

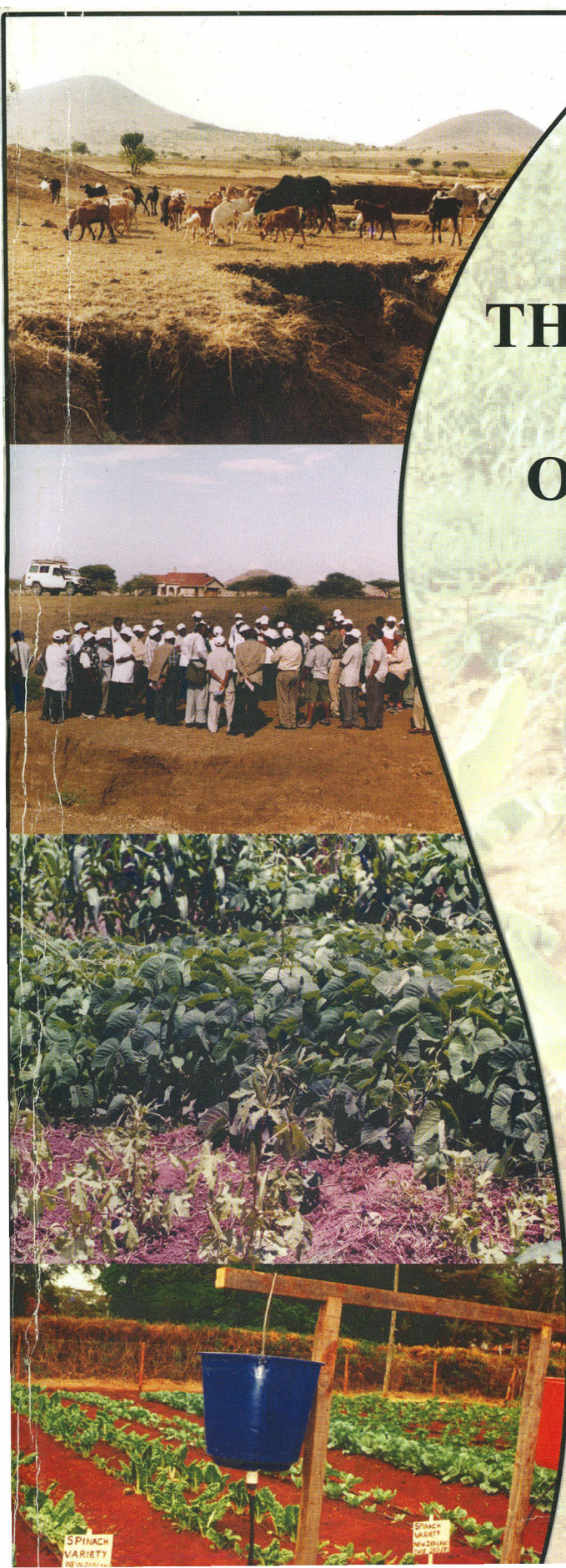


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EFFECTS OF BIOLOGICAL TECHNIQUES IN SOIL CONSERVATION AND SUBSOIL INORGANIC-N ACCUMULATION IN THE CENTRAL HIGHLANDS OF KENYA

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ABSTRACT

Soil erosion and nutrient leaching are some of the factors hindering realization of full crop production potential in the central highlands of Kenya. A participatory trial involving use of calliandra, leucaena, napier, leucaena + napier and calliandra + napier contour hedges was started in farmers' fields of central highlands of Kenya in September 2001 to evaluate the effectiveness of hedges in soil conservation and nutrient cycling. At the start of the trial there was a substantial accumulation of inorganic N with depth. Twenty months later, leucaena, calliandra, and leucaena + napier substantially depleted the subsoil inorganic N by more than 50%. On the other hand napier decreased mineral-N leaching slightly and showed a small bulge beyond 30-90 cm depth. Treatments on 10-20 % slope category registered a higher average soil loss compared to others on 5-10, 10-20, 20-30 and >30 % slope categories. There was soil loss of up to 140 t ha⁻¹ on the control at 10-20% slope category over the study period and a reduction of up 78% of this by sole napier (*Pennisetum purpureum*) hedge. The overall efficiency of the hedges in soil erosion control followed the order: napier > calliandra + napier > leucaena + napier > calliandra > leucaena > control.

Key words: soil loss, nitrate - N, ammonium - N

INTRODUCTION

The small-scale farmers of central highlands of Kenya are constrained by low farm income and few sources of livelihood. Consequently they can not afford to invest in sufficient inorganic fertilizers to offset the high nutrient depletion occurring through leaching, soil erosion and harvest with plant products. Recent studies in this locality have revealed leaching of up to 300 kg N ha⁻¹yr⁻¹ (Mugendi et al; 2000) and a soil loss of 150 - 200 t ha⁻¹yr⁻¹ (Angima, 2000). At modest soil loss level of 10 t ha⁻¹yr⁻¹, it is estimated that soils loose an average of 28 kg N, 10 kg P and 33 kg K ha⁻¹yr⁻¹ (Mantel and Van Engelen, 1999). Leached NO₃⁻ eventually reach underground water aquifers polluting them and thus becoming a health hazard to both man and animals (Gemma et al., 2000). The usefulness of agro-forestry systems in soil erosion control has been demonstrated in Java Philippines (Pacardo and Monecillo, 1983), Kenya (Raintree and Torres, 1986, Angima, 2000), and Nigeria (Lal, 1989). However, most of the reported figures are from on-station data and they have not sufficiently simulated on-farm situations where many uncontrolled factors account for the resultant soil and nutrient losses.

Against this background, an on farm trial was started on thirty-three farms in the central highlands of Kenya. The research was researcher-designed but farmer-managed and its main objective was to

establish the extent of top fertile soil and available N loss through soil erosion and leaching in soils and to develop nutrient and soil loss control technologies for use by farmers.

MATERIALS AND METHODS

Description of the study area

The trials were conducted in Kirege Sub-location, Mugwe Location, Chuka Division, Meru South District, which is a predominantly maize growing zone in the central highlands of Kenya. The area lies in the upper midland zones (UM2-UM3) (Jaetzold and Schimidt, 1983). It is on the eastern slopes of Mt Kenya at an altitude of approximately 1500 m above the sea level with annual mean temperature of about 20°C and annual rainfall varying between 1200 and 1400 mm. The rainfall is bimodal, falling in two distinct seasons. The long rains (LR) are from March to June while the short rains (SR) are from October to December. The soils of this area are mainly humic Nitisols derived from basic volcanic rocks.

Experimental design and methodology

Thirty-three farms were selected through a focused PRA at the start of trial in September 2001. The slopes and contours of the trial farms were determined by use of a clinometer and surveyors level respectively. The treatments under evaluation were double row hedges of: calliandra, leucaena, napier, calliandra + napier, leucaena + napier and control (no hedge). The hedge species were arranged in a completely randomized block design (CRBD) in a zig-zag manner with an inter-row spacing of 0.25 m and an intra-row spacing of 0.5 m with each farm representing a block. The aim of blocking was to minimize the effects of site variation so that the treatment effects could be more accurately quantified using statistical tests. The plots were 10 m long with variable inter

hedge spacing (vertical interval) determined by use of the guidelines demonstrated by Young (1997) p.73, i.e. $W = 100/S^\circ$ where W = inter hedgerow spacing in metres and S° is the slope in degrees. The micro topographic and soil conditions of the site sometimes constrained the continuity of plots in any one farm as installation of plots on relatively flat parts or on plots with other conservation measures was avoided.

Soil sampling, analysis and loss determination

At least six samplings were randomly done by use of soil augers in each plot for 0-30, 30-90 and 90-150 cm depth at the start and 20 months after the start of trials. The bulked soil samples from the respective plots were packed into polythene bags, kept and transported in cool boxes filled with ice to the laboratory for analysis. The samples were refrigerated before extraction with 2 N KCl after which the extracts were frozen awaiting NH_4^+ and NO_3^- analysis. To avoid contamination, samples were always analyzed first for NH_4^+ followed by NO_3^- . Ammonium was determined by the salicylate-hypochlorite colorimetric method (Anderson and Ingram, 1993) while NO_3^- was determined by cadmium reduction method (Dorich and Nelson, 1984).

Levels of soil loss on various plots were identified on the basis of changes in top-soil depth. Changes in top-soil depth were assessed by use of plastic erosion pins fixed at a spacing of 4 × 4 m (from one pin to the next) on each plot.

Calculation of soil loss

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:

$$V_{\text{plot}} = (\text{depth of soil washed}) \times (\text{length of plot}) \times (\text{Width of alley})$$

The resulting volume was then multiplied by bulk density to get the mass of soil lost which was then converted to tons per hectare.

Formulae: calculation of mass of lost soil (g)

$$\text{Plot area} = \text{Plot length} \times \text{plot width}$$

$$\text{Volume of plot lost soil (cm}^3\text{)} = (\text{Plot area cm}^2\text{)} \times \text{depth of soil lost (cm)}$$

$$\text{Mass of lost soil (g)} = \text{Volume of plot lost soil (cm}^3\text{)} \times \text{Bulk density (g/cm}^3\text{)}$$

Conversion of mass (g) to tons/ha

$$\text{Plot area (m}^2\text{)} = \text{Plot area cm}^2/10^4$$

$$\text{Mass (tons)} = \text{Mass (g)}/10^6$$

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:

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

❖ 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) = $1.1\ g/cm^3$; NB: The bulk density for each plot was estimated.

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

$$\text{Plot area (cm)} = 10^3\ \text{cm} \times 10^3\ \text{cm} = 10^6\ \text{cm}^2$$

(10 m = 10^3 cm or 10 cm x 100)

$$\text{Volume of plot lost soil (Plot area} \times \text{depth of soil lost)} = 10^6\ \text{cm}^2 \times 0.5\ \text{cm} = 500,000\ \text{cm}^3$$

Since $BD = \text{mass}/\text{volume}$, then $\text{Volume} \times BD = \text{mass}$

$$\text{So mass of lost soil (g)} = 500,000\ \text{cm}^3 \times 1.1\ \text{g/cm}^3 = 550,000\ \text{g of soil}$$

$$\text{Conversion of mass (g) to mass (tons)} = 550,000/10^6 = 0.55\ \text{tons of soil}$$

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

$$= 55\ \text{tons/ha}$$

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

$$100\ m^2$$

DATA ANALYSIS

Analysis of variance (ANOVA) was done for inorganic N and soil loss data by use of Genstat program (Genstat, 1995). The ANOVA results were used to determine whether the observed differences were significant at 5% level.

RESULTS AND DISCUSSIONS

Rainfall

The rainfall trend for the entire study period was as presented in Figure 1. There were no serious deviations from the expected averages for the long and short rains.

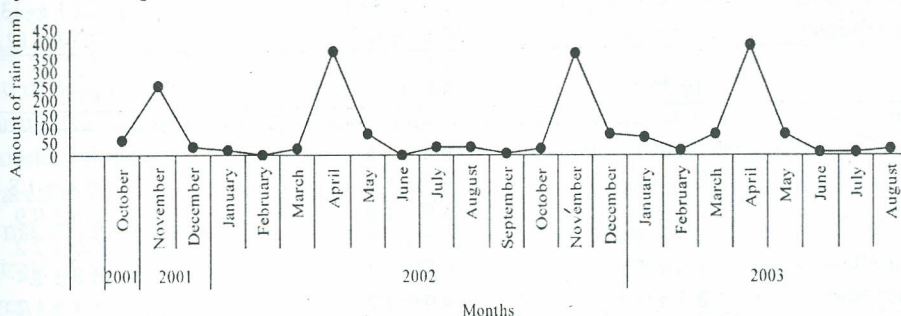


Fig 1: Rainfall pattern in Kirege location during the study period

Soil inorganic nitrogen

Table 1 and 2 show the amount of ammonium-N and nitrate-N at various depths at the start and end of the trial. The bulk (almost 90%) of soil mineral-N was in form of nitrate-N with ammonium-N contributing less than 10%.

Total available N 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. There was generally on average, a higher amount of mineral-N at the start of trial as compared to 20 months of treatment. During the first sampling (0 months of treatment) most of the plots showed a bulge of mineral-N in the subsoil (beyond 0-30 cm depth) (Fig 2).

Table 1: Levels 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

Depth (cm)	0-30	30-90	90-150
Treatment	-----Nitrate-N (kg ha ⁻¹) ± SE-----		
Control	53.2 ± 4.3	134.8 ± 6.7	98.5 ± 19.4
Calliandra	54.5 ± 6.9	108.6 ± 19.3	104.2 ± 17.0
Leucaena	62.2 ± 4.7	123.9 ± 13.9	137.7 ± 28.4
Napier	62.8 ± 6.7	118.4 ± 26.5	152.3 ± 43.0
Calliandra + Napier	66.5 ± 5.3	121.6 ± 18.1	111.4 ± 26.7
Leucaena + Napier	68.4 ± 9.6	126.5 ± 26.0	157.2 ± 34.5
Mean	61.3	122.4	127.0
SED	5.80	17.85	24.33
Treatment	-----Ammonium-N (kg ha ⁻¹) ± SE-----		
Control	4.8 ± 4.5	9.3 ± 4.0	11.0 ± 1.9
Calliandra	5.3 ± 2.6	6.0 ± 2.6	12.5 ± 2.0
Leucaena	4.4 ± 1.4	7.1 ± 1.9	12.1 ± 1.7
Napier	7.5 ± 5.0	18.1 ± 6.0	13.9 ± 3.8
Calliandra + Napier	5.3 ± 1.1	10.4 ± 2.5	9.5 ± 1.3
Leucaena + Napier	9.7 ± 10.3	14.1 ± 2.5	12.2 ± 1.2
Mean	6.2	10.8	12.2
SED	1.61	2.57	1.62

Table 2: Levels 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)

Depth (cm)	0-30	30-90	90-150
Treatment	-----Nitrate-N (kg ha ⁻¹) ± SE-----		
Control	22.9 ± 6.8	75.3 ± 25.0	100.2 ± 28.0
Calliandra	36.5 ± 5.2	23.2 ± 5.6	52.0 ± 12.1
Leucaena	40.5 ± 16.0	28.2 ± 7.0	36.2 ± 7.3
Napier	25.7 ± 4.4	66.8 ± 14.0	94.0 ± 19.4
Calliandra + Napier	27.7 ± 7.1	51.6 ± 13.6	77.1 ± 13.6
Leucaena + Napier	28.0 ± 6.2	30.8 ± 6.7	42.3 ± 12.4
Mean	28.8	48.3	72
SED	12.79	24.26	61.1
Treatment	-----Ammonium-N (kg ha ⁻¹) ± SE-----		
Control	1.2 ± 0.3	6.6 ± 3.6	7.5 ± 1.4
Calliandra	2.3 ± 0.2	4.3 ± 1.1	5.8 ± 1.8
Leucaena	3.5 ± 1.9	3.9 ± 1.0	2.6 ± 0.9
Napier	1.7 ± 0.6	6.2 ± 1.9	6.9 ± 2.2
Calliandra + Napier	1.8 ± 0.8	5.3 ± 1.7	4.8 ± 2.4
Leucaena + Napier	2.1 ± 0.9	4.9 ± 2.2	5.8 ± 3.2
Mean	1.9	5.1	12.2
SED	1.06	2.76	1.62

During the second sampling (20 months after establishment of trials), inorganic N (nitrate-N + ammonium-N) in the 0-30 cm depth was lowest for control (24.1 kg N ha⁻¹) and napier (27.4 kg N ha⁻¹) intermediate for calliandra + napier (29.5 kg N ha⁻¹) and leucaena + napier (30.1 kg N ha⁻¹) and highest for calliandra (38.8 kg N ha⁻¹) and leucaena (44.0 kg N ha⁻¹). Inorganic N at 30-90 cm depth was higher for control (81.9 kg N ha⁻¹) than napier (73.0 kg N ha⁻¹), calliandra + napier (56.9 kg N ha⁻¹), leucaena + napier (35.7 kg N ha⁻¹) leucaena (32.1 kg N ha⁻¹) and calliandra (27.5 kg N ha⁻¹). The only slight difference between 30-90 and 90-150 cm mineral-N behavior for

all the treatments was that, at 90-150 cm depth there was more inorganic N for calliandra than leucaena and leucaena + napier. Though at time 0 months there was a bulge of inorganic N at 30-90 and 90-150 cm depth, this trend changed highly 20 months after. It was also interesting to realize that during this time (20 months after) in organic N almost linearly increased with depth in plots with calliandra + napier hedge treatment. A relatively small bulge of inorganic-N occurred at 30-90 cm depth while a depletion at the same depth was observed on calliandra, leucaena and leucaena + napier plots (Fig 3).

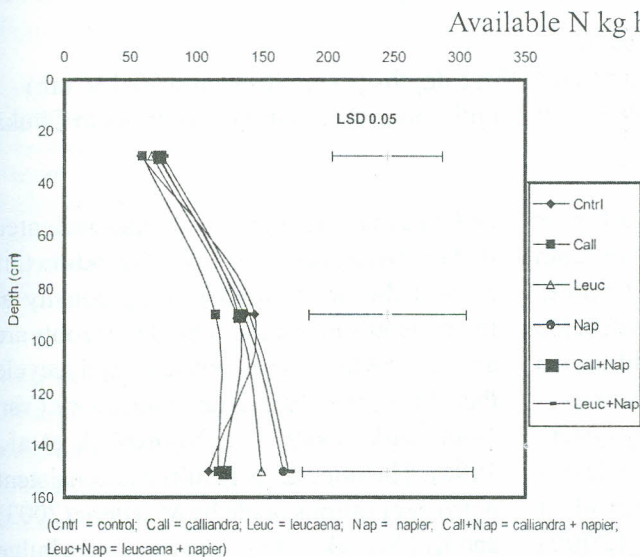


Figure 2:

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 2001 in Chuka farms

The lower 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 a March to May 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. Maize tassling stage has the highest demand for N (Karlen et al., 1988) and probably a lot of

nitrogen was locked in maize plant tissues at that time. The high sub-soil inorganic N after 20 months in plots with napier and control (- hedge) suggest that there was a higher leaching of mineral-N from top soil of these plots than from those with other treatments. Leucaena and calliandra had the highest mineral-N in the top 30 cm soil depth probably due to capture from subsoil to the surface and also as a result of faster mineralization of nitrogen under leguminous trees than under napier (Mazzarino et al., 1991).

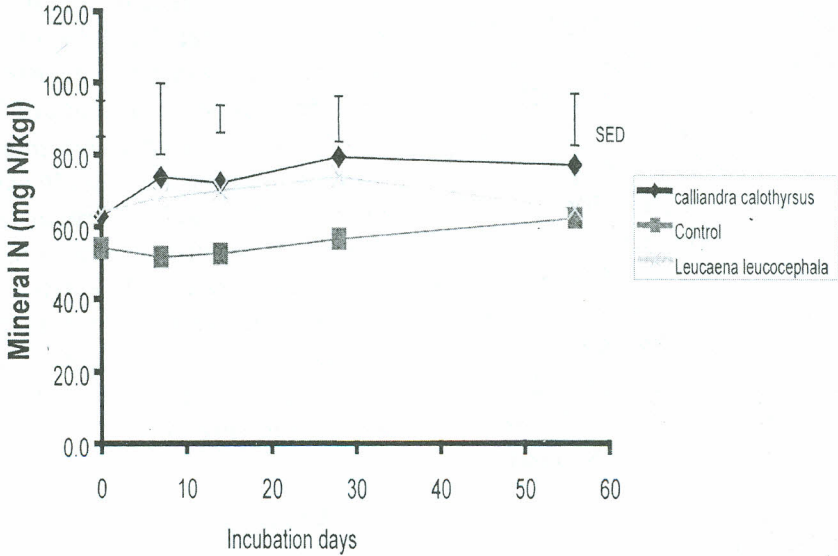


Figure 3: Total available N concentration at three depths (0-30, 30-90 and 90-150 cm) of plots allocated to different treatments 20 months after establishment of trials in Chuka farms

Plots with leucaena however had a higher concentration of mineral-N at 0-30 cm depth than calliandra because of their differences in root morphology. Calliandra trees develop strong superficial root system in addition to tap root (NAS, 1983), whereas leucaena is reported to have a strong tap root system that tends to be confined in the lower levels of the soil (NAS, 1977; Van Noordwijk et al., 1996). Mugendi et al. (2000) demonstrated a root density of 44.0 m cm⁻² and 21.7 for calliandra in 30-90 and 90-150 cm depth respectively and 26.0 m cm⁻² and 49.8 m cm⁻² for leucaena in 30-90 and 90-150 cm depth respectively. This higher amount of root in the subsoil for leucaena presumably explains why it captured mineral-N more exhaustively from these depths than calliandra.

It was also evident that both calliandra and calliandra + napier plots were not as efficient in utilizing NO₃ at 90-150 cm depth

as leucaena + napier which also indicated that leucaena was more advantageous in this respect due to its high rooting density at lower depths than calliandra. 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). The mineral-N results are consistent with observations made by Mucheru (2003) and Kindu et al. (1997) who reported a bulge of nitrate at 0.3 to 1.5 m depth in the maize land use system of central and western Kenya respectively. Braun (1995) also measured 45-mg kg⁻¹ of nitrate-N at 0.15 to 0.3 m depth in an oxisol of western Kenya.

Soil erosion and conservation

Table 3 shows soil loss from plots with various hedges during the first and second season in the 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. Total soil losses during the first season for all the four slope categories followed the order of control

> leucaena > calliandra > leucaena + napier > calliandra + napier > sole napier. The same trend was observed during the second season.

Table 3: Mean soil loss for first season (short rains 2001) and second season (long rains 2002) at Kirege location Chuka Division, central Kenya

Slope category (%)	Soil loss t ha ⁻¹			
	5-10	10-20	20-30	>30
First season				
Control	18.9	69.4	67.2	56.0
Calliandra	12.4	31.9	30.0	19.9
Leucaena	12.6	37.4	31.4	27.7
Napier	6.1	11.1	20.3	13.5
Calliandra+Napier	9.9	29.6	23.5	17.3
Leucaena + Napier	11.6	30.8	30.7	18.5
Seasonal mean	11.9	35.0	33.8	25.5
SED	12.53	21.43	22.27	7.15
Second season				
Control	23.7	73.9	73.1	68.8
Calliandra	8.7	22.0	24.8	19.6
Leucaena	10.5	27.2	25.5	20.9
Napier	5.6	8.7	9.3	7.8
Calliandra+Napier	8.7	16.7	11.9	9.5
Leucaena + Napier	8.6	16.9	13.1	12.9
Seasonal mean	11.0	27.6	26.3	23.2
SED	11.38	15.69	14.41	8.04

The first season (short rains) on average had higher soil losses than second season (long rains) (Fig 4). Soil loss during first and second season were highest on 10-20%, 20-30% and >30% slope categories, and lowest on 5-10% slope category (Fig 4). There were however no significant differences among the six treatments ($P < 0.05$) over the four slope categories during the first season; but significant differences were detected between control and all the other hedges on 10-20, 20-30 and > 30% slope categories during the second season (Table 3).

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 and development and natural terrace formation. During the second season, the hedges were more developed

to sufficiently obstruct runoff and enhance a 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 behind the hedges (Lal, 1989).

The fact that napier was overall the best vegetative hedge in soil erosion control can be attributed to its rhizomatous rooting characteristics. These rhizomatous roots spread out superficially over a large area reinforcing soil around them, 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 in all the slope categories on plots that had calliandra +

napier and leucaena + napier hedges as compared to those that had either sole calliandra or leucaena hedges could partially be attributed to their napier component because of a positive relationship between napier and leguminous tree species. Goudredy (1995) and NAS (1983) observed that calliandra and leucaena tree species improve soil fertility and hence growth of associated crop which in this case was napier. On the other hand, calliandra hedge controlled soil loss more effectively than leucaena hedge probably due to its superficial roots (Jama et al., 1998), which could hold soil together, and because of a thicker stem, which barred run off, and hence retarding its flow velocity, leading to localized deposition of transported eroded sediments (Morgan and Rickson, 1995). The treatments on 10-20% slope category 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 unexpected. This could probably be attributed to higher slope length and concentration of clay on 20-30%, and >30% slope categories. High clay content in the soil leads to 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 as a result of reduction in raindrop energy required to break down their soil clods (Morgan, 1986). On the other hand it has been widely demonstrated that erosion increases with increase in slope length (Young, 1989; Pelleck, 1992; Njoroge, 1994, Morgan and Rickson 1995).

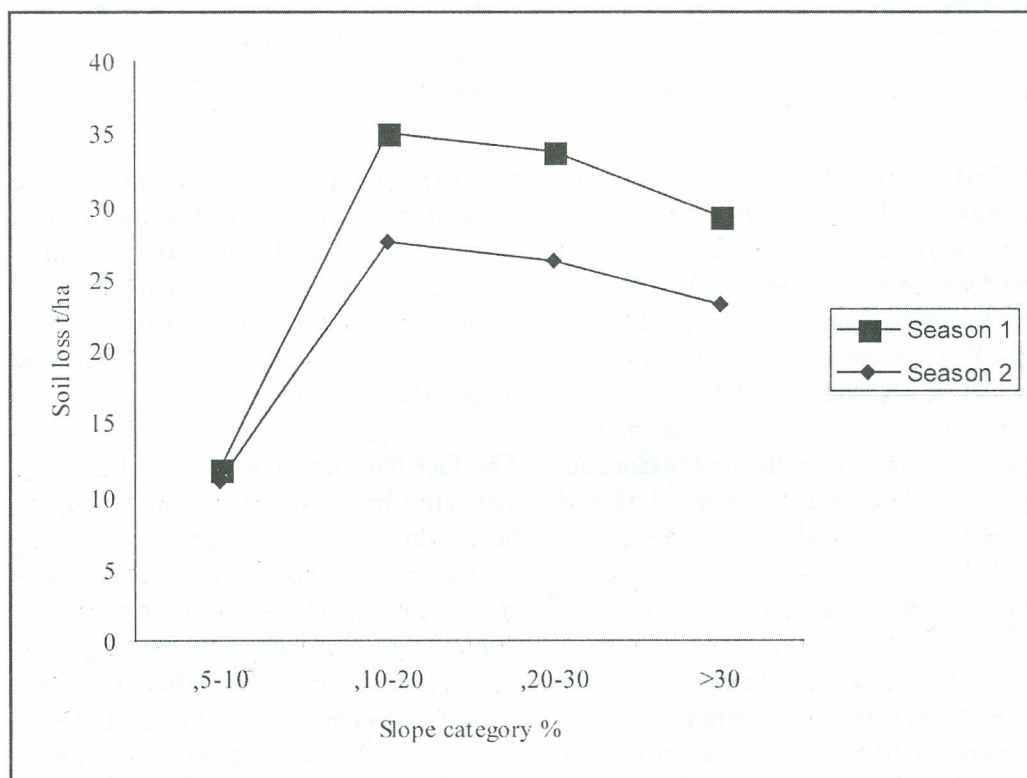


Fig 4: Trend of soil loss over the 4 slope categories during the first and second season of soil loss estimation in Chuka division, Central highlands of Kenya

Elsewhere, 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% may be 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 the greater slope angle, because when the drop impact is spread over a greater surface area it becomes less effective.

CONCLUSION

The results presented herein show that ordinarily central highlands of Kenya loose more than the tolerable soil losses (i.e. 10 t ha⁻¹yr⁻¹). They also make it evident that appropriate contour hedges can significantly manage soil and nutrient losses in this area.

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