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Combining napier grass with leguminous shrubs in contour hedgerows controls soil erosion without competing with crops

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Abstract We established hedges/barriers of calliandra (*Calliandra calothyrsus* Meissner), leucaena (*Leucaena trichandra* (Zucc.) Urban)) and napier grass (*Pennisetum purpureum* Schumach) and combination hedges of either calliandra or leucaena with napier grass on slopes exceeding 5% to study the effect of vegetative barriers on productivity of arable steep-lands in central Kenya. Hedges/barriers were pruned regularly and biomass incorporated into the plots. Hedge plots were monitored for soil fertility, soil losses and maize crop yield changes. Inorganic-N concentration in the tree hedge plots was higher than in the control and napier barrier plots after 20 months. Napier grass barriers were the most effective in reducing erosion losses across the two seasons. The effectiveness of napier grass to significantly reduce soil erosion was detectable in one year old napier barriers. Soil loss from all the other one year old vegetative treatments was similar to soil loss from the control. Seventeen month old combination hedge plots recorded lower soil losses than tree hedges of the same age ($P = 0.012$). Maize crop yields throughout the trial period were high and similar for leguminous and combination hedge plots, but lower in the napier grass and control plots. Overall, we observed that the combination hedges seemed to provide a win-win scenario of reduction in soil erosion combined with improvement of maize crop yields and soil fertility enhancement. We conclude that vegetative hedges have a potential for improving soil productivity in arable steep-lands of the central highlands of Kenya, and that in adoption of vegetative hedges for this purpose there are trade-offs between soil conservation, soil fertility and maize crop yields to be considered.

Keywords Contour hedges · Soil erosion · Soil fertility

Throughout the text, tree hedges and leguminous hedges are used interchangeably to imply calliandra and leucaena hedges while use of barrier/s to refer to a treatment is restricted to monospecific grass strips

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Introduction

Recent studies in the central highlands of Kenya have revealed soil losses of up to 150–200 t ha^{-1} $year^{-1}$ (Angima et al. 2003). At a modest soil loss of 10 t ha^{-1} yr^{-1}, it is estimated that soils lose on average 28 kg N, 10 kg P and 33 kg K $ha^{-1}year^{-1}$ (Mantel and Van Engelen 1999). Construction of physical soil conservation structures is expensive, laborious and time-consuming. Due to resource scarcity and the multiple competing enterprises that characterize most households in the central highlands of Kenya, farmers often lack adequate resources to invest in these soil conservation structures. This has exposed arable land to heavy soil and nutrient losses which in addition to causing serious monetary losses at a farm level, pollute rivers and other water bodies, potentially causing eutrophication and bottom water hypoxia (CAST 1985; Justic et al. 1995; Novotny 1999; Koning et al. 2000).

The usefulness of contour hedges as alternatives to physical soil conservation structures has been demonstrated in Kenya (Raintree and Torres 1986; Angima et al. 2001), Nigeria (Lal 1989) and in Java, Indonesia (Pacardo and Montecillo 1983). Basically, contour hedgerows control soil erosion by two mechanisms: (1) the hedgerows act as permeable barriers for slowing the flow of runoff and (2) the pruned biomass which is deposited as green manure between the hedges provides a protective cover from raindrop impact (Young 1997).

Incorporating leguminous pruning residues from contour hedges improves soil fertility as these materials decompose and release nutrients, which translates into better crop production (Yemoah et al. 1986; Mugendi et al. 1999). Apart from improving the soil nutrient status, the pruned residues may also increase the soil organic matter content (Yemoah et al. 1986). This in turn improves the soil physical properties, creating favorable conditions for plant growth. In alley cropping trials of nine leguminous trees with maize in Hawaii, Rosecrane et al. (1992) reported an increase in maize yields with addition of leguminous tree pruning mulches. For every kilogram of nitrogen applied in form of mulch, approximately 12 kg of additional maize grain was produced.

Most of these studies, however, have been done on-station on a few slope categories and under restricted management and therefore do not adequately simulate farm scenarios where a number of factors account for poor performance of technologies that have proven successful under on-station conditions. Due to increasing human population, limited livelihood sources and fixed land sizes, it can be expected that in future more steep lands will be put into production to meet the food and fiber requirements for additional population. Studies linking the soil conservation aspects of agroforestry with nutrient enhancement and crop production, the ultimate farmers' goals, are few.

The objectives of this study were: (1) to determine the extent of top-soil loss by water erosion from a number of slope categories under continuous cultivation in farmers' fields, (2) to determine the effect of soil loss on maize crop production, and (3) to determine the effectiveness of leguminous hedges of *Calliandra calothyrsus* Meissner (hereafter referred to as calliandra) and *Leucaena trichandra* (Zucc.) Urban))(hereafter referred to as leucaena), napier grass (*Pennisetum purpureum* Schumach) barriers, and a combination of either calliandra or leucaena hedge with napier grass barrier (hereafter referred to as combination hedge) in soil conservation, nutrient enhancement and maize crop production.

Materials and methods

Description of the study area

This study was conducted in Chuka Division, Meru South District, which is a predominantly maize growing zone in the central highlands of Kenya. The area is on the eastern slopes of Mt Kenya at an altitude of approximately 1500 m above sea level. Mean annual rainfall is 1200 mm, distributed in two distinct seasons; the long rains (mid March to June) with an average precipitation of 650 mm and the short rains (mid October to December) with an average of 550 mm of rainfall. The average monthly maximum temperature is 25 °C and the minimum is 14 °C. The long-term monthly average temperature is 19.5 °C. The soils of this area are mainly humic Nitisols (FAO 1990), equivalent to Paleustalf in the USDA soil taxonomy system (Soil Survey Staff 1990) with a reformation rate of 2.2–4.5 Mg ha^{-1} per year for the top 0–25 cm soil depth and 4.5–10 Mg ha^{-1} per year for the 25–50 cm soil depth (McCormack and Young 1981; Kilewe 1987). They are deep, well weathered with friable clay texture with moderate to high inherent fertility.

Experimental design and methodology

We selected 33 farms each with 5–10%, 10–20%, 20–30% and >30% slope categories. Within each farm, we established monospecific hedges/barriers of calliandra, leucaena, napier grass and combination hedges of calliandra + napier and leucaena + napier across the bottom of each slope category. In each farm, treatments for each slope were randomized within one long hedge. Plots with no species in the hedge (conventionally equivalent to continuous cropping) acted as controls in this arrangement. Calliandra and leucaena species were inoculated with effective strains of *Rhizobium* spp. before planting to ensure nodulation in order to enhance their N fixing ability. Each hedge/barrier was made up of 2 rows of the above species arranged in an interlocking/zig zag manner with inter-row spacing of 0.25 m and intra-row spacing of 0.5 m. The plots were 10 m long with variable inter-hedge/barrier spacing estimated according to Young's (1997) formula for biological hedge efficiency as influenced by degree of arable land steepness stated as:

$$W = 200/S\% \quad (1)$$

where W = inter-hedge/barrier spacing in metres and $S\%$ = per cent slope. Where there was a napier + either calliandra or leucaena combination, the tree row always preceded the napier grass row upslope. Horizontally, plot boundaries were effectively defined by galvanized steel sheets 50 cm high inserted up to 20 cm below the soil surface to restrict lateral exchange of eroded soil between test plots. Each farm represented a block. The aim of blocking was to minimize the effects of site variation so that the treatment effects could be more accurately quantified by use of statistical tests. 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. We also trenched the plots on the upper lateral borders to prevent eroded sediments from upslope areas from entering into the test plots.

After planting, the hedges/barriers were left for one year to establish, after which they were pruned regularly (after every 2 months) to a height of 50 cm for trees and 10 cm for napier. This was meant to ensure that they did not overgrow the crop to pose significant aboveground competition. The resulting biomass from any one hedge/barrier was cut into fine pieces and incorporated into the test plot it served.

Soil sampling and analysis

Initial sampling for soil characterization was done on each farm before commencing the trials. The second set of soil samples were collected 20 months after establishment of the trials. For each collection date, at least six samples from each plot were collected. The six samples were thoroughly mixed and sub-sampled to form one composite sample. Field moist sub-samples were refrigerated at 4°C immediately after collection. Twenty grams of this field moist soil was extracted using 5 mL of 2 N KCl within 3 days of collection (ICRAF 1995) by shaking for 1 h at 150 revolutions min^{-1}. The solution was filtered using a pre-washed Whatman No.5 filter paper. Soil water content was determined gravimetrically from stored field moist soil at the time of extraction and used for expression of inorganic-N on a dry weight basis. Nitrate plus NO_2^- were determined by the cadmium reduction method (Dorich and Nelson 1984). Ammonium (NH_4^+) was determined by the salicylate-hypochlorite colorimetric method (Anderson and Ingram 1993). Soil bulk density was determined by the undisturbed core method (Anderson and Ingram 1993) and used to convert NO_3 concentration values from mg kg^{-1} to kg ha^{-1}.

For other analyses, soils were air dried and then crushed to pass through a 2 mm sieve. Soil pH was determined in H_2O (1:2.5 wt/vol) (McLean 1982), exchangeable Ca and Mg by 1 M KCl extraction, and exchangeable K by 0.5 M $NaHCO_3$ + 0.01 M ethylene-diamine-tetra-acetic acid (EDTA) extraction. Soil texture/particle size was determined by use of the hydrometer method (Gee and Bauder 1986). Total organic C was determined by digesting the soil at 130 °C for 30 min with concentrated H_2SO_4 and $K_2Cr_2O_7$, after which C was determined colorimetrically (Anderson and Ingram 1993).

Soil loss assessment

Soil movement in each plot was assessed by use of calibrated plastic erosion pins (FAO 1993) installed at a spacing of 2 × 2 m. Erosional pin readings were taken to the nearest millimeter, to allow any seasonal change in soil level to be clearly recognized. The net change in soil depth within the test plot was estimated as the difference between deposited soil; increment in soil depth on erosional pin scale (common along the hedges) and washed away soil; reduction in depth on the erosional pin scale. The resulting soil loss measurements were converted to t ha^{-1} by first calculating the volume of topsoil washed per plot by use of an equation:

$$V\text{plot} = (\text{Average depth of washed soil}) \times (\text{Plot length}) \times (\text{Alley width}) \quad (2)$$

The resulting volume was then multiplied by the bulk density to get the mass of soil lost, which was then converted to t ha^{-1}.

Maize yield assessment

We determined maize harvest area from the plots that were served by hedges and then harvested maize within it by cutting at the root collar. We catered for edge effects by leaving any maize that was within 1 m of the plot margins. Maize was weighed immediately after harvest to determine the total fresh weight (stover + unshelled cobs). We then separated the unshelled maize cobs from the stover, determined the total stover fresh weight and took a sub-sample 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. To determine dry weight, the above sub-samples (cobs, stover and grain) were oven dried at 60 °C for three days to a constant weight. The proportion of dry matter was calculated by use of the formula:

$$\text{Yield (t/ha)} = [10 \times \text{TFW} \times \text{SSDW}]/(\text{HA} \times \text{SSFW}) \quad (3)$$

Where 10 is a constant for conversion of yields in kg m^{-2} to t ha^{-1}; 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).

To determine the relationship between topsoil loss and maize crop growth parameters, the control plots on 10–20% slope within 26 of the 33 farms were used. Control plots were selected so as to avoid treatment interference, while the 10–20% slope category was used because it was the most widespread slope category in the study area. These farms were sampled on the basis of the farmer's adherence to proper and uniform agronomic aspects such as planting time, weeding, plant population and planting the same seed variety (i.e. H513). H513 is one of the recommended and most widely used maize varieties in the central highlands of Kenya. In addition to the yield parameters cited above, crop height was measured at the maize tasselling stage.

Statistical analysis

We analyzed data by use of GenStat for Windows software (version 6.1, Rothamsted Experimental Station) (GenStat 2002). We used analysis of variance (ANOVA) to test the hypothesis that leguminous contour hedges could enhance soil fertility, reduce soil losses and enhance crop yields. Protected least significant difference (LSD) at $P = 0.05$ (Fisher 1935) was used to separate the means. The hypothesis that soil erosion is directly linked to losses in maize production was tested by regressing soil loss values against various maize crop growth parameters. The best fit models were fitted into the data based on one that had the highest R^2 to describe the nature of relationships between soil loss and maize crop growth parameters.

Results

Rainfall characteristics

We observed a total annual rainfall of 1032 mm split into 467 mm during the long rains and 565 mm during the short rains. This annual rainfall was about 14% lower than the long-term average for this area (i.e. 1200 mm). Rainfall peaks coincided with the months of April and November while the lowest precipitation was recorded in the months of February, June and September (Fig. 1). This monthly rainfall distribution was in agreement with the expected rainfall pattern for this region.

Soil characteristics

Treatment effects on soil characteristics were not affected by site gradient/slope ($P > 0.05$). We

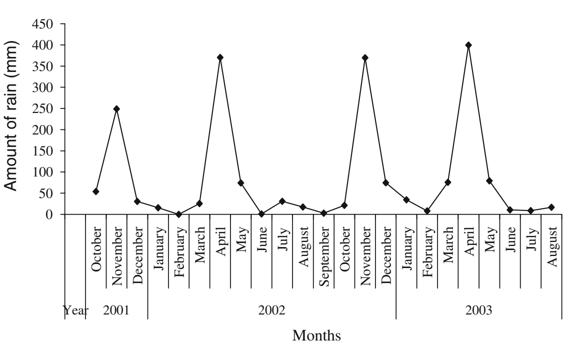

Fig. 1 Monthly rainfall pattern in Kirege location during the study period

Table 1 Properties of top 0–30 cm depth of soil at the start and after 20 months of experimentation in Kirege location

Treatment	pH H_2O[a]	Exchangeable Ca $Cmol_c\ kg^{-1}$	Exchangeable Mg $Cmol_c\ kg^{-1}$	Exchangeable K $Cmol_c\ kg^{-1}$	Total organic C $g\ kg^{-1}$	Inorganic-N ($NH_4^- + NO_3^-$) $kg\ ha^{-1}$
Before establishment of trials (Time 0 months)						
Control	4.8c ± 0.09 (132)	4.2c ± 0.18 (129)	2.1a ± 0.07 (129)	0.5bc ± 0.03 (132)	17.4 cd ± 0.28 (130)	62.7a ± 5.88 (130)
Calliandra	4.7d ± 0.11 (132)	3.8c ± 0.18 (127)	1.4 cd ± 0.04 (127)	0.4c ± 0.04 (132)	17.0d ± 0.13 (132)	60.9a ± 4.31 (131)
Leucaena	4.9c ± 0.15 (132)	3.9c ± 0.14 (132)	1.1e ± 0.06 (132)	0.5b ± 0.02 (132)	17.1 cd ± 0.22 (130)	66.1a ± 3.39 (129)
Napier	4.6d ± 0.08 (128)	4.2c ± 0.15 (132)	1.7b ± 0.02 (132)	0.5bc ± 0.02 (130)	17.1 cd ± 0.25 (131)	70.3a ± 3.11 (130)
Calliandra + Napier	4.6d ± 0.02 (130))	3.9c ± 0.20 (130)	1.3de ± 0.09 (130)	0.4c ± 0.05 (131)	16.8d ± 0.16 (132)	71.8a ± 7.46 (127)
Leucaena + Napier	4.8c ± 0.03 (128)	4.0c ± 0.08 (127)	1.6bc ± 0.03 (127)	0.5bc ± 0.02 (129)	17.6bcd ± 0.27 (129)	70.3a ± 4.07 (125)
After 20 months of experimentation (Time 20 months)						
Control	4.9c ± 0.09 (130)	3.8c ± 0.10 (128)	1.0e ± 0.16 (128)	0.2d ± 0.03 (127)	18.3bc ± 0.26 (132)	26.6d ± 3.40 (130)
Calliandra	5.2ab ± 0.06 (129)	4.7b ± 0.12 (128)	1.5bc ± 0.04 (128)	0.6b ± 0.05 (128)	21.7a ± 0.82 (129)	38.7bc ± 0.85 (127)
Leucaena	5.1b ± 0.03 (129)	4.6bc ± 0.21 (131)	1.5bcd ± 0.04 (131)	0.7a ± 0.03 (131)	20.8a ± 0.76 (128)	43.7b ± 0.26 (129)
Napier	4.7d ± 0.13 (132)	3.3d ± 0.07 (130)	1.3de ± 0.13 (130)	0.4c ± 0.06 (130)	18.2bc ± 0.15 (132)	27.4d ± 0.22 (132)
Calliandra + Napier	5.3a ± 0.04 (132)	5.5a ± 0.22 (127)	1.7b ± 0.11 (127)	0.4c ± 0.04 (132)	20.7a ± 0.29 (128)	31.6 cd ± 3.17 (130)
Leucaena + Napier	5.2ab ± 0.05 (130)	5.1a ± 0.10 (128)	1.8a ± 0.07 (128)	0.6b ± 0.09 (132)	18.6b ± 0.22 (129)	30.0 cd ± 0.27 (127)

Values are means ± SE; values in parentheses represent number of observations. Means within a column followed by different letters indicate significant difference based on Fisher's protected LSD test ($P = 0.05$)

observed higher inorganic-N at 0 months than at 20 months ($P < 0.0001$) (Table 1). We did not observe any significant differences in inorganic-N concentration between treatments at time 0 ($P = 0.68$), but we did observe significantly higher inorganic-N in the sole leguminous hedge plots relative to the control and napier barrier plots after 20 months ($P = 0.027$). Though at time 0 combination hedge plots had on average 7.5 kg ha^{-1} more inorganic-N than tree hedges, 20 months later we observed 10.4 kg ha^{-1} more inorganic-N in tree hedge plots relative to combination hedge plots. We consistently observed significantly higher soil pH, exchangeable bases (Ca and Mg) and C in both sole leguminous hedge treatments and combination hedges at 20 months than at 0 months ($P < 0.0001$). Soil exchangeable K increased significantly in the sole leguminous hedge plots after 20 months of experimentation ($P = 0.006$).

Effects of hedges on soil erosion

Table 2 shows soil loss from plots with different types of hedge during the first and second seasons, classified by slope categories: 5–10, 10–20, 20–30 and >30%. 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 hedge establishment. The first season on average, registered higher soil losses ($P = 0.004$) than the second season for treatments with hedges and vice versa for the control. Soil losses from plots on 5–10% slope had a narrow range (10–17 t ha $year^{-1}$) for different treatments and seasons in comparison to other slopes and were not significantly different ($P < 0.05$). During the first season, there were significantly lower ($P < 0.001$) soil losses in plots under napier grass barriers relative to the control on 10–20% and 20–30% slope categories. Apart from the napier grass barriers, soil loss differences between different vegetative hedge plots during this season on these slope categories were not significant ($P < 0.05$). Consistent significant differences between hedges were observed during the second season on slopes exceeding 10% ($P < 0.05$).

Napier barriers were the most effective at reducing erosion losses across the two seasons (Table 2). Seventeen month old combination hedge plots recorded lower soil losses than tree hedges of the same age ($P = 0.012$).

Soil loss on the 10–20% slope category was higher than soil loss on any other slope category ($P = 0.043$) although ordinarily we would have expected soil loss to increase with slope. In efforts to explain this unexpected phenomenon, we analyzed the soil texture results on a per slope basis. We found significantly lower ($P < 0.001$) levels of clay particles on the 10–20% slope relative to 20–30 and >30% slopes (Table 3).

Maize growth and yield

The presence of tree and combination hedges did not significantly affect maize crop yield during the first season ($P < 0.05$) (Table 4). Napier barriers suppressed yields during this season, but not during the second. Tree and combination hedges resulted in significant increases in yields in the second season. Maize yield in all vegetative hedge/barrier plots increased by between 1.2 and 1.3 t ha^{-1} during the second season relative to the first season but decreased by 0.2 t ha^{-1} in control plots during the second season relative to the first season.

The influence of soil loss on crop growth for each season was not consistent ($P < 0.05$). Cumulative soil losses on the 10–20% slope were 4 to >20 fold higher than the established tolerable soil loss limit of 10 t ha^{-1} $year^{-1}$, implying that this was a highly fragile slope category in this region (Table 5). We observed significantly lower grain yield when cumulative soil loss exceeded 200 t ha^{-1} $year^{-1}$ ($P = 0.01$) and significantly lower plant height (cm) and stover weight (t ha^{-1} $year^{-1}$) when cumulative soil loss exceeded 150 t ha^{-1} $year^{-1}$ ($P < 0.0001$) (Table 5). Total aboveground biomass was significantly affected by any soil loss above 100 t ha^{-1} $year^{-1}$ ($P < 0.0001$). We regressed cumulative soil loss against maize crop growth parameters. The relationship between cumulative soil loss and maize grain weight, stover weight, plant height, and total above ground biomass was negative, linear and highly significant ($P < 0.0001$) (Fig. 2).

Discussion

Soil analytical characteristics

The increase in soil pH on tree and combination hedge plots was associated with an increment in

Table 2 Mean soil loss for first season (short rains 2001) and second season (long rains 2002) at Kirege location for different slope categories

Slope category (%) Treatment	5–10 Soil loss (t ha^{-1})	10–20 Soil loss (t ha^{-1})	20–30 Soil loss (t ha^{-1})	>30 Soil loss (t ha^{-1})
First season (Time: 12 months after trial establishment)				
Control	16.8a ± 1.85	79.5a ± 7.96	77.4a ± 7.46	67.5a ± 7.25
Calliandra	15.5a ± 2.51	37.5b ± 1.54	34.9b ± 1.91	26.5b ± 2.91
Leucaena	14.7a ± 1.90	46.6b ± 4.40	37.5b ± 1.49	29.6b ± 8.38
Napier	12.6a ± 1.84	20.9c ± 2.69	22.9c ± 1.89	20.6b ± 2.76
Calliandra + Napier	13.6a ± 1.93	30.6b ± 2.49	26.5bc ± 2.10	26.9b ± 2.98
Leucaena + Napier	14.2a ± 0.94	35.2b ± 4.76	33.7b ± 1.79	21.8b ± 1.87
Second season (Time: 17 months after trial establishment)				
Control	16.5a ± 1.67	79.6a ± 8.41	79.3a ± 7.63	78.9a ± 5.85
Calliandra	11.0a ± 1.52	26.1b ± 3.82	28.9b ± 3.15	22.2b ± 2.68
Leucaena	12.3a ± 1.64	29.7b ± 6.22	28.6b ± 3.58	23.5b ± 4.56
Napier	10.1a ± 2.13	10.2c ± 0.25	11.9c ± 0.44	9.7c ± 0.62
Calliandra +Napier	12.8a ± 1.98	17.7bc ± 1.85	14.2c ± 1.40	11.6c ± 0.931
Leucaena + Napier	10.7a ± 1.31	17.8bc ± 1.46	13.4c ± 0.34	13.0c ± 0.44

Values are means ± SE; for every treatment and slope category, $n = 33$.

For each slope category and season, means within a column followed by different letters indicate significant difference based on Fisher's protected LSD test ($P = 0.05$)

Table 3 Characteristics of soil texture at different slope categories in Kirege

Slope category (%)	Particle size (g kg^{-1})		
	Sand	Silt	Clay
5–10	318.6a ± 8.8	284.9ab ± 9.2	396.5a ± 1.5
10–20	304.3a ± 5.3	310.1a ± 7.8	385.6a ± 8.1
20–30	299.6a ± 9.5	279.8b ± 9.7	420.5b ± 3.7
>30	299.5a ± 7.3	300.5ab ± 11.3	411.0b ± 5.2

Values are means ± SE . For every slope and soil textural characteristic, $n = 33$

For each column, means followed by different letters indicate significant difference based on Fisher's protected LSD test ($P = 0.05$)

exchangeable bases (Ca^{2+} and Mg^{2+}). 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 a corresponding increment in pH (Loomis and Connor 1992).

The observation of enhanced inorganic-N in plots served by leucaena and calliandra tree hedges after 20 months is consistent with results from a number of earlier studies (Mugendi et al. 1999, 2003). This improvement in soil inorganic-N concentration can be attributed to the ability of these leguminous trees to fix and recycle N and act as a 'safety net' against N leaching (van Noordwijk et al. 1996; Jama et al. 1998; Mugendi et al. 2003). Low inorganic-N concentration after 20 months relative to initial levels probably resulted from weather and sampling time differences. Whilst the first sampling was done towards the end of September after a long dry spell and during land preparation for planting, the second sampling (time 20 months) was done in July after the March to May rains (long rains) and July drizzles and at maize tasselling stage. It is possible that a substantial amount of nitrate had been immobilized, leached, denitrified or even taken up by the growing crop at the time this sampling was done. Maize has the highest demand for N at the tasselling stage (Karlen et al. 1988), so a significant amount of nitrogen would be locked in maize plant tissues at that time.

Effects of soil losses on maize crop yield

The negative regression relationship between soil loss and maize crop yield and growth parameters is attributable to topsoil losses. Soil loss increment from

Table 4 Maize yield at Kirege farms in plots served by various vegetative hedges during first and second season of the trial (2002 and 2003 respectively)

Treatment	First season Maize grain (t ha^{-1} ± 1SE)	Second season Maize grain (t ha^{-1} ± 1SE)	Treatment mean Maize grain (t ha^{-1} ± 1SE)
Control	2.2a ± 0.5 (121)	2.0a ± 0.3 (122)	2.2a
Calliandra	1.9a ± 0.4 (124)	3.2b ± 0.4 (124)	2.6ab
Leucaena	2.1a ± 0.6 (125)	3.3b ± 0.5 (116)	2.7b
Napier	0.9b ± 0.1 (114)	2.1a ± 0.4 (115)	1.5c
Calliandra + Napier	2.2a ± 0.7 (119)	3.4b ± 0.8 (122)	2.8b
Leucaena + Napier	2.3a ± 0.8 (122)	3.6b ± 0.6 (116)	2.9b

Values are mean yield ± SE; values in parentheses represent the number of observations (*n*)

For each column, means followed by different letters indicate significant difference based on Fisher's protected LSD test ($P = 0.05$)

Table 5 Relationship between observed soil erosion classes with selected maize crop growth parameters in the 10–20% slope category

Soil loss (t ha^{-1} yr^{-1})	Grain weight (t ha^{-1})	Plant height (cm)	Stover weight (t ha^{-1})	*TAGB (t ha^{-1})
40–100	1.9a ± 0.2 (8)	247.3a ± 5.0 (8)	7.0a ± 0.2 (8)	10.2a ± 0.5 (8)
100–150	1.5a ± 0.2 (8)	259.0a ± 8.5 (8)	7.3a ± 0.2 (8)	4.1b ± 0.3 (8)
150–200	1.5a ± 0.2 (6)	226.2b ± 8.6 (6)	5.6b ± 0.5 (6)	3.2bc ± 0.1 (6)
>200	0.9b ± 0.3 (4)	190.1c ± 2.8 (4)	3.3c ± 0.2 (4)	1.6c ± 0.1 (4)

Values are means ± SE; values in parentheses represent number of observations (n)

For each column, means followed by different letters indicate significant difference based on Fisher's protected LSD test ($P = 0.05$).
*TAGB – total above ground biomass

40–100 t ha^{-1} year^{-1} to 100–150 t ha^{-1} year^{-1} on 10–20% slope categories would result in approximately 21% loss in grain yield, while a further increment to >200% would lead to >52% loss of maize grain yield (Table 5). Most of the soil erosion studies agree that erosion reduces crop production but the level of reduction varies with soil type and the level of inherent fertility. For example, erosion reduced corn yield by 12–21% in Kentucky, 24% in Illinois and Indiana, 25–65% in the southern Piedmont, Georgia, and 21% in Michigan (Frye et al. 1982; Olson and Nizeyimana 1988; Mokma and Sietz 1992). In the Philippines in 15 years, erosion caused an 80% decline in corn productivity (Dregne 1992). Basically, soil erosion affects crop productivity by reducing the availability of water, nutrients, and organic matter, and, as the topsoil thins, by restricting rooting depth (Lal 1984; Gachene et al. 1997, 1998). Such major reductions in food-crop yields are particularly serious at a time in history when the growing human population continues to require increased quantities of food and more than 2 billion people in the world are malnourished (World Health Organization 1995; Pimentel et al. 1997).

Effects of hedges/barriers on soil conservation and maize crop performance

Low erosional losses and lack of treatment effects on soil erosion on 5–10% slopes is consistent with results from a number of studies across erodable soil types (see Pelleck 1992; El-Swaify 1992; Young 1997). High soil erosional losses from steeper continuous cropping (control) plots (>10%) have previously been reported by Angima et al. (2000, 2001). These results suggest that while land with slopes of <10% can be put into production without threat of erosion, land with slopes exceeding 10% may be highly susceptible to soil erosion and related losses. Sustainable utilization of land on slopes exceeding 10% for agricultural activities would therefore call for implementation of soil conservation measures.

Lower soil losses during the second season in the contour hedge plots in comparison to the first season

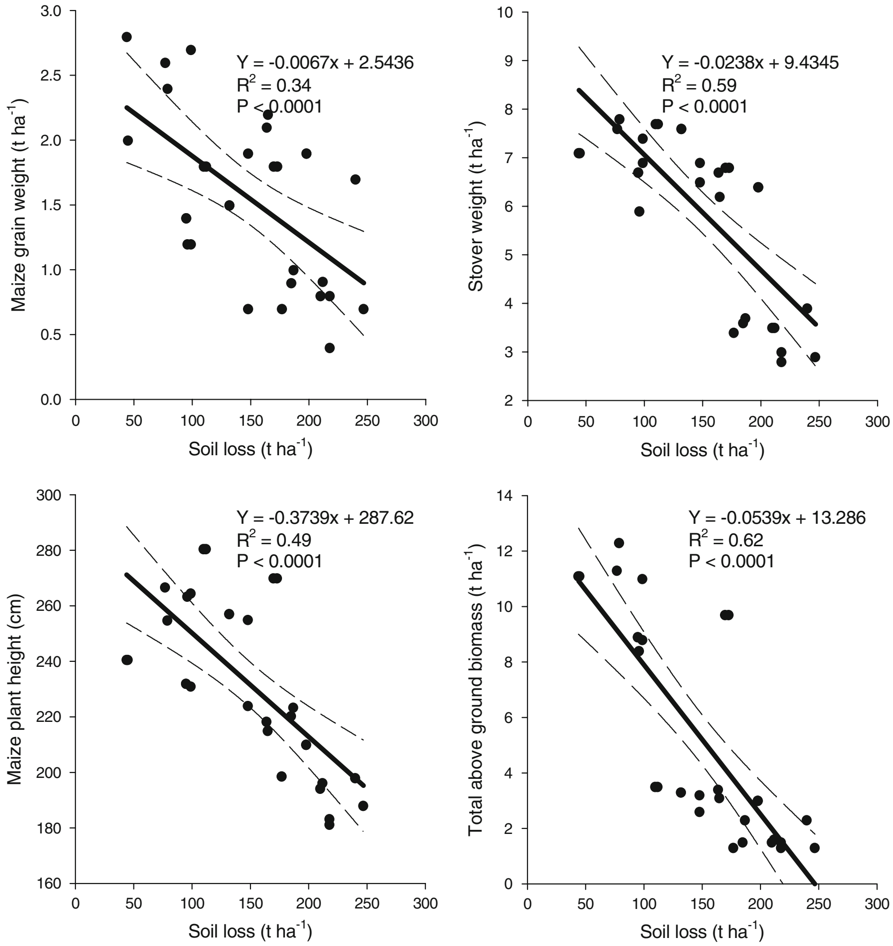

Fig. 2 Relationship between cumulative soil loss and various maize crop growth parameters for control plots in the 10-20% slope category. Dotted lines represent the 95% confidence interval for regression (n = 26)

can be attributed to differences in stage of growth of hedge species over the two seasons, and natural terrace formation. During the second season, hedges/barriers were more mature and therefore formed a more intact barrier to sufficiently obstruct runoff and enhance deposition of the sediment load carried down slope by the runoff. Natural terraces form along contour hedges/barriers, advance and become more effective in obstruction of soil movement with time due to entrapment of washed off soil on the up-slope side of the hedge (Lal 1989; Pelleck 1992; Young 1997).

Napier barriers reduced soil loss better than any other vegetative hedge over the course of the study. Surprisingly, the effectiveness of napier barriers in soil loss control did not translate to higher maize grain yield relative to the control. Despite experiencing higher soil erosional losses than napier barrier plots, the tree and combination hedge plots produced higher maize grain yield than napier barrier plots. The effectiveness of napier grass in soil conservation is attributed to its fibrous and rhizomatous root growth and fast tillering characteristics. These roots spread out superficially (in the 0–30 cm soil depth) over a large area, reinforcing soil around them and bringing about an increase in cohesion and hence in soil shear strength (Dissmeyer and Foster 1985). This superficial rooting characteristic, however, implies that the rooting depths of napier grass and maize are similar and therefore belowground competition for water and nutrients could have led to the low maize yield we observed in napier barrier plots (Mureithi 1992; Mugendi et al. 2003). This shallow rooting characteristic of napier grass contrasts significantly with leucaena and calliandra's deep rooting characteristics (Mugendi et al. 2003). As a result of being deep rooted, calliandra and leucaena exploit a different layer in the soil profile than that exploited by maize, and therefore compete less with the maize crop for water and nutrients (Mureithi 1992; Kang et al. 1985; Mugendi et al. 2003). Apart from reduced competition, deep rooting leguminous species are capable of restricting N leaching and capturing and transferring already leached N from deep soil horizons to topsoil via incorporated biomass and leaf fall (van Noordwijk et al. 1996; Jama et al. 1998), ultimately improving the conditions for associated crops.

Improved maize yield in plots that had a leguminous component, whether as sole tree hedges or combination hedges, may therefore be linked to the improved soil fertility status under those treatments. The two main system positive performance indicators in this study, i.e. soil conservation and maize crop yields were, however, only simultaneously optimized in combination hedge treatments. This could probably be attributed to positive interactions between leguminous species (calliandra and leucaena) and non-leguminous napier grass (see National Research Council 1983; Mureithi et al. 1995). Positive interaction of hedge species would imply fast, robust growth, higher tillering ability and more biomass; factors that are a pre-requisite for effective soil conservation and nutrient transfer to alleys via incorporated biomass.

Controlled studies have shown a significant direct transfer of fixed-N to the associated non-legume species (Eaglesham et al. 1981; Giller et al. 1991; Frey and Schüepp 1993; Stern 1993; Chu et al. 2004). There is evidence that mineralization of decomposing legume roots in the soil can increase N availability to associated crops (Schroth 1995). Additionally, it has been shown that in addition to performing better when grown in association with legumes (Mureithi et al. 1995; Willey 1979), grasses stimulate legumes to increase the rate of N fixation by creating nitrogen deficiency in the soil (Willey 1979; Mureithi et al. 1995). A combination of these factors would suggest enhanced N availability/reduced nutrient losses from plots and reduced napier barrier-maize crop competition (Schroth 1995; van Noordwijk 1989; van Noordwijk et al. 1996) in plots served by combination hedges and hence improved conditions for maize crop growth leading to improvement in maize crop yield.

Estimates of lower soil loss on 20–30% and >30% slope categories relative to 10–20% slope category agrees with earlier observations by Angima et al. (2000, 2001). These lower soil loss values in the 20–30 and >30% slope categories relative to 10–20% slope can be associated with higher clay concentration in the 20–30% and >30% slopes relative to the 10–20% slopes. High soil clay content leads to surface sealing, resulting in low soil particle detachment (Morgan and Rickson 1995). A high percentage of silt and fine sand decreases the raindrop energy required to break down soil clods, increasing the susceptibility of soil particles to detachment and hence erosion (Morgan 1986). This means that on steeper slopes (20–30% and >30% slope categories), the ability of soil to resist detachment by runoff flow energy was higher than on the 10–20% slope category.

Possible trade-offs and win-win scenario in use of different vegetative hedges/barriers

The results of this study have a number of implications for land owners in the central highlands of Kenya and similar regions. For landowners/users with relatively flat land (5–10% slope), adoption of any specific contour hedge/barrier should mainly be guided by the potential effect of hedge/barrier species on crop yield and soil fertility. Our results, however, suggest trade-offs in terms of decision making between soil conservation, soil fertility enhancement and maize crop production for farmers whose farms or part of their farms fall on slopes of >10%. The following scenarios demonstrate the reasons for these trade-offs.

In this study, napier barriers were the best soil conservation treatment, with ability to significantly reduce soil losses only one year after establishment. Though we can not ascertain the extent and exact time because our erosional measurements started when hedge/barrier species were 1 year old, it is apparent that the significant influence of napier grass on soil losses was manifested earlier. Neither leguminous nor combination hedges could significantly reduce soil erosion one year after establishment. Leguminous and combination hedge plots, however, recorded higher maize crop yields than napier grass plots throughout the trial.

Mineral-N is the most limiting nutrient to crop production in the central highlands of Kenya and therefore could be used as an indicator of potential land productivity in this region (Mugendi et al. 1999). Leguminous hedges improved soil N status, better than any other hedge/barrier. On the other hand, combination hedges were not as good as napier grass in soil conservation, but better than tree hedges, and not as good as tree hedges in soil fertility amelioration but better than napier grass. For most of the other soil nutrients, the effects of either combination or leguminous hedges were similar. These differences in vegetative hedge/barrier performance for different desirable agricultural attributes demonstrate a need for trade-offs in selecting specific vegetative hedges/barriers from those demonstrated in this study. Adopters would have to decide whether long term benefits associated with soil conservation or immediate benefits associated with soil fertility amelioration and maize crop yield are more important.

A win-win scenario for production, long term soil health and environmental management in this case would be guaranteed by adoption of combination hedges for three reasons: (i) the combination hedge performed better than leguminous hedges and control in soil conservation, (ii) soil fertility in combination hedge plots was better than in napier barrier and control plots but comparable to that in leguminous hedge plots and, (iii) maize crop yield from combination hedge plots was better than yield from napier grass and control plots but comparable to leguminous hedge plots.

Conclusion

The results of this study lead us to a number of conclusions: (i) soil erosion is a major cause of declining maize crop yields in arable steep-lands of the central highlands of Kenya, (ii) well selected vegetative hedges have a potential to significantly improve and manage soil productivity in these arable steep-lands, (iii) though napier barriers are efficient in soil conservation in the short run, they are incapable of contributing to enhanced crop yields as is the case with leucaena, calliandra and combination hedges. Considering that none of the hedges/barriers performed best in all the desirable characteristics, the results of this study suggest a need for trade-offs in selecting the most suitable hedge for sustainable arable steep-land production. A combination of napier grass with either calliandra or leucaena in the hedge (combination hedge) seems to provide the best win-win scenario for reducing soil erosion, improving soil fertility and enhancing crop yield.

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