Bekele, 1998). Bekele particularly showed that farmers' decision to retain soil and water conservation structures was positively and significantly related to soil erosion perceptions, attitude towards new technology and exposure to new practices. Such was not the case in Tanzania where farmers' perception of soil erosion

problems failed to explain household behavior towards adoption of improved soil and water conservation practices (Napier and Sommers, 1993). Further non-perception of soil erosion problem did not always translate to households being un-willing and/or un-able to use improved soil conservation measures.

Scientists perceive soil erosion as a three step process involving: detachment of soil particles by wind and water from the surface, the transportation of the particles, and deposition of these particles at another site (Sfeir-Younis and Dragun, 1993). On the other hand farmers see movement of soil from one place to another as a result of deposition, and could see small rills and observe development of gullies by water erosion but the exact extent of soil erosion and associated losses are not clear to them and therefore they may not be induced to reverse it (Brouwers, 1993). Furthermore, unlike outsiders whose perceptions are often controlled by a single objective when promoting a technology, farmers are faced with multiple objectives in pursuit of their livelihood. In adoption of any one technology farmers therefore make a compromise with their multiple objectives, resources, level of problem, urgency of household need and profitability among others. Therefore the best soil conservation practice from the farmers' point of view is not necessarily the one that conserves most soil (Kerri and Sanghi, 1993). They may understand that the extent of the problem can be reduced but the alternatives they are aware of to address the problem may be too costly relative to the perceived benefits. In view of this, farmers often favor soil conservation technologies that will give them quick, tangible, and multiple benefits while minimizing soil erosion and cost.

A farmer's decision-making process could be enhanced or impeded by the intrinsic characteristics of the technology such as observability, complexity and divisibility/triability, and from its extrinsic characteristics such as compactability and relative advantage to household domain (Rogers, 1983). When the benefits of a technological option are easily observable, a farmer can easily form an idea and proceed to evaluate the option. Observability of the results of an option helps the farmer to easily compare it with previous experiences or the problem at hand. When the option is perceived as complex, it is likely that farmers' risk perception increases, while their motivation declines, therefore negatively affecting the cognition process and thereby their attitude. Similar to lower observability, complexity also hinders farmer's reflection on the compatibility and relative advantage of the option at hand (Tasfaye, 2003).

Essentially, the characteristics of a technology affect soil conservation decisions. Farmers do not accept a practice that merely reduces soil erosion rates purely from an agronomic point of view unless they also address the soil fertility problem. This often brings a choice between the physical measures that are known to reduce soil erosion rates and the biological measures that have a quick response to soil fertility objectives, while also controlling soil erosion. However, this does not mean that farmers do not refrain from adopting biological conservation technologies as these too have their own disadvantages depending on who has tried to adopt them (Hudson, 1993; Tasfaye, 2003).

2.6 Gaps in literature

Despite availability of all the above literature, the effectiveness of different species in either sole or combination hedge arrangement in both soil and nutrient management has not been fully documented. The determinants of farmers' decision to adopt/not adopt and their adaptations of these technologies are not clear. This study therefore aimed at filling some of these gaps by investigating the effectiveness of *Calliandra*, *Leucaena* and napier as either sole or combination hedges in both soil conservation and nutrient cycling. It also evaluated the rate of adoption and the determinants of farmers' decision to adopt/not adopt, hand in hand with farmers manipulation of these technologies to fit their own situations (technology adaptation).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Study area description

The study was conducted in Kirege Sub-location, Mugwe Location, Chuka Division, in Meru south District. This is a predominantly maize growing zone in the central highlands of Kenya. According to agro-ecological conditions (based on temperature and moisture supply), this area is in the upper midland zones (UM2-UM3) (Jaetzold and Schemidt, 1983). It lies on the slopes of Mt Kenya at an altitude of approximately 1500 m above the sea level with an annual mean temperature of 20° C. It experiences bimodal rainfall, which ranges from 1200 to 1400 mm annually. The long rains (LR) are from March to June, and the short rains (SR) are from October to December. The predominant soil types are Humic Nitisols, commonly called the red Kikuyu loams. They are deep, well weathered, free draining with a friable clay texture and moderate to high inherent fertility.

The farming systems of this area have a complex integration of both crops and livestock. A wide variety of species and breeds of livestock as well as crop species are found within individual farm holdings. Coffee (*Coffea arabica*) and tea (*Camelia sinensis*) are the major cash crops grown in the area. Maize (*Zea mays*) and beans (*Phaseolus vulgaris*) are the main food crops grown by farmers. Other food crops include potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomea batata*), bananas (*Musa* spp), cassava (*Manihot esculanta)* and various fruits and vegetables. All land is

currently demarcated and owned individually under freehold system of land tenure. The average farm size is about 1.5 ha per household with the majority of farmers owning between 0.4 ha and 3 ha. The area is highly populated with a population density of about 700 persons per km^2 (Republic of Kenya, 2001) and there is therefore potentially high-pressure on land with intense competition between various enterprises.

Table 1: Physical and chemical properties of soil in farmers fields of Kirege Location prior to establishment of trials.

Soil properties	Mean	Min	Max	SEM
pH (1:2.5 Soil:H_2O)	4.9	4.3	6.0	0.08
Total Organic Carbon (g kg^{-1})	18.0	15	23	0.30
Total Nitrogen (g kg^{-1})	2.0	1	0.3	0.13
Total Organic P (g kg^{-1})	1.0	0.0	0.1	0.14
Exchangeable Acidity ($cmol_c$ kg^{-1})	1.1	0.2	3.8	0.17
Exchangeable Ca ($cmol_c$ kg^{-1})	4.6	1.5	7.0	0.33
Exchangeable Mg ($cmol_c$ kg^{-1})	1.7	0.6	2.7	0.12
Exchangeable P ($cmol_c$ kg^{-1})	6.7	1.3	15.9	0.71
Exchangeable K ($cmol_c$ kg^{-1})	0.4	0.1	0.8	0.03
Sand (g kg^{-1})	332.0	270.0	364.0	0.88
Silt (g kg^{-1})	281.0	171.0	290.0	0.53
Clay (g kg^{-1})	394.0	362.0	439.0	0.64

Min = minimum value; Max = maximum value and SEM = standard error of the mean

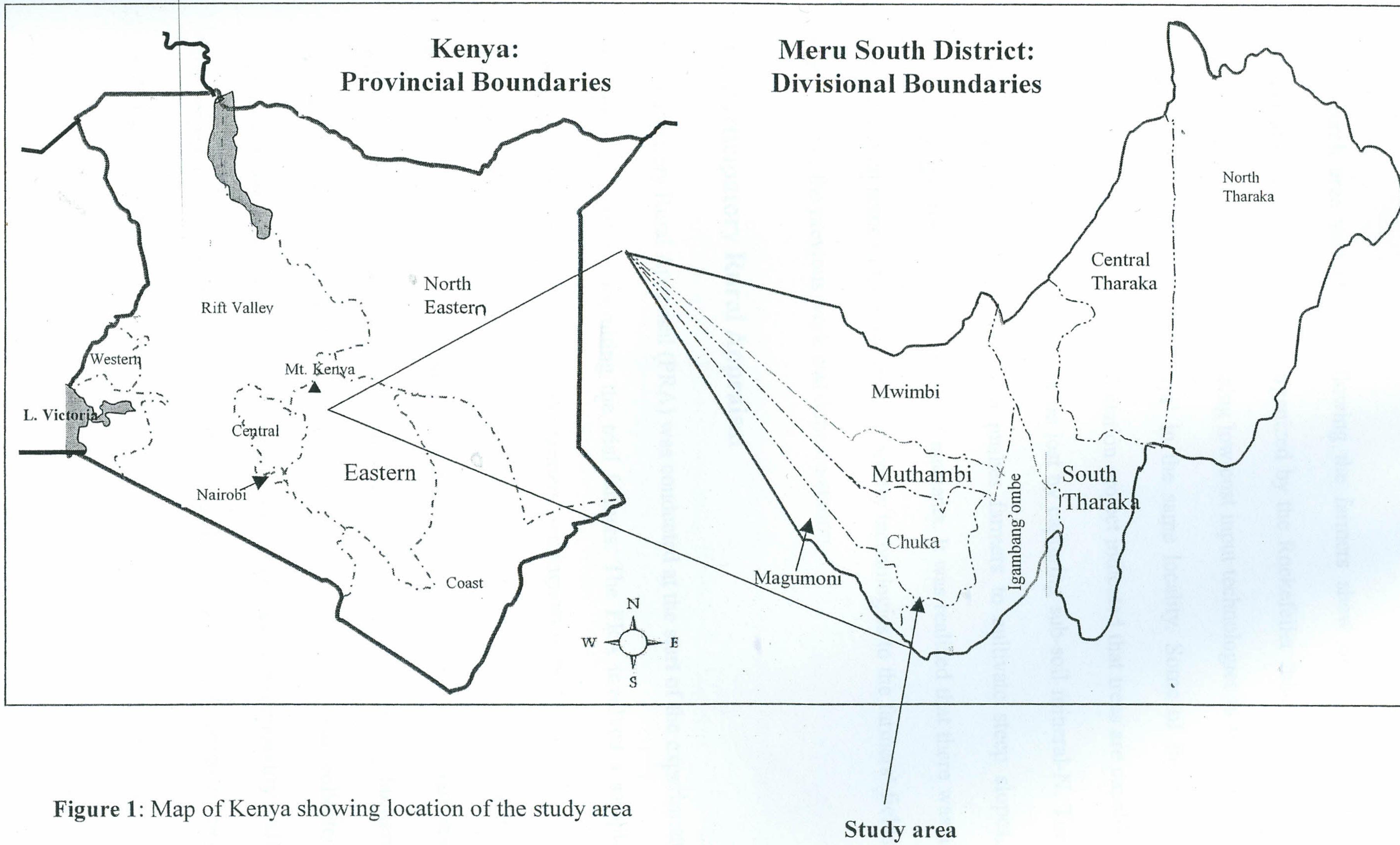


Figure 1: Map of Kenya showing location of the study area

The research area was chosen following the farmers show of interest through constant attendance of field days organized by the Rockefeller funded project on 'enhancement of soil productivity using low-cost input technologies in smallholder farms in central highlands of Kenya' in the same locality. Some of the major findings that emanated from this off-station project indicated that trees are capable of recycling N that would otherwise be lost by capturing sub-soil mineral-N. The high population density of this area pushes farmers to cultivate steep slopes, leading to high erosion rates and loss of nutrients. It was realized that there was a need to extend some of the relevant agroforestry technologies to the farmers' fields since most of the previous work was done on-station.

3.2 Participatory Rural Appraisal

A Participatory Rural Appraisal (PRA) was conducted at the start of the experiment in September 2001 for recruiting the trial farmers. The PRA involved a sample population of 60 farmers. Based on the farmers' willingness to participate, slope of their farms, farm distribution within the area and gender (efforts made to balance gender), a total of 33 farmers were recruited. During this exercise data on farmers' willingness to participate in the trial, characteristics of species preferred by farmers, the actual species and the relative weight of each preference was collected. *Calliandra* and *Leucaena* tree nursery groups were established in the locality under the project facilitation from where both trial and non-trial and non-trial farmers would get seedlings as they required.

3.3 Experimental design and management

The experiment was established immediately after the PRA. Slopes and contours of participating farmers' fields were determined by use of a clinometer and surveyors level respectively and treatments allocated along the contours on gradients ranging from 5-35% slopes in a randomized complete block design (RCBD) with blocks parallel to slopes. Care was taken to ensure that none of the plots fell on obvious convex zones of higher than average net erosion, or deposition zones of net sedimentation. The plots were also trenched on the upper lateral borders to prevent erosion of sediments from other areas into it. This was meant to ensure that the deposited and collected sediments were from a known area enabling the rate to be compared with other published studies. Recruited farmers were then provided with seedlings and trained on how to plant them along a marked contour in a zig-zag manner at an inter and intra-row spacing of 0.25 and 0.5 m respectively. The plots were 10 m long with variable inter-hedge spacing (vertical interval) determined by use of guidelines demonstrated by Young (1997) p.73 i.e. $W = 200/S\%$ where W = inter-hedge spacing in metres and $S\%$ is the per cent slope.

The experiment was composed of 6 treatments, namely:

1. *Calliandra calothyrsus* tree hedges
2. *Leucaena tricandra* tree hedges
3. Napier grass (*Pennisetum purporeum*) hedges
4. *Calliandra calothyrsus* tree hedges + napier grass (*Pennisetum purporeum*) hedges
5. *Leucaena tricandra* tree hedges + napier grass (*Pennisetum purporeum*) hedges
6. Control (no soil conservation structures)

For the purpose of statistical analysis, care was taken to ensure that all the treatments were sufficiently replicated in the 33 farms. The tree and grass hedges were pruned after establishment at the height of 50 and 10 cm respectively to ensure that they didn't pose any significant above-ground competition to crops. The resulting biomass was weighed and incorporated into the plots served by appropriate hedges.

3.4 Biophysical methods

3.4.1 Climatological data

Rainfall was measured by use of rain gauges established in the then on going off farm Rockefeller Forum project entitled *'enhancement of soil productivity by use of low-cost input technologies in the smallholder farms of central highlands of Kenya'.* located in Kirege location.

3.4.2 Soil loss estimation

Levels of soil loss were estimated based on changes in topsoil depth, which was determined by use of ten plastic erosional pins (FAO, 1993) fixed at a spacing of 4 x 4 m from one another on plots served by the hedges. Use of erosional pins is a widely accepted method of soil erosion estimation involving driving calibrated pins into the soil so that the top of the pin gives datum from which changes in soil surface level can be measured. Erosional pins are particularly important because farmers are able to see and visualize the actual changes in soil depth. It is however evident that farmers interfere with such erosion pins as they tend their farms. To reduce this, farmers were

educated and involved in all the stages of project planning and implementation. The pegs were read immediately after installation (at establishment of contour hedges) and then once after every month during rainy seasons. The measurements were taken to the nearest millimeter, which allowed any seasonal changes in topsoil level to be clearly recognized. The resulting soil loss measurements were converted to t ha^{-1} by first calculating the volume of topsoil washed per plot by use of the formula:

V plot = (depth of soil washed) x (length of plot) x (Width of alley)

The resulting volume was then multiplied by bulk density to get the mass of soil lost which was then converted to tons per hectare. The whole calculation was carried out as shown in appendix 2. The erosional results presented in this work are meant to show the extent of soil loss on different land gradients with and without vegetative contour hedges in an appropriate arrangement.

3.4.3 Crop yield assessment

Yield assessment was done on sub-plots of 5 x 5 m. Maize was harvested by cutting at the root collar. It was weighed immediately to determine the total fresh weight (stovers + unshelled cobs). The unshelled cobs were then separated from the stover. The total fresh weight of the stover was then determined and a sub-sample taken for dry weight determination. To obtain grain yields, grains were separated from the core by hand shelling; weighed, and a sub-sample taken for dry weight determination. Similarly, empty cobs (without grains) were weighed and a sub-sample taken for dry weight determination. The above sub-samples (cobs, stover and grain) were oven dried at 60 ^{0}C for three days to a constant weight. For correlation purposes, fifteen farms were

sub-sampled from the 33 trial farms and their control plots (no hedge) on 10-20% slope used to establish the relationship between topsoil loss and maize crop growth parameters. Control plots were used because it is on these plots where there was no treatment interference while 10-20% slope was used because it was the most common slope in the study area and the soils on it were similar. These farms were sub-sampled on the basis of farmers adherence to proper and almost uniform agronomic aspects such as planting time, weeding, plant population and planting the same seed variety i.e. H513. The crop parameters measured for correlation with topsoil loss were: grain yields, crop height, stover weight and total above ground biomass (grains + empty cobs + stover). Crop height was measured at maize tassling stage. The proportion of dry matter was calculated by use of the formula:

Yield (t/ha) = [10 x TFW x SSDW]/ (HA x SSFW)

Where 10 is a constant for conversion of yields in kg/m^2 to t/ha; TFW is total fresh weight (kg); SSDW is sub-sample dry weight (g); HA is harvest area (m^2) and SSFW is sub-sample fresh weight (g).

3.4.4 Soil sampling

Initial soil characterization was done before commencing the trials on each particular farm. At least six samplings were randomly done by use of soil augers in each plot (for baseline data) and also for the specified depths (for mineral-N determination). The six samples were then mixed to form one composite sample for a particular plot or depth. The sampling depths for mineral-N assessment were 0-30, 30-90, 90-150 cm; the first sampling depth was meant to capture the dynamics

of the top plough layer, whereas the second captured the maximum rooting depth of maize, and the last sampling depth captured the influence of tree roots on the deep soil layers.

3.4.5 Bulk density

The bulk density of experimental farms was determined by use of un disturbed core samples (Anderson and Ingram, 1993). A sharp-edged steel ring was driven into the soil to a depth of 15 cm and then carefully removed so as not to disturb the soil. The ring was then cut free and the two ends trimmed flat with a sharp straight edged knife. The ring plus the soil was then dried at 105^{0}C for 48 hours. The sample + ring were later cooled and weighed. The bulk density was then calculated as follows

$$D = (M_1 - M_c) / V$$

Where: **D** = Bulk density (g cm^{-3})
M$_1$ = Mass of core sampler and oven dry soil (g)
M$_c$ = Mass of the core sampler (g)
V = Volume of soil sample (cm^3)

3.4.6 Particle size analysis

The hydrometer method was used in this analysis (Gee and Bauder, 1986). An air-dry sample weighing 50 g was put in a 400 mL beaker and 125 mL of distilled water added. The organic matter was destroyed by use of 5 mL 30% hydrogen peroxide. Ten mL of 10% sodium hexametaphosphate solution was added to aid dispersion of soil particles. The sample was mixed with a high-speed mixer for 2 minutes and the suspension transferred quantitatively into 1000 mL measuring cylinder. The cylinder was then filled with water to the 1000 mL mark. The contents were then mixed thoroughly using a

circular plunger attached to a wooden rod. Two to three drops of amyl alcohol were added to the cylinder to minimize foaming, and hydrometer readings taken at 40 seconds and 2 hours from the time mixing stopped. The 2 hours reading was used for calculating percent clay while the 40 seconds reading was used in calculation of percentage sand. Percentage silt was obtained by subtracting the sum of percentage sand and clay from 100%.

3.5 Analytical methods

3.5.1 pH determination

A sample of 10 g of soil was put in a 60 mL plastic bottle and 25 mL of distilled water or 0.01M $CaCl_2$ added to give a soil water ratio of 1:2.5. The mixture was stirred for 10 minutes, left to stand for 20 minutes and finally stirred again for 2 minutes. Measurements of pH were done by use of pH metre with a combination electrode. Buffer solutions of pH 4 and 7 were used to calibrate the meter before measurements were taken (ICRAF, 1995).

3.5.2 Extraction of soil nitrate and ammonium

Soil was stored in a refrigerator (about 4^0C) between collection and extraction. Twenty grams of field moist soil was extracted using 5 mL of 2N KCl within 3 days after collection (ICRAF 1995). This was followed by gravimetric filtration through a pre-washed Whatman No.5 filter paper. The filtered extract was kept in a refrigerator awaiting ammonium and nitrate determination.

3.5.3 Ammonium determination

This was done using the salicylate-hypochlorite colorimetric method (Anderson and Ingram, 1993). This method makes use of two reagents, which are namely: Reagent N1 and reagent N2. Reagent N1 was prepared by dissolving 68 g sodium salicylate, 50 g sodium citrate, and 50 g sodium tartrate in 1500 mL of deionised water and then adding 0.24 g sodium nitroprusside. After full dissolution the solution was made up to 2 litres by topping with deionised water. On the other hand reagent N2 was prepared by dissolving 60 g of sodium hydroxide in 1500 mL deionised water and left to cool. 12.5 mL of sodium hypochlorite solution was then added and the solution made up to 2 litres with deionised water followed by proper mixing. Five (5.0) mL of reagent N1 was added to 2.0 mL of each standard and sample. The solution was mixed thoroughly by use of vortex mixer and left for 15 minutes after which 5.0 mL of reagent N2 was added and mixed again and then left for one hour for full colour development. The absorbance of samples, blanks and standards was then read at 655nm using a spectrophotometer.

3.5.4 Extractable soil nitrate

One (1) mL concentrated ammonium chloride was added into the Cd column and 3mL of sample pipetted into column and the solution was then drained (into a test tube containing 5 mL sulphanilic acid reagent) almost to top of the granules, leaving 2mm of solution on top. Forty- five (45) mL of dilute ammonium chloride solution was added to the reservoir and drained within 25-30 seconds leaving approximately 2 mm of solution on top of the column. The test-tube was then removed and stoppered, shaken well and let to stand for five minutes after which 5 mL of 5-amino-2-naphthalene sulphanilic acid (5-2 ANSA)

solution was added, stoppered well and shaken. The solution was let to stand for 30 minutes and then absorbance read using spectrophotometer at 525 nm. No effort was made to separate NO_3^- and NO_2^- because NO_2^- was assumed to be small relative to NO_3^-, the values were reported as NO_3^-.

3.5.5 Total soil N and P determination

About 0.4 g of dry soil sample ground to pass through 0.3 mm mesh was weighed into labelled digestion tubes and 1.8 g K_2SO_4 added. To this was added 7.5 mL of soil digestion mixture (selenium powder, concentrated sulphuric acid and salicylic acid) and left to stand overnight. The contents were heated at 100 ^{0}C for 2 hours, after which 3 mL of H_2O_2 was added. The test tubes were heated for another 4 hours at 360 ^{0}C and then left to cool, after which they were thoroughly mixed. The tubes were stoppered and let to stand so that a clear solution could be taken for analysis. 0.2 mL of sample or standard taken for analysis had N1 and N2 reagents added as in the ammonium determination method. The samples were read on the atomic adsorption spectrophotometer at 655 nm (Skalar, 1993).

3.5.6 Total organic carbon in soils

Organic carbon was determined by wet oxidation with heated acidified dichromate followed by colorimetric determination of Cr^{3+} (Anderson and Ingram, 1993). About 1.0 g of soil samples, ground to pass 0.3 mm mesh was weighed into labelled digestion tubes and 2 mL deionised water added. Ten mL of 5% $K_2Cr_2O_7$ solution was added into both standard and sample tubes. After this 5 mL concentrated H_2SO_4 was slowly added from an Eppendorf pipette. The acid was added 1 mL at a time while swirling on a vortex mixer. Then, the soils were digested at 150^{0}C for 30 minutes and then allowed to cool. After

cooling, 50 mL 0.4% barium chloride solution was added and mixed thoroughly. The solution was allowed to stand overnight, so as to leave a clear supernatant solution. The following day concentration of each standard and sample was read at 600 nm on the spectrophotometer. This was done after determining absorbance values for the standards so as to check on linearity of the standard curve and proper functioning of the spectrophotometer. The spectrophotometer was then calibrated in concentration mode, setting the calibration with the 15 mg C standard. Then blanks and samples were read in the concentration mode.

3.5.7 Determination of exchangeable calcium and magnesium

About 2.5 g of dry soil was extracted with 25 mL of 1M KCl. The soils and KCl in bottles was stirred for 10 minutes. An extract for analysis was then filtered through Whatman No. 5 filter paper into clean 60 ml bottles. 1 mL of the extract or standard and 9 mL of deionised water were dispensed into clean 60 mL bottles and 10 mL of 1% lanthum solution added. Calcium and magnesium were then determined on a flame spectrophotometer (Yurimaguas Exp. Stn. Staff, 1989).

3.5.8 Determination of exchangeable potassium and phosphorus

Approximately 2.5 g of dry soil was extracted with 25 mL of 0.5 M $NaHCO_3$ + 0.01 M EDTA, pH 8.5 (modified Olsen) using 1:10 soil solution ratio. The slurry was stirred for 10 minutes and then filtered through Whatman No. 5 filter paper into clean 60 ml bottles. Two millilitres of a sample and 8 mL of deionised water were dispensed into clean 60 mL bottles and swirled gently to mix. Exchangeable K was then analysed by

flame spectrophotometer (Yurimaguas Exp. Stn. Staff, 1989) while P was determined calorimetrically (molybdenum blue).

3.6 Participatory methods

3.6.1 Field and evaluation days

A Farmers' field/evaluation days were held at the end of every season of the study period. The evaluations involved farmers walking through different trial farms to learn about the technologies. The farmer whose trial was visited would explain the benefits and losses he was realizing from the hedges. During these occasions, farmers would also have an opportunity to compare different treatments either for crop yield differences or for indication of soil conservation. They would later sit down in groups and discuss as they filled the questionnaires. This was also supposed to act as a way of exposing as many farmers as possible to the technologies.

3.6.2 Semi-structured interviews

Semi-structured questionnaires (appendix 4) were the main instruments used to gather data on adoption, perception and adaptation from both the trial and non-trial farmers in the locality. Local language was used entirely during this exercise to ensure that all the interviewees did not have problems understanding the questions. Enumerators were drawn from the locality and given an intensive training course including a day of research instruments pre-testing. Each completed questionnaire was checked for omissions and commissions and where anomalies were realized, the enumerator revisited the respondent to rectify the errors.

3.6.3 Observations

Direct observations were carried out to verify and supplement interview data. Issues emerging from observations were used to guide interviews and discussions with the study population. Transect walks and visits were carried out to create opportunities for direct observations and evaluation.

3.7 Data analysis

For biophysical data such as soil loss, nutrients and crop yield, farms were treated as blocks and as such treatment means per farm and per treatment were calculated. These means were subjected to analysis of variance (ANOVA) by use of Genstat 5 software (Genstat, 1995).

Social data was coded into Excel spreadsheet and Statistical Packages for Social Sciences (SPSS) computer software and analyzed for percentages, frequencies and then means separated by use of Standard Error of the Difference (SED). Multiple regression analysis was used to test the relationships in the perception model. A logit model was used to analyze whether farmers adopted or not due to dichotomous response outcomes i.e. the farmers decision takes the form of whether or not to adopt contour hedges hence the observed value for Y is either 0 or 1. A Tobit model was used to analyze the dependent variable willingness to invest in contour hedges. For non-adopters the value is 0 while for adopters the response is a continuous variable with values ranging from 1-100. The Logit model is based on cumulative logistic probability function and is specified as:

$$Pi = F(\propto + \beta Xi) = \frac{1}{1+e^{-(\propto+\beta Xi)}}$$

Where: Pi is the probability that individual will make a certain choice Xi, E is the base of natural logarithms and is approximately equal to 2.718, Xi is a vector of exogenous variables while $\propto$ and β are parameters of the model. On the other hand the tobit model is specified as: $Y_{it} = \beta X_{it} + U_{it}$ if $\beta X_{it} + u_{it} => 0$

$Y_{it} = 0$ if $\beta X_{it} + u_{it} = \leq 0$

Where: Y_{it} is the dependent variable, defined as the proportion of the farmer's plot with contour hedge technologies for farm i in season t (i = 1,2… n; t =1, 2…t). X_{it} is a vector of exogenous explanatory variables consisting of personal attributes of farmers that are relevant to conservation investment in farm i. u_{it} is the residual error that is assumed to be normally distributed with zero mean and constant variance δ^2. The parameters of the model β_i, and δ^2, were estimated using maximum likelihood techniques.

3.8 Definition of exploratory variables used in the adoption model

AGE – age of the responding farmer (years)

EDUC- Number of years spent in school

FDDAT- Field day attendance and training

LANDSZ – Total area of land operated by the responding farmer (ha)

SLOPE – average slope of the farm in question (%)

FINC – Total annual farm income (USD)

LVST- Total number of herbivore animals owned

LABOUR – available labor (Man hours)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter is divided into three sections. The first section presents the rainfall trend of the study area during the study period. The second section describes the general soil characteristics of the study area and trends of ammonia and nitrate (mineral-N). The third part presents results on soil conservation, maize yield under these treatments and the relationship between maize growth parameters with soil loss. The forth section deals with farmers' attitudes, perceptions, evaluations and adoption of contour hedges. The calculation formulas, regression coefficients and questionnaires are presented as appendices.

4.1 Rainfall Characteristics

The characteristics of rainfall during eighteen months of study were as shown in Figure 2. The rainfall peaks coincided with the months of April and November through out the study period while the lowest rainfall totals were recorded in February, June and September. This is the kind of rainfall pattern expected for this area.

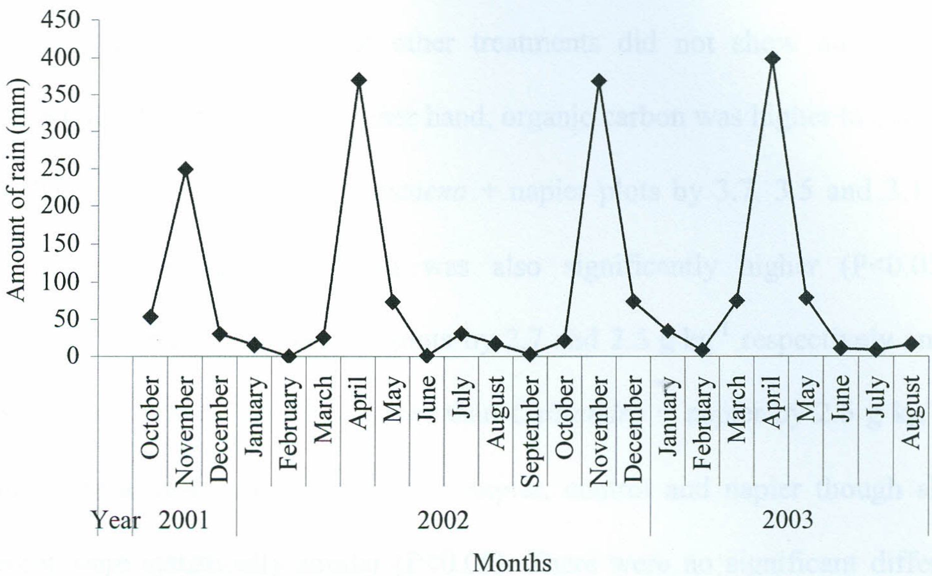


Figure 2: Rainfall pattern in Kirege Location during the study period.

4.2 Analytical Results

4.2.1 General soil characteristics

The general soil characteristics of plots in research farms allocated to different treatments 20 months after establishment of the trials were as shown in Table 2. There was a significant increase (P<0.05) in soil pH 20 months after establishment of the trials on *Calliandra* + napier, *Leucaena* + napier, *Leucaena* and *Calliandra* plots in comparison to the control. The exchangeable acidity did not vary significantly between different treatments. Exchangeable calcium was significantly higher (P<0.05) for *Calliandra* + napier, *Leucaena* + napier, *Leucaena* and *Calliandra* than for either napier or control. Similar results as those of exchangeable

calcium were observed for exchangeable magnesium across the treatments. *Leucaena* and *Calliandra* also had higher potassium than the control by 0.5 and 0.4 $cmol_c\ kg^{-1}$ respectively. All the other treatments did not show any significant difference in potassium. On the other hand, organic carbon was higher in *Calliandra* plots than napier, control and *Leucaena* + napier plots by 3.7, 3.5 and 3.1 $g\ kg^{-1}$ respectively. The organic carbon was also significantly higher ($P<0.05$) for *Leucaena* than napier and control plots by 2.7 and 2.5 $g\ kg^{-1}$ respectively and also significantly lower ($P<0.05$) in napier than *Calliandra* + napier by 2.5 $g\ kg^{-1}$. The organic carbon results for *Leucaena* + napier, control and napier though slightly different were statistically similar ($P<0.05$). There were no significant differences between various treatments for exchangeable P, total N, total P, clay, sand and silt. Soils from all the treatments belonged to clay loam textural class with similar particle size distribution.

Table 2: Physical and chemical properties of Kirege location soil after 20 month of experimentation.

Trt	pH H2O[a]	EA	Ca	Mg	P	K	C	TN	TP	Clay	Sand	Silt
		-----------$cmol_c\ kg^{-1}$-------					----------------$g\ kg^{-1}$-------------------------					
Contl	4.5	1.3	3.8	1.1	6.0	0.2	18.3	2.5	0.9	373.6	325.1	302.3
Call	5.0	1.1	4.5	1.4	6.8	0.6	21.8	2.8	1.0	390.1	311.1	299.2
Leuc	5.1	1.0	4.6	1.4	7.0	0.7	20.8	2.8	1.0	399.3	325.0	255.0
Nap	4.7	1.7	3.3	1.0	4.0	0.4	18.1	2.6	0.9	383.4	307.4	310.4
Call+ Nap	5.3	0.9	5.5	1.7	6.1	0.4	20.7	2.7	0.9	390.7	348.2	262.1
Leuc+Nap	5.2	0.9	5.2	1.8	6.7	0.5	18.7	2.8	0.9	394.4	320.6	286.0
SED	0.2	0.8	0.5	0.2	1.9	0.2	1.2	0.2	0.1	33.2	28.4	28.5

Trt – treatment; Contl - control; Call- *Calliandra*; Leuc - *Leucaena*; Nap- Napier; Call + Nap – *Calliandra* + napier; Leuc + Nap -*Leucaena* + Napier; EA-exchangeable acidity; TN- total nitrogen; TP - total phosphorus; [a]1:2.5 soil:H_2O

The increase in soil pH on plots with tree hedges could be attributed to increment in calcium and magnesium and retention of NO_3^- in these plots due to reduction in both leaching and soil erosion losses (sections 4.2.2 and 4.3). Increased calcium and magnesium reacts with acid soils replacing hydrogen and aluminum on the colloidal complex (Cahn et al., 1993). This adsorption of calcium and magnesium ions raises the percentage base saturation of the colloidal complex leading to corresponding increment in pH. Nitrate on the other hand is a strong acid, which is accompanied by Ca^{2+} and Mg^{2+} when it leaches because metallic cations are far more abundant than protons at a pH of 4 to 7. With Ca^{2+} or Mg^{2+} as the accompanying ions in leachate, 2 mols of H^+ accumulates in the soil per mol of N lost (Loomis and Connor, 1992). Reduction of nitrate leaching by tree hedges therefore could have reduced H^+ accumulation leading to increment in soil pH.

The improvement in the level of carbon in treatments that had *Calliandra*, *Leucaena* and *Calliandra* + napier can be attributed to the fact that adequate prunings resulting from these hedges were transferred to these plots. On the other hand, *Leucaena* + napier and sole napier did not significantly influence the level of organic carbon because either inadequate or no prunings at all were transferred to their respective plots by farmers. It was found that most farmers did not associate napier with soil fertility improvement and therefore were reluctant to incorporate enough napier cutting or its resultant manure into the respective plots. On the other hand *Leucaena* is known to yield relatively little biomass in comparison to Calliandra. It is therefore probable that little biomass from *Leucaena* coupled with farmers unwillingness to

incorporate napier into the plots made *Leucaena* + napier not to significantly influence levels of organic carbon. Increase in soil organic carbon in plots that had trees suggests increase in organic matter and hence cation exchange capacity. Rider and Van Keulen (1990) established that an increase of 1g kg^{-1} of organic carbon leads to an increase of 4.3-mol kg^{-1} of CEC. The observed enhancement of soil carbon in treatments that had leguminous hedges may be important as it suggests that tree biomass manure may contribute to rebuilding of the soil organic matter status of impoverished agricultural soils in steep landscapes.

The exchangeable bases (Ca and Mg) were lower for napier plots than on plots served by any other hedge because napier was utilizing Ca and Mg in the topsoil as a result of its shallow roots. The other hedges had a tree component, which possibly captured and transferred these elements to the surface from deeper soil horizons through incorporation of their resultant manure. It was also probable that high leaching on the control and napier plots accelerated downward loss of exchangeable bases leading to low Ca and Mg in these plots in comparison to the plots that had *Calliandra* and *Leucaena* either as sole or combination hedges. On the other hand, lack of difference in exchangeable P, total P, total N, and soil texture (clay, sand and silt) in all the treatments could be the result of relatively short duration of the study, since these soil properties take a long time to change significantly.

4.2.2 Soil inorganic nitrogen

Tables 3 and 4 show the amount of ammonium-N and nitrate-N at various soil depths at the start and end of the trial. The bulk of mineral-N (almost 90%) found in

soil was in form of nitrate-N with ammonium-N contributing less than 10%. There was on average more mineral-N at the start of trial than 20 months later. Nitrate-N at time 0 of the trial ranged from 53.2-68.4, 108.6-134.8 and 98.5-157.2 kg N ha^{-1} for 0-30, 30-90 and 90-150 cm depth respectively. Ammonium-N ranged from 4.4-9.7, 6.0-18.1 and 9.5-13.9 kg N ha^{-1} for 0-30, 30-90 and 90-150 cm depth respectively (Table 3). Nitrate-N twenty months later ranged from 22.9-40.5, 23.2-75.3 and 36.2-100 kg N ha^{-1} for 0-30, 30-90 and 90-150 cm depth respectively while ammonium-N ranged from 4.4-9.7, 6.0-18.1 and 9.5-13.9 kg N ha^{-1} for 0-30, 30-90 and 90-150 cm respectively (Table 4).

Table 3: Concentrations of nitrate-N (kg ha^{-1}) and ammonium-N (kg ha^{-1}) at different depths in farms of Kirege location at the start of experiment in November 2001. Values are mean ± SE.

Depth (cm)	**0-30**	**30-90**	**90-150**
[1]Treatment		**Nitrate-N (kg ha^{-1}) ± SE**	
Contl	53.2 ± 4.3	134.8 ± 6.7	98.5 ± 19.4
Call	54.5 ± 6.9	108.6 ± 19.3	104.2 ± 17.0
Leuc	62.2 ± 4.7	123.9 ± 13.9	137.7 ± 28.4
Nap	62.8 ± 6.7	118.4 ± 26.5	152.3 ± 43.0
Call + Nap	66.5 ± 5.3	121.6 ± 18.1	111.4 ± 26.7
Leuc + Nap	68.4 ± 9.6	126.5 ± 26.0	157.2 ± 34.5
Mean	61.3	122.4	127.0
SED	7.8	17.8	34.3
Treatment		**Ammonium-N (kg ha^{-1}) ± SE**	
Contl	4.8 ± 4.5	9.3 ± 4.0	11.0 ± 1.9
Call	5.3 ± 2.6	6.0 ± 2.6	12.5 ± 2.0
Leuc	4.4 ± 1.4	7.1 ± 1.9	12.1± 1.7
Nap	7.5 ± 5.0	18.1 ± 6.0	13.9 ± 3.8
Call + Nap	5.3 ± 1.1	10.4 ± 2.5	9.5 ± 1.3
Leuc + Napier	9.7 ± 10.3	14.1 ± 2.5	12.2 ± 1.2
Mean	6.2	10.8	12.2
SED	1.6	2.6	1.6

[1]Contl - control; Call- *Calliandra*; Leuc - *Leucaena*; Nap- Napier; Call + Nap – *Calliandra* + napier; Leuc + Nap -*Leucaena* + Napier

The concentration of nitrate-N at 0-30 cm depth 20 months after establishment of the trials was significantly higher in *Leucaena* than control plots (Table 4). All the other treatments did not show any significant accumulation of nitrate at this soil depth. At 30-90 cm depth all the other treatments except *Calliandra* did not significantly influence soil nitrate-N. *Calliandra* had significantly lower amount of nitrate-N than the control at this depth. There were no statistical differences among treatments that had hedges at 30-90 cm depth.

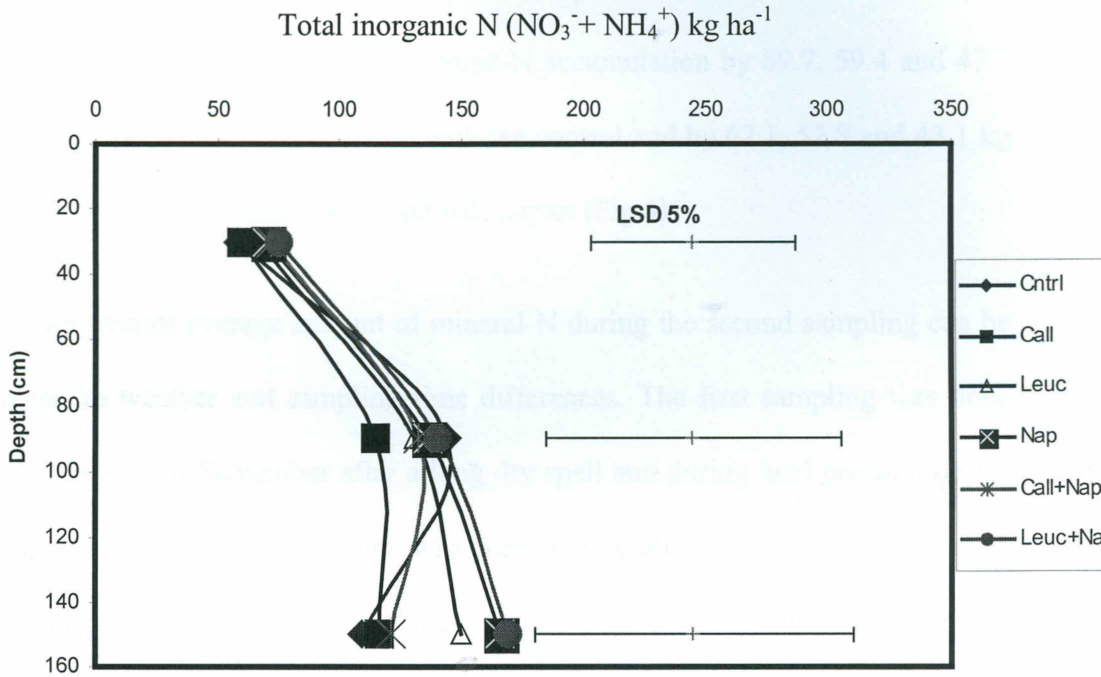
Table 4: Concentrations of nitrate-N (kg ha^{-1}) and ammonium-N (kg ha^{-1}) at different depths in farms of Kirege location after 20 months of experimentation (July 2003). Values are mean ± SE.

Depth (cm)	**0-30**	**30-90**	**90-150**
[1]Treatment	**Nitrate-N (kg ha^{-1}) ± SE**		
Contl	22.9 ± 6.8	75.3 ± 25.0	100.2 ± 28.0
Call	36.5 ± 5.2	23.2 ± 12.2	52.0 ± 12.1
Leuc	40.5 ± 16.0	28.2 ± 10.4	36.2 ± 11.4
Nap	25.7 ± 4.4	66.8 ± 14.0	94.0 ± 19.4
Call+ Nap	27.7 ± 7.1	51.6 ± 13.6	77.1 ± 13.6
Leuc+ Nap	28.0 ± 6.2	30.8 ± 12.0	42.3 ± 12.4
Mean	28.8	48.3	72
SED	6.8	24.3	21.1
Treatment	**Ammonium-N (kg ha^{-1}) ± SE**		
Contl	1.2 ± 0.3	6.6 ± 3.6	7.5 ± 1.4
Call	2.3 ± 0.2	4.3 ± 1.1	5.8 ± 1.8
Leuc	3.5 ± 1.9	3.9 ± 1.0	2.6 ± 0.9
Nap	1.7 ± 0.6	6.2 ± 1.9	6.9 ± 2.2
Call+ Nap	1.8 ± 0.8	5.3 ± 1.7	4.8 ± 2.4
Leuc+ Nap	2.1 ± 0.9	4.9 ± 2.2	5.8 ± 3.2
Mean	1.9	5.1	12.2
SED	1.1	2.8	1.6

[1]Contl - control; Call- *Calliandra*; Leuc - *Leucaena*; Nap- Napier; Call + Nap – *Calliandra* + napier; Leuc + Nap -*Leucaena* + Napier

Nitrate-N at 90-150 cm depth was significantly ($P<0.05$) lower on *Leucaena*, *Calliandra* and *Leucaena* + napier treatments than the control. *Leucaena* and

Leucaena + napier hedge plots also had significantly lower nitrate than sole napier plots at this depth (Table 4). Ammonium-N concentrations showed a relatively low variation with depth and treatments both prior and 20 months after establishment of trials (Tables 3 and 4). Total available N (nitrate + ammonium) on plots allocated to different treatments was calculated and plotted against depth to show the mineral-N behavior prior and after 20 months of experimentation



(Cntrl = control; Call = *Calliandra*; Leuc = *Leucaena*; Nap = napier; Call+Nap = *Calliandra* + napier; Leuc+Nap = *Leucaena* + napier)

Figure 3: Total available N concentration at three depths (0-30, 30-90 and 90-150 cm) of plots allocated to different treatments at the beginning of trials in September 2001in Chuka farms.

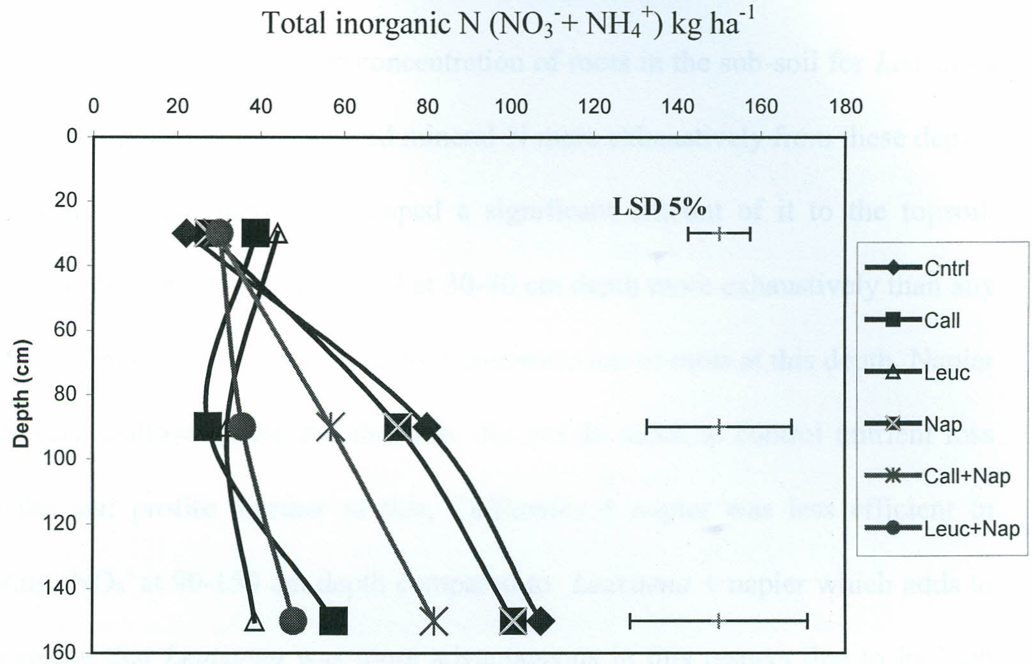
During the second sampling (20 months after establishment of trials) (Fig 4), inorganic N (nitrate-N + ammonium-N) in the 0-30 cm depth was significantly higher for *Leucaena* than the control by 21.9 kg N ha^{-1}. *Leucaena* plots also had

higher concentration (P<0.05) of inorganic-N than sole napier plots by 16.7 kg N ha^{-1}. The other treatments did not show any significant difference at this depth. Inorganic N at 30-90 cm depth was lower (P<0.05) in *Calliandra*, *Leucaena* and *Leucaena* + napier than the control plot by 52.4 kg N ha^{-1}, 47.8 kg N ha^{-1} and 43.2 kg N ha^{-1} respectively. It was also lower for *Calliandra*, *Leucaena* and *Leucaena* + napier than sole napier by 45.5 kg N ha^{-1}, 40.9 kg N ha^{-1} and 37.3 kg N ha^{-1} respectively. On the other hand at 90-150 cm depth, *Leucaena*, *Leucaena* + napier and *Calliandra* reduced (P<0.05) inorganic-N accumulation by 69.7, 59.4 and 47.7 kg N ha^{-1} respectively in comparison with the control and by 62.1, 52.8 and 43.1 kg N ha^{-1} respectively in comparison with sole napier (Fig 4).

The lower overall average amount of mineral-N during the second sampling can be attributed to weather and sampling time differences. The first sampling was done towards the end of September after a long dry spell and during land preparation for planting while the second sampling was done in July after the March to May rains (short rains) and July drizzles and at maize tassling stage. So probably a lot of nitrate had been immobilized, leached or even taken up by the growing crop.

As observed by Karlen et al. (1988), maize tassling stage happens to be the phase when maize has the highest demand for N, so nitrogen would be locked in maize plant tissues at this time. The high sub-soil inorganic N after 20 months in plots with napier and control (- hedge) suggests that there was a higher leaching of mineral-N from topsoil of these plots than from those with other treatments. *Leucaena* had the highest mineral-N in top 30 cm probably because it was able to capture and pump up

more of it from sub-soil to the surface due to deep roots, fix nitrogen and also as a result of faster mineralization of nitrogen under leguminous tree than under napier (Mazzarino et al., 1991).



(Cntrl = control; Call = *Calliandra*; Leuc = *Leucaena*; Nap = napier; Call+Nap = *Calliandra* + napier; Leuc+Nap = *Leucaena* + napier)

Figure 4: Total available N concentration at three depths (0-30, 30-90 and 90-150 cm) of plots allocated to different treatments 20 months after establishment of trials in Chuka farms.

The difference in inorganic-N concentration between the treatments at different depths could be attributed to species differences in root morphology and architecture. *Calliandra* trees are known to develop a strong superficial root system in addition to a tap root (NAS, 1983), whereas *Leucaena* is reported to have a strong tap root system that develops few lateral roots. The few lateral roots that develop also grow downward following emergence with later root development tending to be

confined in the deeper levels of the soil (NAS, 1977; Van Noordwijk et al., 1996). Mugendi et al. (2003) demonstrated a root density of 25.7 m cm^{-2}, 44.4 m cm^{-2} and 21.7 m cm^{-2} for *Calliandra* in 0-30, 30-90 and 90-150 cm depth respectively and 9.4 m cm^{-2}, 26.0 m cm^{-2} and 49.8 m cm^{-2} for *Leucaena* in 0-30, 30-90 and 90-150 cm depth respectively. This high concentration of roots in the sub-soil for *Leucaena* presumably explains why it captured mineral-N more exhaustively from these depths than *Calliandra* and therefore pumped a significant amount of it to the topsoil. *Calliandra* also captured inorganic N at 30-90 cm depth more exhaustively than any other treatment because it had the highest concentration of roots at this depth. Napier is relatively shallow rooted and therefore did not do much to control nutrient loss down the soil profile. Further to this, *Calliandra* + napier was less efficient in capturing NO_3^- at 90-150 cm depth compared to *Leucaena* + napier which adds to the evidence that *Leucaena* was more advantageous in this respect due to its high rooting density at lower depths than *Calliandra*.

Accumulation of soil nitrate-N in the sub-soil layers (lower depths) depends on the sorption ability of soil which in turn is related to decreased soil organic matter (which increase with depth) and increased kaolinitic clay minerals resulting to positively charged surfaces (Hartemink et al., 1996). The sorption ability retard the downward movement and leaching of soil nitrate-N. Appreciable sorption of nitrate-N presumably result from combination of mineralization rates in topsoil, low N demand by plants, downward movement of NO_3^- by high rainfall and shallow rooting conditions by annual crops. Deep roots are able to capture leached nutrients

and recycle them back into annual crop rooting zone (Van Noordwijk, 1989, Van Noordwijk et al., 1996). These mineral-N results are consistent with observations by Kindu et al. (1997) and Mucheru (2003) who reported a bulge of nitrate at 0.3 to 1.5 m depth in the maize land use system.

4.3 Soil erosion and conservation

Table 5 shows soil loss from plots served by various hedges during the first and second season over 5-10, 10-20, 20-30 and >30% slope categories. The first season of soil loss estimation was done 12 months (short rains) after establishment of hedges while the second season was done 17 months (long rains) after establishment of trials. The first season (short rains) on average registered higher soil losses than second season (long rains) for treatments with hedges and vice versa for the control. During the first season there were significantly lower (P<0.05) soil losses in plots that had hedges for 10-20, 20-30 and >30% slope categories in comparison to the control. There were, however, no significant differences among individual hedges for all the slope categories evaluated. During the second season, there were significantly lower soil losses in all the plots served by different hedges in comparison to the control on 10-20, 20-30 and >30% slope categories.

Soil loss on 10-20% slope category during the second season was lower for napier hedges than for all the other treatments. *Calliandra* + napier and *Leucaena* + napier plots lost significantly lower amount of soil than *Calliandra*, *Leucaena* and control at this slope category. The same trend was observed on 20-30% and > 30% slope

category except that on 20-30% slope there was no significant difference between napier, *Calliandra* + napier and *Leucaena* + napier.

Table 5: Mean soil loss for first season (short rains 2001) and second season (long rains 2002) at Kirege location, Chuka Division, central Kenya (n = 165 plots).

Slope category (%)	**5-10**	**10-20**	**20-30**	**>30**
	--------------------------Soil loss t ha^{-1}	----------------		
		First season		
Contl	21.8	79.5	77.4	67.5
Call	15.9	37.5	34.9	26.5
Leuc	14.7	42.2	36.2	29.2
Nap	8.1	12.9	22.7	20.6
Call+Nap	10.7	26.5	25.6	26.5
Leuc+ Nap	13.6	36.6	35.1	21.8
Seasonal mean	14.4	39.2	38.7	32.8
SED	7.5	12.6	14.1	5.0
		Second season		
Contl	25.5	79.3	79.2	78.9
Call	9.7	26.1	28.9	22.2
Leuc	12.3	29.6	28.5	23.6
Nap	7.4	10.3	12.0	9.5
Call+Nap	9.5	17.7	14.0	11.6
Leuc+ Nap	10.2	17.6	13.4	12.9
Seasonal mean	12.4	30.1	29.3	26.5
SED	11.4	1.9	2.1	4.0

Contl - control; Call- *Calliandra*; Leuc - *Leucaena*; Nap- Napier; Call + Nap – *Calliandra* + napier; Leuc + Nap -*Leucaena* + Napier

The lower soil losses during the second season on plots that had contour hedges in comparison to the first season can be attributed to hedge species differences in stage of growth over the two seasons and natural terrace formation. During the second season the hedges were more mature and therefore had more branches, and bigger trunk diameter to form a more intact hedge to sufficiently obstruct runoff and enhance significant deposition of sediment load carried down slope by the runoff.

Natural terraces on the other hand form along contour hedges and advance with time due to entrapment of washed off soil on the up-slope side of the hedge (Lal, 1989).

Napier was overall the best vegetative hedge in soil conservation possibly due to its rhizomatous rooting characteristics. These rhizomatous roots spread out superficially over a large area reinforcing soil around them and bringing about an increase in cohesion and hence in shear strength (Dissemeyer and Foster, 1985). It also sprouts into many napier tillers within a short time, forming an intact hedge.

The lower soil loss values on plots that had *Calliandra* + napier and *Leucaena* + napier as compared to those that had sole *Calliandra* and *Leucaena* hedges could partially be attributed to the fact that these hedges had a napier component and there was a positive relationship between napier and leguminous tree species which recycle (section 4.2.2) and fix N (Young, 1997). This corroborates with the findings by National Research Council (1983) and Goudreddy (1995) that *Calliandra* and *Leucaena* tree species improve soil fertility and hence growth of associated crops which in this case was napier.

The treatments on 10-20% slopes with exception of napier in the first season and *Calliandra* during the second season consistently registered higher average soil loss than even those on 20-30 and >30% slope which was rather surprising. This could be due to higher concentration of clay in comparison to sand and silt on 20-30%, and >30% slope categories. High clay content in the soil leads to surface sealing resulting in low soil particle detachment (Morgan and Rickson, 1995) while high

percentage of silt and fine sand increases the susceptibility of particles to detachment and hence erosion due to reduction in raindrop energy required to break down their soil clods (Morgan, 1986). This means that on 20-30% and > 30% slope, the ability of soil to resist detachment by runoff flow energy was probably higher than on 10-20% slope category. This finding corroborates with Angima (1996), who reported that the cumulative soil loss in central highlands of Kenya was higher for 20% slope in comparison to 40% slope.

Else where, Odemerho (1986) found that erosion by water on cut road banks in Nigeria followed a curvilinear pattern with peak rates occurring on slopes of 15-20%. The decline in erosion on slopes greater than 20% was explained by changes in hydrological processes. Dunn (1975) suggests that, with increasing slope steepness above 20% the transport capacity of the runoff increases more rapidly than detachment of soil particles. Erosion thus in this case becomes limited by rate of detachment. Further, the main agent of particle detachment, which is raindrop impact declines with increase in slope angle, because when the drop impact is spread over a greater surface area it becomes less effective.

4.4 Maize Yield

The average maize grain yields for plots served by different hedges during the first and second season are presented in Table 6. During the first season, maize yield followed the order; *Leucaena* + napier > *Calliandra* + napier = control > *Leucaena* > *Calliandra* > napier. Maize yield was higher during the second season than first

season for all the treatments with vegetative hedges but lower on the control. The order for the second season (highest to lowest) was *Leucaena* + napier > *Calliandra* + napier > *Leucaena* > *Calliandra* > napier > control. The overall mean maize yield for first and second season was highest in *Leucaena* + napier and *Calliandra* + napier, intermediate in *Leucaena* and *Calliandra*, low in control and lowest in napier hedge plots.

Table 6: Maize yield at Chuka farms in plots served by various vegetative hedges during first and second season of the trial (2002 and 2003 respectively).

[1]Treatment	First season	Second season	Treatment mean
	----------Maize grain (t ha^{-1} ± SE)----------		
Contl	2.2 ± 0.5	2.0 ± 0.3	2.1
Call	1.9 ± 0.4	2.9 ± 0.4	2.4
Leuc	2.1± 0.6	3.1 ± 0.5	2.6
Nap	0.9 ± 0.1	2.1 ± 0.4	1.5
Call+Nap	2.2 ± 0.7	3.4 ± 0.8	2.8
Leuc+ Nap	2.3 ± 0.8	3.6 ± 0.6	2.9
Seasonal mean	1.9 ± 0.5	2.9 ± 0.9	2.4
SED	0.3	0.3	0.3

[1]Contl - control; Call- *Calliandra*; Leuc - *Leucaena*; Nap- Napier; Call + Nap - *Calliandra* + napier; Leuc + Nap -*Leucaena* + Napier

The high maize yield in the control plots relative to *Calliandra*, *Leucaena* and napier hedges during the first season could be explained by the fact that these species were competing with crops during establishment and had not started adding any significant nutrients to the soil. During the second season, the control had the lowest yield because the hedge species had started improving soil fertility, reducing soil erosion and capturing leached inorganic N (sections 4.2.1, 4.2.2 and 4.3). Napier had the lowest yields during the first season; a condition that could be attributed to competition with adjacent crops since majority of farmers did not agree to cut napier

before it had adverse effect on crops as they had been advised. During the second season, farmers had the napier hedges cut early enough and hence avoided the above ground competition. This explains the relatively higher yields from napier plots than control during the second season. However, through out the experiment, napier registered lower maize yields than any other hedge a situation that could be attributed to its root concentration on the upper soil horizon which competes with maize crop and lack of nitrogen enhancement as is the case with deep rooting leguminous species such as *Calliandra* and *Leucaena*.

Plots that were associated with combination hedges (*Leucaena* + napier and *Calliandra* + napier) consistently produced higher yields probably because they were more efficient than most of the other treatments in both soil conservation and nutrient cycling (sections 4.2.2 and 4.3). On the other hand, treatments that had *Calliandra* whether as sole or in combination with napier produced lower maize yields than Leucaena in the two arrangements though previously both *Calliandra* and *Leucaena* had been observed to have almost identical fertility factors (F) across the seasons (Mugendi et al., 1999). This implies that probably *Calliandra* competed with maize for nutrients in the topsoil owing to its root concentration in the same soil layer as maize rooting depth. Generally however, over the two seasons the control plot continuously experienced a rapid yield decline as opposed to other treatments, which could be associated with the continued loss of nutrients resulting from soil erosion and leaching on these plots.

Else where, IBSRAM (1994) reported a substantial crop yield decline under farmers' practice on slopping landscapes where no soil conservation measures were employed. In this trial, the contour hedgerow recorded almost twice the yield of farmers' practice over a three-year period. Contour hedge system also maintained maize yield at 2 t ha^{-1} on a 44% slope land in Malawi compared with drastic reduction (from 0.81 to 0.15 t ha^{-1}) in crop control without any soil conservation, over six year period (Banda et al., 1994).

4.5 Relationship between soil loss and maize yields

The relationship between topsoil loss and various maize growth parameters such as maize grain weight, plant height, stover weight and total above ground biomass (grains + stover + empty cobs) are shown in Figures 5, 6, 7 and 8 respectively. There was a highly significant and negative correlation between soil loss and grain weight ($r = -0.68$, $P = 0.006$), plant height ($r = -0.64$, $P = 0.003$) stover weight, ($r = -0.73$, $P < 0.0001$) and total above ground biomass ($r = -0.80$, $P < 0.001$). All the evaluated maize growth parameters, displayed a concave relationship with soil loss. The regression coefficients and ANOVAs for these parameters were as shown in appendix 3.

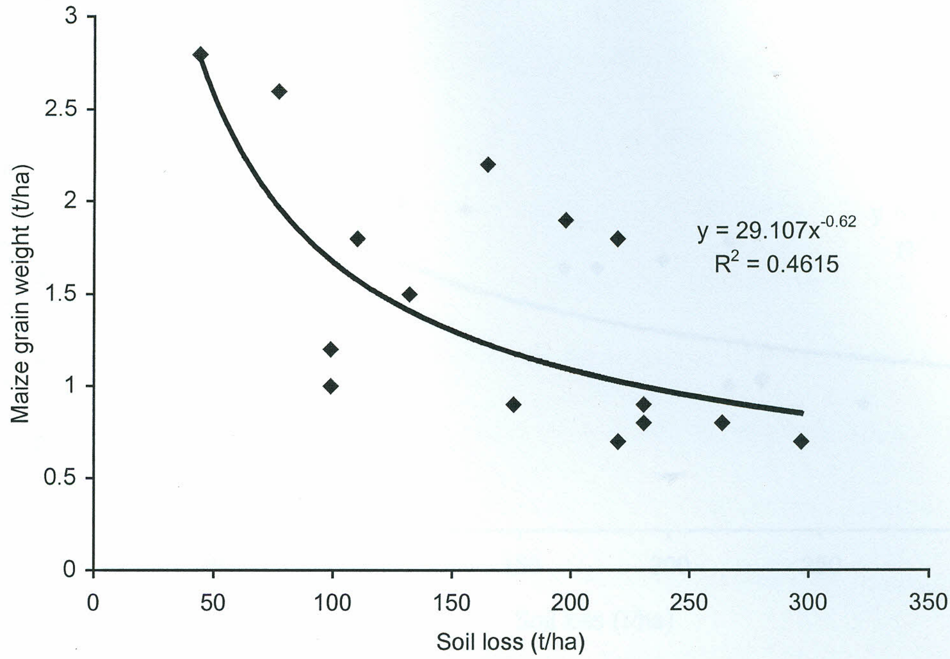


Figure 5: Variation of maize yield with soil loss in fifteen trial farms of Chuka division, central highlands of Kenya during the study period.

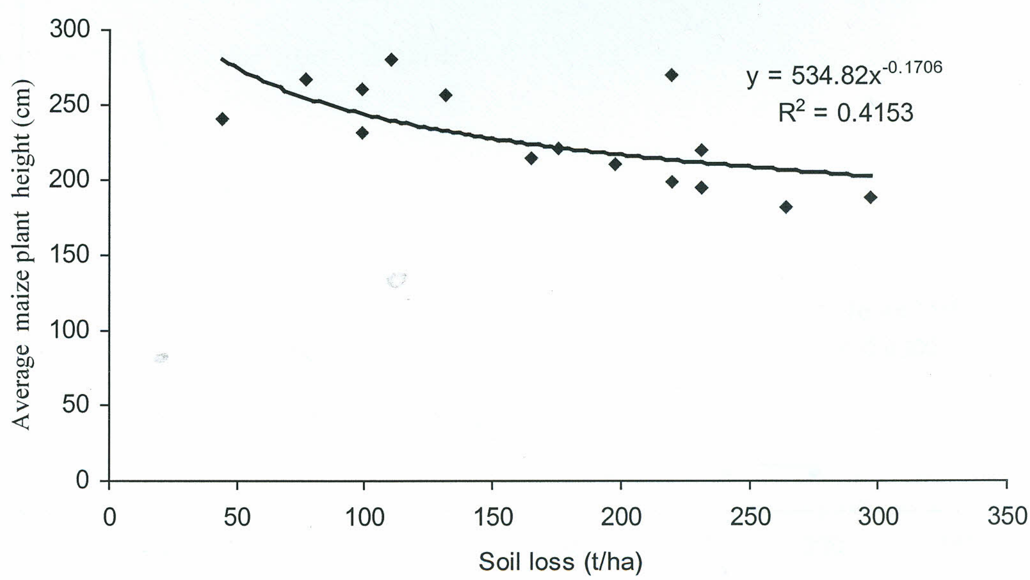


Figure 6:Variation of maize plant height with soil loss in fifteen farms of Chuka division, central highlands of Kenya during the study period.

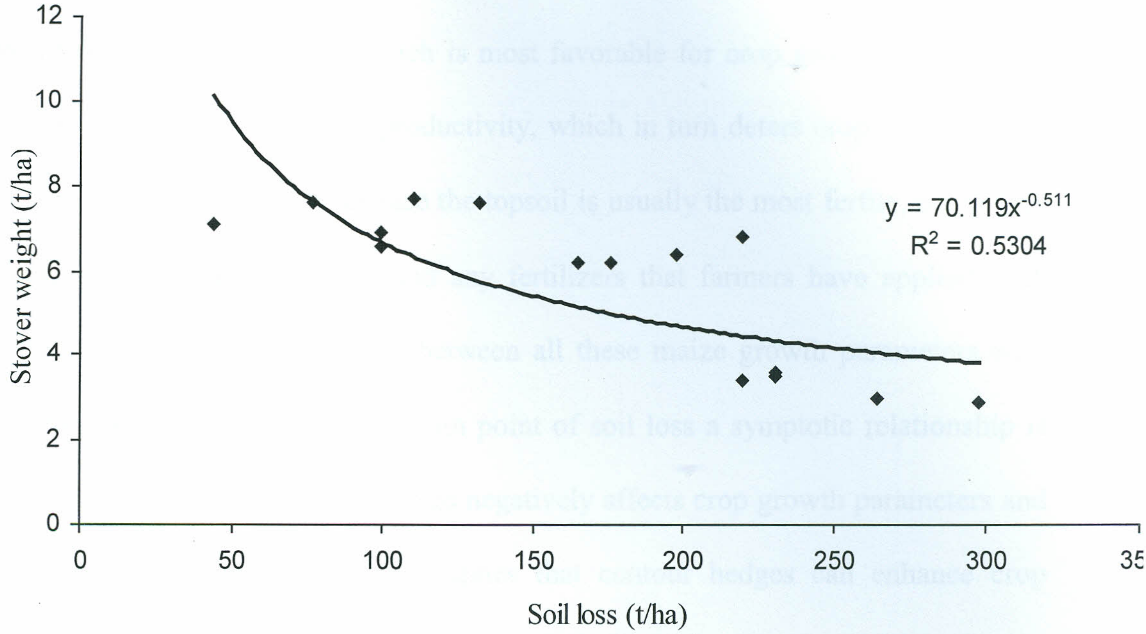


Figure 7: Variation of maize stover weight with soil loss in fifteen trial farms of Chuka division, central highlands of Kenya during the study period.

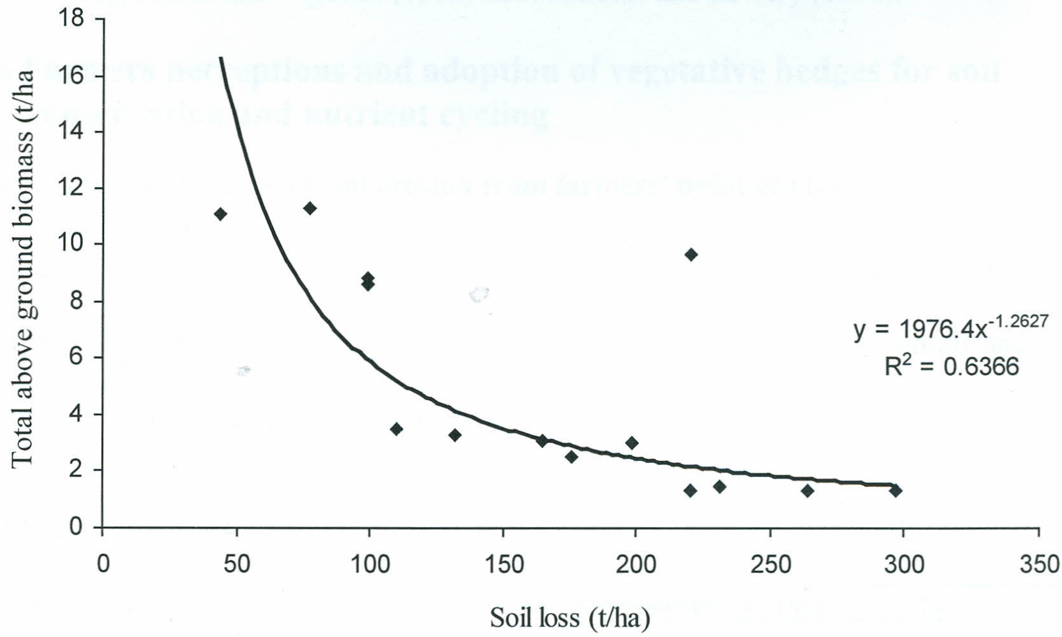


Figure 8: Variation of total above ground biomass weight with cumulative soil loss in Chuka division, central highlands of Kenya during the study period.

The negative correlation between maize growth parameters and soil loss can be attributed to loss of topsoil, which is most favorable for crop growth. The loss of topsoil inevitably reduces soil productivity, which in turn deters crop physiological and morphological growth because the topsoil is usually the most fertile, containing natural plant nutrients, humus and any fertilizers that farmers have applied (Lal, 1989). The concave relationship between all these maize growth parameters with soil loss means that beyond a certain point of soil loss a symptotic relationship is likely to set in. The fact that soil loss negatively affects crop growth parameters and contour hedges reduce soil loss implies that contour hedges can enhance crop production on slopping landscapes (section 4.2). Reduction in crop yields and other crop growth parameters as a result of soil erosion has also been reported by Gachene et al. (1996), Pesant and Vigneux (1992) and Andraski and Lowery (1992).

4.6 Farmers perceptions and adoption of vegetative hedges for soil conservation and nutrient cycling

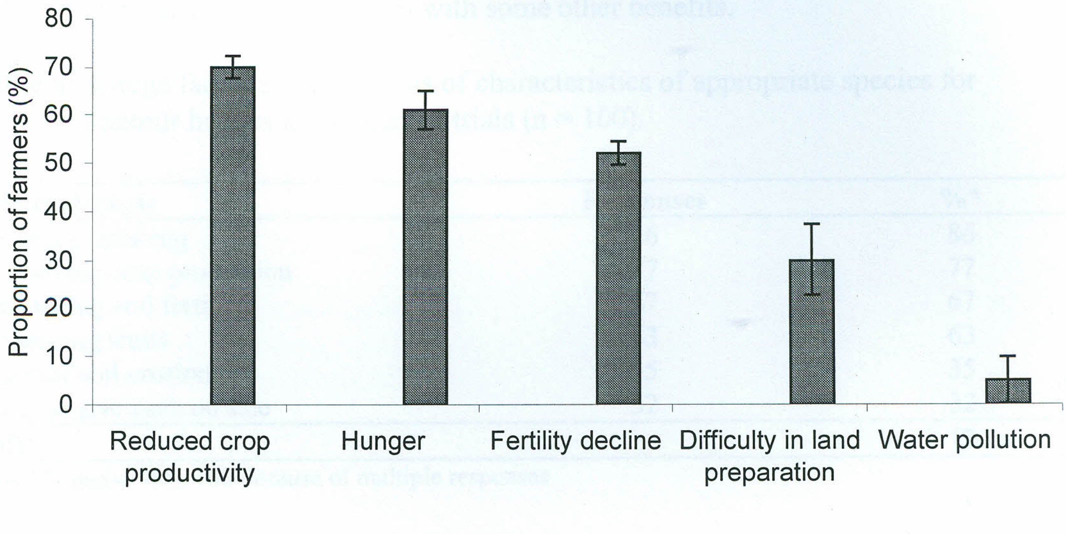
4.6.1 Causes and effects of soil erosion from farmers' point of view

Farmers were asked to identify the causes of soil erosion. As Table 7 shows, majority of the farmers identified lack of ground surface cover, high rainfall and topography as the main causes of soil erosion.

Table 7: Causes of soil erosion as perceived by Kirege farmers.

Cause of soil erosion	No. of responses (n=160)	%
Lack of surface cover	55	34
High rainfall	44	28
Topography	43	27
Over-cultivation	12	8
Over-population	6	4
SED		8

In order to determine whether farmers could link soil erosion to land productivity, they were asked to identify and score the effects of soil erosion. They identified reduced crop productivity, hunger, soil fertility decline, land preparation difficulties and water pollution as the main consequences of soil erosion in proportions shown in Figure 9.



*Bars show standard deviations of the scores

Figure 9: Major effects of soil erosion according to Kirege farmers.

The fact that farmers could identify the causes and effects of soil erosion implied that they perceived the occurrence of soil erosion on their land/farms.

4.6.2 Characteristics of appropriate species for soil conservation

The question of characteristic of species required for hedgerow is very important in judging what other characteristic of the hedge would be instrumental in encouraging

adoption of the technology in any one locality. Over 60% of surveyed farmers preferred species that would either provide fodder, improve crop production, enhance soil fertility, produce fruits or play two or more of these roles simultaneously. It is only less than 40% of the respondent who preferred species that would control soil erosion and give cash on sale of their products (Table 8). This implies that farmers are very unlikely to embrace technologies that solely address soil erosion without providing them with some other benefits.

Table 8: Kirege farmers' perceptions of characteristics of appropriate species for contour hedges at the start of trials (n = 100).

Characteristic	**Responses**	**%***
Fodder producing	86	86
Improving crop production	77	77
Enhancing soil fertility	67	67
Producing fruits	63	63
Control soil erosion	35	35
Able to give cash on sale	32	32
SED		12

*Total % higher than 100 because of multiple responses

4.6.3 Farmers' perceptions of positive and negative attributes of contour hedges

Farmers' decisions on soil conservation technologies are highly influenced by benefits, losses and risk perceptions (Ruthenberg, 1985). Technologies perceived to have higher positive values and lower risks, have a higher likelihood of adoption and vice versa (Kerri and Sanghi, 1993). Kirege farmers' evaluation of the established contour hedges in terms of resultant benefits and losses after three seasons of experimentation revealed that there were more positive (390 responses) than negative (221 responses) effects of these technologies on farm households. Thirty

seven percent of the respondents had not seen any negative characteristics of contour hedges by the third season (Table 9).

Table 9: Kirege farmers' knowledge of positive and negative contribution of hedges after three seasons of experimentation.

Evaluation	Responses (n=100)*	% *
Positive evaluations		
Provide high quality fodder	85	81
Enhance crop production	81	77
They control soil erosion	64	61
Provide cheap organic fertilizer	60	57
Improve soil fertility	41	39
Low cost of establishment	39	37
Source of income	20	19
Total positive evaluations	**390**	
SED		11
Problems associated with contour hedgerows		
None	39	37
Maintenance labor requirement is high	80	76
Shortage of planting materials	57	54
Competition with associated crops	30	28
Makes ploughing difficult	20	19
Harbors rodents and pests	15	14
Total negative responses	**221**	
SED		13

*In most cases there were multiple responses

4.6.4 Parameters associated with effectiveness of contour hedges in control of soil erosion

Farmers went through the trials in two consecutive seasons during the field/evaluation days to monitor and evaluate them. During the 2nd season (9 months after establishment of trials) farmers identified visible forming terraces, accumulation of trash on up-slope side of the hedge and visible gullies on the control as the main indicators of contour hedge effectiveness in soil conservation.

During the 3rd season, build-up of soil on erosional pegs, accumulation of trash along the hedges and visible forming terraces were identified by farmers in proportions shown on Table 10. More farmers were able to identify the parameters associated with ability of contour hedges to control soil erosion during the third season than second season because the hedges had been on the ground for a longer time and hence these attributes had become more visible. On the other hand, farmers report during the 3rd season of appearance of soil build up on erosional pegs fixed along the hedges perhaps point to a possibility of enhancing farmers perceptions of soil erosion down steep landscapes by use of measuring devices that farmers can easily read and interpret.

Table 10: Parameters used by farmers in Kirege to visualize ability of vegetative hedges to control soil erosion at maize tassling stage during the 2nd season of trial.

Parameter	Frequency (n=150)	%*
Second season		
Accumulation of trash up-slope of hedge	50	48
Visible forming terraces	55	52
Gullies on the control	25	24
Third season		
Rise of soil on the erosional peg scale	88	88
Accumulation of trash up-slope of hedge	68	68
Visible forming terraces	52	52
Gullies on the control	31	31

*Total column % higher than 100 because of multiple responses

4.6.5 Farmers uses of contour hedge products

Farmers' immediate use of hedge products is very important in determining the channel through which nutrients are recycled. It is also important because farmers

tend to adopt more readily technologies that are perceived to yield benefits within a short time. Table 11 shows how Kirege farmers utilized hedgerow products.

Table 11: Uses into which Kirege trial farmers put their hedge prunings.

Use of prunings	Frequency	%
Livestock feed	25	69
Fuel wood	1	3
Incorporated into soil	10	21
SED		31

The high rate of farmers feeding hedge prunings to livestock could be related to farmers' realization that these species could supply high quality feed to supplement commercial concentrates. Murithi (1998) observed that 45% of the farmers in central highlands of Kenya buy commercial dairy meal (nominally 16 percent crude protein) to supplement their livestock diet. However, they complain that the price ratio between dairy meal and milk is not favorable, that they lack cash for buying enough dairy meal, that its nutritive value is suspicious and highly variable, and that it is difficult for them to transport dairy meal from the market to the homestead (Franzel et al., 1999). The economic analysis carried out on the importance of *Calliandra* as a source of fodder by Franzel et al. (1999), revealed that after planting, a farmer with an average of 500 shrubs would earn an extra US$130 per year either through increased milk production or through reduced purchase of dairy meal. On the other hand Nyaata (1998) showed that Leucaena could act interchangeably with *Calliandra* in provision of quality fodder for animals. This partly explains why most of the farmers used *Calliandra* and *Leucaena* prunings as animal feeds and shows a high potential for adoption especially now that most of their multiple perceptions of

ideal species for soil conservation seems to be well met by these species when planted in an appropriate arrangement.

The high number of farmers who fed prunings to animals in comparison to those who incorporated prunings could be interpreted to imply that the most feasible pathway for nutrient cycling in Kirege farmers fields especially when high quality fodder species are used is the one that goes through the animal system other than direct transfer of green manure to the soil. A very low proportion of farmers used contour hedge products as a source of firewood possibly because *Calliandra* and *Leucaena* yield low quality fuel and the distance from Kirege to the forest where they get very high quality fuel is less than a kilometer.

4.6.6 Farmers adoption and adaptation of contour hedgerows

The use of contour hedges among farmers in Kirege location rose from the 33 trial farmers who were recruited during the PRA to 70 farmers during the first field day (9 months after PRA) and then to over 200 farmers during the second field day (15 months after PRA). In total an average of 14,500 m of contour hedges had been established by these farmers for fodder, soil fertility enhancement and soil erosion control after only one year and three months. *Calliandra* + napier hedge technology had the highest adoption of about 4,000 m followed by *Leucaena* + napier, *Calliandra* alone and then Leucaena alone. Of this establishment, the trial farmers established about 3,000 m of hedgerow on their own while non-trial farmers in the locality established 11,500 m.

From the 33 trial farmers that were recruited during the PRA, 12 (36%) of them dropped out with 5 (15%) preferring to turn the land occupied by these hedges to cash crop, 5 (15%) abandoning hedges all together due to competition with crops, high labor requirement, poor tree establishment and land tenure problems. The remaining 2 (6%) opted to put their entire farm into napier production.

Some farmers incorporated other plant species into hedgerows in combination with *Calliandra*, napier and *Leucaena*. Some of these species included *Tithonia diversifolia*, which was planted in combination with *Calliandra* in 5 farms, *Leucaena* in 8 farms, napier in 10 farms and as sole hedge in 7 farms. One farmer explained that in plots where *Tithonia* was incorporated the current crop did very well both because of improved soil fertility status and pests control. The farmer explained that traditionally *Tithonia* was used for pest control owing to the fact that it is very bitter and as such many pest opted to keep away from plots mulched with it. They also used other species of grass in combination with *Leucaena* and *Calliandra* hedges. These grass species were *Panicum maximum* which was found on 3 farms in combination with *Calliandra* forming hedges totaling to 145 m in length and in 5 farms in combination with *Leucaena* forming 220 m long hedges. Apart from planting along the contours farmers explored other niches for planting double hedges such as along the fences. Sixty percent of the interviewed farmers revealed using *Calliandra* and *Leucaena* hedges as high value fences around their homesteads. It was also found that farmers varied differently the hedgerow species spacing from the 0.25 m that was demonstrated for all the species. On average they

spaced these species by 0.30, 0.50 and 0.75 for *Leucaena*, napier and *Calliandra* respectively.

The high adoption of hedges incorporating napier can be explained by the readily available napier planting material in the locality. On the other hand, the high incidence of *Tithonia diversifolia* along the hedges can be associated with its promotion in the locality by the off farm Rockefeller Forum project *'enhancement of soil productivity by use of low-cost input technologies in the smallholder farms of central highlands of Kenya'.*

Farmers modifications of the introduced hedgerows by using different species combinations in the hedges and different spacing could be attributed to their attempt to solve some of the hedge problems such as competition with adjacent crops, poor establishment of *Calliandra* and *Leucaena* and lack of enough planting materials. Farmers had a higher spacing for *Calliandra* than napier and *Leucaena* a condition that can be explained by farmers realization that *Calliandra* is more competitive than *Leucaena* because of its root morphology (Mugendi et al., 1999).

4.6.7 Household characteristics of adopters and non-adopters of contour hedges

The household characteristics of interviewed farmers and the adoption of contour hedges are as shown in Table 12. A higher percentage of female led households (55%) than male (36%) had adopted these technologies by the end of the 3rd season of trial. Adoption also rose with the level of formal education from 0-1 years of education category to 8 -12 years of education category and then declined sharply

beyond there. The adopters also had on average more heads of livestock than non-adopters. Farmers who had bought their land had the highest adoption rate (56%) followed by those who had inherited land (32%). The least adopters were farmers who hand rented land who registered less than 10% adoption.

Table 12: Household characteristics of adopters and non adopters of contour hedgerow technology in Kirege location.

Variable	Parameter	Non-adopters (n = 60)	Adopters (n = 40)
Household sex	Male (%)	64	36
	Female (%)	45	55
Education (%)	0-1 years	64	36
	1-4 years	51	49
	5-8 years	45	55
	8-12 years	40	60
	Above 12 years	78	22
Livestock- cattle	Cows	1	3
	Goats	2	2
	Sheep	2	3
Land tenure	Rented (%)	96	4
	Inherited (%)	68	32
	Bought (%)	56	44

The rise of adoption with education up to 8-12 years could probably be due to rise in understanding level with improvement in literacy which is consistent with Ruthenberg (1985) argument that basic education makes a direct contribution to technology adoption and diffusion. On the other hand, low adoption amongst those educated beyond 12 years could be attributed to their access to alternative sources of livelihood like off-farm employment and ability to purchase animal feed supplement. The higher adoption among farmers owning more livestock could be related to their realization of the potential of *Calliandra* and *Leucaena* to act as excellent supplements to commercial concentrates. The lowest adoption among farmers under rental land arrangements can be associated with insecurity of tenure. This is in

agreement with Napier and Sommers (1993) finding that tenant farmers are unlikely to want to bear the full cost of technology while the benefits are long term and therefore shared with the landlords. Similarly, systems based on revolving cultivation of land amongst family members where the degree of certainty of eventual ownership is not very clear may have a similar effect as is the case with farmers with inherited land. Therefore biological contour hedges may be more relevant where farmers have a long-term security of tenure over discrete areas of land. This is so especially when we consider that contour hedges take quite some time to accrue tangible benefits (Ruthenberg, 1985).

4.6.8 Analysis of determinants of farmers' decision to adopt vegetative hedges for soil conservation

Table 13 lists regression results for each of the three independently estimated models to give the relationship between independent and dependent variables (perceptions, adoption and farmers willingness to invest in contour hedges). The average slope (SLOPE) of farmers land, field day attendance and training (FDDAT) and land size (LANDSZ) significantly affected the farmers' perception of soil erosion problem. The slope variable was however the most important of the three variables affecting perception as indicated by the magnitude of its coefficient and the level of significance. Field day attendance and training variable was also significant and positive while the coefficient of land size was significant and negative.

On the other hand, education (EDUC), livestock (LVST), total annual farm income (FINC) and land size (LANDSZ) were found to significantly affect farmers' decision

to adopt vegetative contour hedges. Land size was the most important variable affecting adoption as indicated by the level of significance and its absolute magnitude of coefficient.

Table 13: Estimated coefficients and slopes for farmers perception of soil erosion, adoption and investment in vegetative contour hedges by Kirege farmers.

Dependent variable	**Perception**	**------Adoption------------**		**--------Investment-------**	
Model	OLS regression	-------Logit-------		---------Tobit---------------	
	Coefficient	Coefficient	[a]Slope	Coefficient	[a]Slope
Independent variables					
AGE	---	---	---	-1.701*	0.941*
EDUC	---	2.403*	1.320*	---	---
FDDAT	0.700***	---	---	---	---
LANDSZ	-0.571***	-16.430**	8.31*	---	---
SLOPE	0.842***	---	---	---	---
LVST	---	12.30*	6.40*	3.340**	2.800**
FINC	---	0.0006*	0.0002*	0.006**	0.002**
R^2	0.72	0.90		0.64	

* Significant at 0.10; **significant at 0.05; ***significant at 0.01
OLS- ordinary least square; [a]Slope- rate of change of dependent variable with unit change in independent variable; --- indicate that either the value was not significant or the dependent and independent variables were not related at all

The result of Tobit run showed that livestock (LVST), total annual farm income (FINC) and age (AGE) variables significantly affected the farmers' decision to invest in contour hedges. The order of importance of variables affecting farmers decision to invest in contour hedges was: livestock > total annual financial income > age as shown by their respective coefficients and level of significance. The coefficient of age (AGE) was negative suggesting that younger farmers tended to make greater conservation efforts.

The positive relationship between slope and farmers perception of soil erosion problem could be attributed to visible soil colored runoff, which moved down the slope of steep landscapes on the farmers fields especially during the rainy seasons. The positive and significant correlation between perception of soil erosion and field day attendance and training (FDDAT) was expected since field days provided farmers with exposure and training about the adverse effects of soil erosion, means of soil conservation and easier and more cost effective ways of establishing contour hedges. This is in agreement with Ruthenberg (1985) who found that exposure and training broadens farmers' perspective irrespective of their level of education and age.

The coefficient of land size was negative and the most important factor affecting adoption of contour hedges. The negative coefficient of land size implies that farmers with large farm holdings had lower probability of adopting contour hedges. This could probably be because farmers with large tracts of land could not easily feel the impact of loss of small portion of land to degradation as compared to farmers with small plots who had to take maximum care of their land since they didn't have anywhere else to shift to in event their small pieces became unproductive. The number of livestock held by farmers also significantly affected adoption and willingness to invest in contour hedges, a condition that was attributed to farmers' realization that *Calliandra* and *Leucaena* hedges could provide high quality fodder (Nyaata, 1998). Total farm income (FINC) also positively affected both adoption and willingness to invest in contour hedge technology because higher income

translates to lower financial constraints (Garcia et al., 1995). This implies that farmers with higher income could solve most of the problems associated with contour hedges (Section 4.6.3) by use of cash.

4.6.9 Farmers' plans for contour hedges

Farmers' future plans for already established contour hedges were as shown in Table 14.

Table 14: Kirege farmers' stated plan for already established contour hedges.

Planned activity	Responses (n = 50)	%*
None	24	48
Expand contoured area	17	34
Maintain/Prune hedges before they become competitive	39	78
Plant cash crops on plots with hedges	18	36
Acquire additional livestock	18	36
Start selling hedge products	14	28
SED		10

*Total column % higher than 100 because of multiple responses

The percentage of farmers planning to maintain their hedges was significant in relation to those planning to use contour hedges as a source of money. This implied that in adoption of contour hedges it is only a few farmers who were motivated by direct monetary gains, rather their main source of motivation was other benefits like provision of livestock fodder and crop production improvement (section 4.6.2). From these farmers future plans it also became evident that a few farmers were likely to abandon use of contour hedge soon (especially those who planned to introduce cash crops on the land occupied by the hedges) while on the other hand, majority of the farmers planned to improve on the products of the hedges while reducing the negative attributes of the hedges such as competition with adjacent

crops for nutrients and water. Similar studies elsewhere have yielded varying results, e.g., Fujisaka (1992) during a similar study in Claveria, Philippines found that farmers' preferred species that could provide cash income. The farmers he worked with were particularly very impressed by mulberry, which could produce products that could sell easily to the silkworm project. It is particularly notable that Philippines farmers despite learning that *Gliricidia sepium* was a source of organic fertilizer were very hesitant in taking it because of high amount of labor required for biomass incorporation.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

From these results, contour hedges of napier, *Calliandra* and *Leucaena* in sole or combined arrangement when planted along the contours on slopping landscapes are effective in control of soil erosion. Further results from this study indicated that *Leucaena* and *Calliandra* in sole or in combination with napier are effective in control of nutrient leaching down the soil profile to levels that are in accessible by annual crops. Maize crop performance was best in *Leucaena* + napier plots and lowest in napier and control plots. On the other hand, napier, *Calliandra* + napier and *Leucaena* + napier hedges significantly reduced soil loss after just 17 months in most of the slope categories as a result of their speedy establishment and inherent species characteristics. The multi-purpose nature of these hedges could make them more attractive options for soil conservation than mechanical methods, which lack other agronomic benefits and also require a lot of labor for installation and maintenance. Among these contour hedges, some meet these multiple roles better than others e.g. hedges that combined *Calliandra* or *Leucaena* and napier were capable of controlling soil erosion sufficiently, recycle nutrients, improve crop production and provide quality and quantity fodder simultaneously while sole napier hedges could only control soil erosion and provide fodder.

The study also provides ample evidence that Kirege farmers perceive causes, occurrence and effects of soil erosion on farmland. It was however evident that they

rank soil erosion very low in the list of problems requiring attention. This implies that measures of soil erosion control that do not embrace other benefits may not be readily adoptable by these farmers. The validity of this is made even more obvious by farmers' statement that the most appropriate species for contour hedge is the one that simultaneously improves crop production, produces both sufficient and high quality fodder and controls soil erosion. They also seem to perceive that there are more positive than negative effects of contour hedges as long as the species used are selected to meet their multiple objectives. The fact that they have future plans for hedges gives an indication that they are willing to continue using contour hedges to meet their multiple objectives. It can therefore be concluded that the researchers need to put into account farmers perceptions when developing soil erosion control packages since measures that solely control soil erosion irrespective of the effectiveness are not likely to be wholly embraced by farmers in this region. Kirege farmers should therefore be encouraged to use *Leucaena tricandra* + napier and *Calliandra calothyrsus* + napier contour hedges to avert the high levels of soil erosion on their farms while simultaneously improving crop production and getting high quality and quantity fodder for their livestock from slopping landscapes.

This study didn't fill all the related gaps owing to limitation of time and resources. More research is required in order to partition the nutrients recycled by *Calliandra*, *Leucaena* and combination hedges into those recycled and those that are fixed since these are leguminous plants. Further research is also required to capture the runoff and estimate the amount and exact types of soil nutrients lost with runoff and

therefore the contribution of hedges in reduction of loss of each and every nutrient. In addition to this, more research should be carried out to determine the prevailing intra-household dynamics and the effects of culture and gender division of labor on farmers' perceptions of contour hedges.

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Appendix 1: Formulae for calculation of soil nutrient levels

1. Exchangeable acidity, calcium and magnesium

i. *Exchangeable acidity*

-Exchangeable acidity (soil volume basis):

$$EAME100M = (EATITRAT - EABLANK)\frac{(NNAOH)}{0.01}$$

Where: EAME100M = Exchangeable acidity (me/100 ml soiL)
EATITRAT = Titration volume for sample (ml)
EABLANK = Titration volume for blank (ml)
NNAOH = Normality of NaOH

Exchangeable acidity (soil mass basis):

$$EAME100G = EAME100M\frac{(EASOLVOL)}{EASOILWT}$$

Where: EAME100G = Exchangeable acidity (me/100 g soil)
EASOLVOL = Volume of extracted soil (ml)
EASOILWT = Weight of dry soil extracted (g)

ii. *Exchangeable calcium and magnesium*

-Exchangeable calcium and magnesium (soil volume basis)

$$EXCA100M = EXCACONC - EXCABLNK$$
$$EXMG100M = EXMGCONC - EXMGBLNK$$

Where: EXCA100M, EXMG100M = Exchangeable ca, mg respectively (me/100 ml soil)
EXCACONC, EXMGCONC = Concentration of ca, mg, respectively, in sample (instrument reading for sample (me/100 ml soil)
EXCABLNK, EAMGBLNK = Concentration of ca, mg, respectively, in blank (instrument reading for blank in me/100 ml soil)

-Exchangeable ca, mg (soil mass basis)

$$EXCA100G = EXCA100M\frac{(EASOLVOL)}{EASOILWT}$$

$$EXMG100G = EXMG100M\frac{(EASOLVOL)}{EASOILWT}$$

Where: EXCA100G, EXMG100G = Exchangeable Ca, Mg respectively (me/100 g soil)
EASOLVOL = Volume of extracted soil (ml)
EASOILWT = Weight of dry soil extracted (g)

2. Extractable inorganic phosphorus and exchangeable potassium

i. Exchangeable Potassium

-Exchangeable K (soil volume basis)

$$EXK100M = EXKCONC - EXKBLNK$$

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

-Exchangeable K (soil mass basis)

$$EXK100G = EXK100M \frac{(EXKSOLVL)}{EXKSOLWT}$$

Where: EXK100G = exchangeable K (me/100 g soil)
EXKSOLVL = Volume of extracted soil (ml)

Ii Phosphorus

-phosphorus concentration in soil (EXPMGKG) (mg p/kg)

$$\frac{(EXPCONC - EXPBLNK)\ (EXPVOL)}{EXKSOLWT}$$

Where: EXPCONC = P concentration for sample (mg P/L)
EXPBLNK = Phosphorus concentration for blank (mg P/L)
EXPVOL = Volume of extracting solution (ml)
EXKSOLWT = Weight of dry soil extracted (g)

3. Total nitrogen and phosphorous

The mean blank value was subtracted from the sample values to give a corrected concentration for sample value.

i. ***Total nitrogen***

-N concentration in soil (percent):

$$\frac{((SNCONC\text{-}SNBLNK)\ SNVOL]}{SNSOLWT}\ 0.0001$$

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

ii. ***Total phosphorus***

P concentration in soil (percent):

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

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

4. Total organic carbon

The mean blank value was subtracted from sample concetration values to give a value for corrected concetration.

Total soil organic carbon (percent)

$$\frac{(SCCONC - SCBLNK)\ (0.1)}{SCSSOLWT}$$

Where: SCCONC = carbon content of sample (mg C)
SCBLNK = carbon content of blank (mg C)
SCSOLWT= dry weight of soil sample (g)

5. Soil particle size analysis

Corrected hydrometer readings

- Corrected hydrometer reading at 40 seconds (PSH40COR):

(PSH40SAM - PSH40BLK) + [(PST40-20) 0.36]

- Corrected hydrometer reading at 2 hours (PSH2HCOR):

(PSH2HSAM – PSH2HBLK) + [(PST2H – 20) 0.36]

Where: PSH40SAM = Hydrometer reading at 40 seconds for sample
PSH40BLK = Hydrometer reading at 40 seconds for blank
PST40 = Temperature at 40 sececonds
PSH2HSAM = Hydrometer reading at 2 hours for sample
PSH2HBLK = reading at 2 hours for Blank
PST2H = Temperature at 2 hours

i.Percent clay (CLAY)

$$\frac{(PSH2HCOR)\ 100}{PSSLWT}$$

Where: PSSLWT = Weight of air dry soil (g)

iii. Percent sand (SAND)

$$100 - \left[\frac{(PSH40COR)}{PSSLWT} 100\right]$$

iv. Percent silt (SILT)

100-SAND-ClAY

6. Determination of soil moisture, extractable soil ammonium and nitrate

i. Soil moisture determination

$$\%\ \text{Moisture content} = \frac{\text{Sample fresh weight- Sample dry weight}}{\text{Sample dry weight}} \times 100$$

ii. Ammonium-N concentration in the soil was calculated as follows:

$$EXANMGKG = \frac{(EXACONC-EXABLNK)\{100+(EXNDSWT)\}}{EXNDSWT}$$

Where

EXANMGKG = Ammonium concentration in soil (mg N/kg)
EXACONC = Ammonium concentration for sample (mg N/L)
EXABLNK = Ammonium concentration for blank (mg N/L)
EXNDSWT = Dry weight of extracted soil (g)

iii. Nitrate-N concentration in soil was calculated as follows:

$$EXNMMGKG = \frac{(EXNCONC-EXNBLANK)\{100+(EXNSLWT-EXNDSWT)\}}{EXNDSWT}$$

Where:

EXNNMGKG = Nitrate concentration in soil (mg N/kg)
EXNCONC = Nitrate concentration for sample (mg N/L)
EXNBLNK = Nitrate concentration for blank (mg N/L)
EXNDSWT= Dry weight of extracted soil (g)
EXNSLWT = Field-moist weight of extracted soil (g)

Appendix 2: Calculation of soil loss

Formulae: calculation of mass of lost soil (g)
Plot area = Plot length x plot width
Volume of plot lost soil (cm^3) = (Plot area cm^2) x depth of soil lost (cm)
Mass of lost soil (g) = Volume of plot lost soil (cm^3) x Bulk density (g/cm^3)

Conversion of mass (g) to tons/ha

***Plot area (m^2)** = Plot area $cm^2/10^4$*

Mass (tons) = Mass (g)/10^6

Since mass **M (tons)** is the mass of soil lost in area **A (m^2)** and 1 ha = 10,000 m^2 or 10^4 m^2 then mass of soil lost in a hectare can be calculated as:

$$\textbf{\textit{Mass of lost soil/ha}} = \frac{10000\ m^2 x\ M\ (tons)}{Plot\ area\ (A)\ (m^2)}$$

- **Hypothetical example showing calculation of soil loss**

If a plot had the following characteristics:

Lost 0.5 cm of soil

Plot dimensions =10 m x 10 m

Bulk density (BD) =1.1g/cm^3; NB: The bulk density for each plot was estimated.

Then the soil loss of this plot would be calculated as:

Plot area (cm) = 10^3 cm x 10^3 cm =10^6 cm^2 (10 m = 10^3 cm or 10 cm x100)

Volume of plot lost soil (Plot area x depth of soil lost) = 10^6 cm^2 x 0.5 cm = 500,000 cm^3

Since BD = mass/volume, then Volume x BD = mass

So mass of lost soil (g) = 500,000 cm^3 x 1.1 g/cm^3 = 550,000 g of soil

Conversion of mass (g) to mass (tons) = 550,000/10^6 = 0.55 tons of soil

Since this plot of 100 m^2 lost 0.55 tons of soil

Then 1 ha (10,000 m^2) would loose $\frac{10,000\ m^2 \times 0.55\ tons}{100\ m^2}$ = **55 tons/ha**

Appendix 3: Regression of maize crop growth parameters against soil loss

Maize grain weight against soil loss

Regression Statistics	
Multiple R	0.669363
R Square	0.448047
Adjusted R Square	0.405589
Standard Error	0.54501
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.13453	3.134538	10.5527	0.00634
Residual	13	3.86146	0.297036		
Total	14	6.996			

	Coefficients	*S.E*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.523923	0.36212	6.96968	9.77E-06	1.741591	3.306255
X Variable 1	-0.00634	0.00195	-3.2485	0.006347	-0.01056	-0.00212

Maize plant height against soil loss

Regression Statistics	
Multiple R	0.70984
R Square	0.50388
Adjusted R Square	0.46572
Standard Error	54.5211
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	39248.55	39248.55	13.2036	0.00303
Residual	13	38643.18	2972.552		
Total	14	77891.73			

	Coefficients	*S. E*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*
Intercept	548.089	104.763	5.23171	0.00016	321.7631	774.4163	321.7631
X Variable 1	-1.6475	0.45339	-3.6336	0.00303	-2.62701	-0.668	-2.62701

Maize stover weight against soil loss

Regression Statistics	
Multiple R	0.836699
R Square	0.700065
Adjusted R Square	0.676993
Standard Error	1.044653
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	33.11309	33.11309	30.34277	0.000101
Residual	13	14.18691	1.091301		
Total	14	47.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	9.222991	0.694115	13.28742	6.1E-09	7.723447	10.72253
X Variable 1	-0.02062	0.003743	-5.50843	0.000101	-0.0287	-0.01253

Total biomass above ground biomass against soil loss

Regression Statistics	
Multiple R	0.736019
R Square	0.541723
Adjusted R Square	0.506471
Standard Error	2.722629
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	113.912	113.912	15.367 14	0.001758
Residual	13	96.3652	7.41270		
Total	14	210.277			

	Coefficients	*S. E*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	11.32093	1.80903	6.25798	2.93E-05	7.412743	15.22912
X Variable 1	-0.03824	0.00975	-3.9200	0.0017 58	-0.05932	-0.01717

Appendix 4: Questionnaires

Focused PRA Questionnaire (before establishment of trials)

1.General Information
Date…………………………………………..
District………………………………..
Division………………………………..
Location…………………………………
Sub-location………………………………….
Village…………………………………….
Name of farmer
Sex of farmer: Male or Female

Age of the farmer: 20-30 yrs, 31-50 yrs or above 50 yrs

Position in the household: Husband, Wife, Son, Daughter

Occupation: Full time farmer, employed (specify)

Type of living house: Stone house, Timber house, and Mud house

Total farm size………………

Area under cash crops (specify)
i)--
ii)---

Area under food crops (specify)

i) ----------------------------   ii)-------------------------------------

iii)--------------------------------   iv)--

Do you always produce food for your family? Yes/No
If No, which ones do you buy and when do you buy?

Food type bought	When bought
i	
ii	
iii	
iv	

Soil fertility Management

1.Is low soil fertility a constraint in your farm? Yes/No
----

2. What are the main causes of soil infertility in your farm?

i)---------------------------------- iii)--------------------------------

ii)---------------------- iv)--------------------------------

3. Do you use any farm improvement inputs in your farm? Yes/No

If No, why?

i)---

ii)---

iii)--

If yes list all the soil fertility improvement resources you use in your farm

i)--

ii)---

iii)---

iv)---

4.Do you know of any trees that could be used for soil fertility improvement? Yes/No

If yes, list them

i)-------------- iii)-------------------

ii)---------------------

5. List the ones you are currently using in your farm.

i) ---------------- iii)------------------------

ii)--------------------- iv)-----------------

6.Would you like to plant trees (more) for soil fertility improvement?
Yes/No

If Yes, which are they?
i) -------------------- iii)----------------------
ii) -------------------- iv)-------------------------

7.Where would you prefer to plant these trees?
i) -------------------- iii)----------------------
ii) -------------------- iv)-------------------------

Soil Conservation

1. What area of your land is sloping?
Flat (-------%) Gentle (------%) Severe (--------%)

2. Do you experience any soil erosion problems? Yes/No

If yes, what methods have you used to control soil erosion?
i) Terraces------------------ ii) Plant grass strips---------------------

iii) Spread mulch---------- iv) Plant tree hedges-----------------------

v) Plant tree and grass----------vi) others (specify--------------------------

3.What do you think are some of the causes of soil erosion?
i)--
ii)--
iii)--
iv)---
v)--

4.Which are the effects of soil erosion
i)--
ii)---
iii)--
iv)---
v)--

Score them in order of importance (criteria 5-most important, 4-second in importance, 3 –3rd in importance, 2- 4th in importance, 1, least important

5. List the tree species used to control soil erosion?-------------------------

6. How else do you use any of the grass or trees planted in soil conservation structures?--

7.What characteristics would you look for when planting a tree for soil erosion control?---

8.Are there some trees you would like to plant for soil conservation and you don't know where to get the planting material? Yes/No----------------------

If Yes, which ones?---

9.If you have not planted trees for soil conservation, what are the reasons for not planting trees?

i) Lack of seedlings--------------- ii) Lack of know-how about species-----

iii) Others (specify)----------------------

Farmers follow up Questionnaire

Interviewer--Household Code-------------

Respondent name-------------Sex----------------------Position in Household-------------

Type of household (single man, lady, widow, widower, married with man as head of family, married with woman as family head) (*tick where appropriate*)
(Head of family was defined as controller of day to day operations of the farm)

Age----------------------------Level of education--

On farm labor

What is the size of total area of land that you cultivate---------------size left uncultivated-- Reasons for cultivating some portions while leaving the other if any---
How many are you in this family (family size)---
How many people work on the farm (at least 8 hrs a day)---------------------------------
How many days do these people work per week--
How many of your workers are hired-------------------------for what tasks-----------------
at what wages /day----------------------------------
What percentage of farm labor do you allocate to the following farm operations

I. Land preparation
II. Planting
III. Weeding
IV. Fertilizer
V. Pest control
VI. Pruning
VII. Harvesting
VIII. Livestock care

1.Economic factors

A	Total annual farm income	
B	Total annual off farm income	
C	Subsidy: if a farmer receives any form of subsidy for planting contour hedges (1), 0 for other wise	
D	Cooperative: If a farmer is a member (1) 0 for otherwise	

2.Hedgerow Technology

i.Decision tree Test (Ask al l the farmers, whether using hedgerows or not)

A	Average slope of the farm lot in degrees (to be measured)	
B	Is soil erosion a problem on your farm?	
C	On what percentage of your land is erosion a problem	
D	On what percentage of your land is fallow	
E	Have you rented out some land	
F	Have you rented in some land	
G	Do you think hedgerows improve soil fertility	
H	What crops do you grow in your hedge plots	
I	How does crop production on hedgerow plots compare with those on plots without hedges. Do you know why?	

ii.If farmers have or have ever established contour hedges on their farms (Tick where appropriete)

- ❖ Established
- ❖ Not established

iii	**Hedgerow system description**	**Answer**
a	Hedgerow length (self report or measure in metres	
b	Number of hedgerows	
c	Alley width (estimate width)	
d	Current species in hedgerow, why chosen	
e	Crops grown in alley	
f	How are the hedges maintained?	
g	How much labor is required to maintain hedgerows (Man days)?	
h	What is the pruning frequency	
i	How do you use the prunings?	
J	Do you split prunings into different uses. If Yes which ones and in what proportions. If No why?	
iv	**Hedgerow establishment**	
a	Original area and number of contour hedges	
b	Year/month hedge first established	
c	Primary reason for hedge establishment	
d	Secondary reasons for hedgerow establishment	
e	How did the farmer learn about hedges?	
f	How were contour lines estimated?	
g	What were the original species used in hedges. Why was it chosen?	
h	What other species are you using for hedges?	
i	What changes have you noticed in alley crop growth, soil etc following introduction of hedges? Why?	

j	Is soil fertility/crop productivity improved? What are the indicators according to researcher? What about according to farmers	Y/N i-------------------ii------------- iii-------------------- iv-------------
k	Is soil erosion reduced? Describe the observations	
l	Is field leveling/terracing occurring? Where and when?	
m	Any pest/disease problems due to hedges	
v.	**Benefits**	
a	What are the primary benefits from the hedgerow system?	
b	Estimated income from hedgerow plants	
c	Benefits from hedgerow plants	
vi.	**Problems**	
a	What problems have you been getting from hedges? Are there some that you anticipate?	
b	How do you plan to use your hedgerow in future	
vii	**Modifications**	
a	Have you modified your hedge from that originally demonstrated? If so how?	

3.Training and support to farming

Organizational membership

i. Are you currently a member of any organization that assists in enhancing family livelihood (e.g. cooperative, church, credit union etc.)?--

If so fill in the following table

Organization name	Type	Member since when	Benefits/service provided

4.Information sources

Which are your best sources of information?--- Have you benefited on the issues of hedges from any of these organizations?--- Explain.--

5.Training

Have you or any of your family member attended any agricultural training. If so which ones and when --

6.Adoption

Have you taken up contour hedge technology Yes/No

If No why?

If Yes Why ?

i)--

ii)---

iii)--

iv)--

v)---

7.How many metres of each of the following hedge (let the farmer walk the interviewer to the field for observation)

Adoption	Description	At start	First field day	2nd field day
Metres of hedge adopted				
Calliandra				
Leucaena				
Calliandra + napier				
Leucaena + napier				
Napier				
Other species in combination of any of the above				

8. Have you incorporated any other species other than the ones demonstrated into the hedges (tick where appropriate

Yes-------------No----------------

a. If yes which ones I) ----------------------in combination with----------------

ii----------------------in combination with-----------

iii)-----------------in combination with----------------

b. Why did you have to do these combinations (explain for every combination)

i)--

ii)---

iii)--