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The Role of Biological Technologies in Land Quality Management: Drivers for Farmer's Adoption in the Central Highlands of Kenya

J.K. Mutegi, D.N. Mugendi, L.V. Verchot, and J.B. Kung'u

Abstract We established hedges of calliandra, leucaena, napier, and their combinations along the contours on slopes of between 5 and 40% as options for soil and nutrient management on steep arable landscapes. Hedge biomass was harvested after every 2 months following proper hedge establishment and incorporated into the plots that were served by specific hedges. After 2.5 years farmers–research group interactions were terminated and farmers were left to continue independently. Three years later the region was surveyed for adoption rates, adoption drivers, and technology adaptation. We consistently observed significantly higher soil pH, exchangeable bases (Ca and Mg), and C in both sole leguminous hedge treatments and combination hedges at time 22 months in comparison to time 0 months ($P < 0.0001$). Consistent significant erosion differences between hedges were observed during the fifth season on slopes exceeding 10% ($P < 0.05$). Farmers' adaptations of hedges ranged from changes in type of trees used, contour hedge tree arrangement patterns, and frequency of pruning of hedge trees. The Logit model was significant at 10% level and predicted 72% of both adopters and non-adopters. The variables farmers' contact with extension agents, education level, farm income, livestock numbers, land size, membership to group or cooperative, sex, and age were significant in explaining contour hedge adoption. We conclude that contour hedges are capable of reducing soil losses and improving crop production and that households that have more educated heads with more livestock and higher farm income are more likely to adopt contour hedge technologies.

Keywords Adoption · Calliandra · Leucaena · Napier · Soil conservation

Introduction

Soil degradation is widely recognized as one of the most significant problems impacting the sustainability of agricultural productivity in many parts of the world (Veloz et al., 1985; Lutz et al., 1994; Barrett et al., 2002). In sub-Saharan Africa one of the regions where soil and nutrient degradation is significant is the central highlands of Kenya (Mugendi et al., 2003; Angima et al., 2003). This degradation is associated with, among others, the rapid population growth, cultivation on fragile ecosystems, and continous cropping. For example, Angima et al. (2002) estimated soil loss in central highlands to be in the range of 150–200 t ha^{-1} yr^{-1}. 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} yr^{-1} (Mantel and van Engelen, 1999). In addition to causing serious monetary losses to farmers, soil loss pollutes rivers and other water bodies potentially causing eutrophication, bottom water hypoxia, and health hazards to both humans and animals (CAST, 1985; Justic et al., 1995).

Construction of physical soil conservation structures is expensive, laborious, and time consuming. In such an environment where resources like labor and capital are limited and farmers' strength

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is diminishing due to high disease prevalence and hunger, adoption of such energy- and labor-intensive technologies is difficult. This has ultimately led to low adoption of conventional soil conservation technologies resulting in heavy soil and nutrient losses.

The usefulness of contour hedges as alternatives to physical soil conservation structures has been demonstrated in Kenya (Raintree and Torres, 1986; Angima et al., 2002) and Nigeria (Lal, 1989). Most of these trials have, however, been executed on a few slope categories and therefore do not capture the whole array of landscape differences in the farmers' fields. Additionally, most of the tests for contour hedge efficiency trials have mainly been carried out on-station using controlled conditions and have tended to focus on one attribute at a time such as soil conservation while leaving out the effects of these hedges on soil fertility and crop production (see Angima et al., 2002, 2003). This limits applicability of these earlier results across varying landscape types and farmers' challenges. 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). Experience has shown that appropriate technologies are not always adopted, even where the need is obvious (Guerin, 1999). Farmers may reject or abandon many technologies that have been useful and adopt others in their place since they consider a variety of factors in deciding whether or not to adopt particular conservation practices (Brouwers, 1993; McDonald and Brown, 2000; Soule et al., 2000). This highlights the need to develop a better understanding of the conditions that encourage sustained adoption of conservation practices.

This work was therefore set out to explore and provide implicit data on the effect of contour hedges on soil erosion, soil fertility, and crop production on the steep landscapes of the central highlands of Kenya. We do understand that the purpose of agricultural technology is not yet fulfilled prior to farmers' uptake of the technology. It is due to this recognition that this study went further to investigate farmers' adaptation and determinants of farmers' uptake of contour hedge technologies.

Materials and Methods

Description of the Study Area

This study was conducted in Chuka division, 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 of rainfall 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 humic Nitisols (FAO, 1990) with an average soil reformation rate of 2.2–4.5 t ha^{-1} yr^{-1} for the top 0–25 cm soil depth and 4.5–10 t ha^{-1} yr^{-1} for the 25–50 cm soil depth (McCormack and Young, 1981; Kilewe, 1987). They are deep, well weathered with friable clay texture and moderate to high inherent fertility.

Experimental Design and Methodology

We selected 10 farms each with 5–10, 10–20, 20–30, and 30–40% slope categories. Within each farm and slope we then established and evaluated monospecific double hedges of calliandra, leucaena, napier, and combination hedges of calliandra + napier and leucaena + napier. The controls were continuous maize plots without vegetative hedges but with similar agronomic management. In each farm, all the treatments and the control were randomized across every slope category and replicated three times. Each hedge was made up of two rows of the above species arranged in interlocking/zigzag 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 spacing estimated according to Young's (1997) formula for biological hedge efficiency as influenced by degrees of arable land steepness stated as follows:

$$W = 200/S\% \tag{1}$$

where W = inter-hedge spacing in meters and $S\%$ = the percent slope.

Where there was a napier + either calliandra or leucaena, the tree row preceded the napier grass row upslope. 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 using 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 were left for 1 year to establish after which they were regularly pruned 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 was cut into fine pieces and incorporated into the test plot it served by use of hand hoe.

Soil Sampling and Analysis

Initial sampling for soil characterization was done on each farm before commencing the trials. The second set of soil samples was collected 22 months after establishment of the trials. For each collection date, at least six samples from each plot were collected. The six samples were mixed thoroughly and sub-sampled to form one composite sample for analysis. 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 dry weight basis. Nitrate plus NO_2^- were determined by Cd 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 with the undisturbed core method (Anderson and Ingram, 1993) and used for conversion of NO_3 values from milligrams per kilogram to kilograms per hectare.

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 Bouyoucos 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).

Rainfall and Soil Loss Assessment

Rainfall was measured throughout the study period by use of two centrally placed rain gauges. Soil loss from contour hedge and control plots was estimated during the third and fifth seasons of hedge growth. It was assessed by use of plastic erosion pins (FAO, 1993) fixed at a spacing of 2 × 2 m on each plot. The measurements were taken to the nearest millimeter to allow any seasonal change in soil level to be clearly recognized. The resulting soil loss measurements were converted to tons per hectare by first calculating the volume of topsoil washed per plot by use of an equation:

$$\text{Plot volume} = (\text{average depth of washed soil}) \times (\text{plot length}) \times (\text{alley width}) \quad (2)$$

Using plot bulk density values the resulting volume values were converted to tons of soil lost per hectare.

Maize Yield Assessment

All the plots under evaluation were planted with maize (hybrid 513 variety) at a spacing of 0.75 × 0.25 m (53,000 plants ha^{-1}) which is the local agricultural extension recommendation. Maize was harvested from a net plot after removing the outer row to avoid the edge effect by cutting at root collar. It was weighed immediately to determine the total fresh weight (stover + unshelled cobs). The unshelled cobs were separated from the stover after which the total stover fresh weight was 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. Dry weight was determined by drying the above sub-samples (cobs, stover, and grain) at 60°C for 3 days to a constant weight and then applying the resulting weight in calculation of dry weight of yield per hectare. In addition to the yield parameters, we measured maize crop height at the maize tasseling stage. The proportion of dry matter was calculated by use of the following 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, 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).

Field Survey

Stratified random sampling was used to identify 120 farmers (contour hedge adopters and non-adopters). Adopting households were defined as those households that had planted at least 50 m of contour hedge trees (from the time of research group/farmer contact) and maintained them for at least 2 years. Non-adopting farmers were defined as those with sloping farm but who had not planted trees in a hedge pattern on their arable farms since the time of farmer research/research group contact. Structured questionnaires were used as survey instruments. The questionnaires were pre-tested on 12 randomly selected adopters and non-adopters, analyzed, and then revised to incorporate farmers' suggestions on various observations and practices related to contour hedges on their farms and villages. Village-level data were collected from focused group interviews in the villages.

Analytical Model

To evaluate farmers' adoption decisions on contour hedges a Logit model (Maddala, 1983) was used. Logit analysis is used when the dependent variable takes on discrete categorical (0, 1) values rather than continuous numerical values. It was employed in this study because adoption can be considered a discrete, categorical variable equal to 1 if the farmer adopts contour hedges and 0 if the farmer does not. Logit model has widely been applied in adoption studies (Bagi, 1983; Polson and Spencer, 1991; Adesina and Sirajo, 1995). To define this model in a simple way, let Y be the decision to adopt contour hedge technology and $\mathbf{X}$ a vector of explanatory variables related to adoption. The model can be stated as $\mathbf{X} = F$ (social, institutional, physical, economic factors), where social factors include age, family size, and education; institutional factors include land tenure, membership to groups and cooperatives, and contacts with extension agents; physical factors include land size and slope; and economic factors include farm income, non-farm income, risks, and livestock numbers. The adoption decision of farmers is specified as $Y = f(\mathbf{X}, e)$, where e is an error term with logistic distribution. The conceptual model is stated as follows:

$$\begin{aligned} Y_{ik} &= F(1_{ik}) = \frac{e^{Z_{ik}}}{1+e^{Z_{ik}}} \text{ for } Z_{ik} \\ &= \mathbf{X}_{ik}\beta_{ik} \text{ and } -\infty < Z_{ik} < +\infty \end{aligned} \quad (4)$$

where Y_{ik} is the dependent variable that takes on the value of 1 for the ith farmer who adopted contour hedge and its variants in zone k and 0 if no adoption occurred. $\mathbf{X}_{ik}$ is a matrix of explanatory variables related to adoption of contour hedges by the ith farmer in zone k, and β_{ik} are the vectors of parameters to be estimated. 1_{ik} is the implicit variable that indexes adoption. The Logit model was estimated using maximum likelihood techniques.

Definition of Variables Used in Empirical Model

The definition of all the variables in the empirical model was as shown in Table 1. Relevant variables were selected after thorough review of literature

Table 1 Definition of variables used in empirical/econometric models

Variable	Description
SEX	Dummy variable for gender of the plot owner; 1 if the owner is a man and 0 if the owner is a woman
AGE	Age of the farmer (years)
FSIZE	Family size
EDUC	Number of years spent in school
LVST	Livestock (TLU)
TENURE	Dummy variable for tenure status of the farmer; 1 if the farmer is the farm owner and 0 otherwise
CONTACT	Dummy variable for extension agent contact; 1 if a farmer has contacts with change agents and 0 otherwise
FINC	Variable for total annual farm income
NFINC	Variable for total annual non-farm income
GOCOOP	Dummy variable for membership to group or cooperative; 1 if a farmer is a group/cooperative member and 0 otherwise
AREA	Total farm area owned by the farmer (ha)
SLOPE	Average slope of the farm (degrees) determined by use of a clinometer
PERCEPTION	Dummy variable for farmers' perception of erosion occurrence in his farm; 1 if farmer perceived occurrence and 0 otherwise
RISK	Risk index of respondent

(see Ervin and Ervin, 1982; Atta-Krah and Francis, 1987; Adesina and Sirajo, 1995; Lapar and Pandey, 1999; Garcia, 1997) and from constant interaction with farmers in this region. The personal characteristics of farmers like level of education, age, and family size were expected to affect farmers' perception and adoption of contour hedges. Age (AGE) was expected to negatively affect adoption since younger farmers are likely to perceive a longer time horizon than older farmers. Education (EDUC), on the other hand, was expected to have a positive influence on adoption. Educated farmers have been found to have a great likelihood of adopting soil conservation technologies (Ervin and Ervin, 1982). Family size (FSIZE) is a measure of the size of the household. Large family sizes may indicate more labor availability to establish and manage contour hedges. Research on alley cropping, one of the variants for contour hedges, revealed that tree-based systems for soil management are labor intensive (see Atta-Krah and Francis, 1987) and therefore inappropriate for labor-stretched households.

CONTACT is a dummy variable that takes the value 1 if a farmer had contact with agroforestry extension agent within the last 5 years preceding interview and 0 if otherwise. Often extension agents expose and encourage farmers to take up technologies that have been shown to work for similar conditions elsewhere. It was hypothesized that CONTACT is positively related to adoption of contour hedges. We hypothesized that farmers group, organizations/cooperative (GOCOOP) was positively correlated to adoption due to information flow among involved members.

FINC measures the income a farmer derives from his farming activities. Depending on FINC level, it might imply that either the farmer has more resources to engage additional labor to establish and manage hedges or he does not have. NFINC measures income associated with non-agricultural activities like off-farm employment. Studies have indicated mixed response of farmers' adoption behavior to availability of non-farm income. While a number of these studies have shown a positive correlation between non-farm income and adoption of agroforestry technologies, a number of others have shown an inverse or no relationship between non-farm income and adoption of such technologies (see Adesina et al., 2000). In this case the connection between non-adoption and non-farm income has been associated with availability of non-farm income to meet household requirements while adoption has been associated with ability to take agricultural risks and availability of supplemental income for financing conservation expenditure (Garcia, 1997).

TENURE is a dummy variable for the tenure status of land. Farmers with insecure tenure may not adopt soil conservation technologies due to uncertainty of capturing long-term benefits and vice versa for those with secure land tenure. The farmers' perception of risk (RISK), e.g., risks associated with new technologies like pests and diseases and loss of short-run income, affects technology adoption. Farmers who avoid risk may be reluctant to take up uncertain technologies. Farmers with higher risk index are therefore more likely to take up soil conservation technologies (Garcia, 1997).

Data 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 reduce losses of soil and enhance crop performance. Social data and models were run using Statistical Package for Social Sciences (SPSS).

Results

Rainfall Characteristics

We recorded an average annual rainfall of 1032 mm split into 467 mm during the long rains and 565 mm during the short rains. This annual rainfall was 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. This monthly rainfall distribution was in agreement with the expected rainfall pattern for this region.

Effects of Hedges on Soil Characteristics

We observed significantly higher soil pH ($P = 0.013$), Ca ($P = 0.001$), Mg ($P = 0.042$), and C ($P = 0.032$) after 22 months of trial, relative to the initial conditions. Inorganic N was higher at time 0 relative to 22 months later ($P < 0.0001$). We consistently observed significantly higher soil pH, exchangeable bases (Ca and Mg), and C in both sole leguminous hedge treatments and combination hedges at time 22 months in comparison to time 0 months ($P < 0.0001$) (Table 2). Soil exchangeable K increased significantly in the sole leguminous hedge plots after 22 months of experimentation ($P = 0.006$). 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 hedges relative to the control and napier after 22 months of trial ($P = 0.027$).

Soil Erosion and Maize Crop Performance

The third season (represents the effect of the two seasons old hedges) on average registered higher soil

Table 2 Properties of top 0–30 cm depth of soil at the start and after 22 months of experimentation in Chuka division, central highlands of Kenya

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	$4.8^c \pm 0.09$	$4.2^c \pm 0.18$	$2.1^a \pm 0.07$	$0.5^{b,c} \pm 0.03$	$17.4^{c,d} \pm 0.28$	$62.7^a \pm 5.88$
Calliandra	$4.7^d \pm 0.11$	$3.8^c \pm 0.18$	$1.4^{c,d} \pm 0.04$	$0.4^c \pm 0.04$	$17.0^d \pm 0.13$	$60.9^a \pm 4.31$
Leucaena	$4.9^c \pm 0.15$	$3.9^c \pm 0.14$	$1.1^e \pm 0.06$	$0.5^b \pm 0.02$	$17.1^{c,d} \pm 0.22$	$66.1^a \pm 3.39$
Napier	$4.6^d \pm 0.08$	$4.2^c \pm 0.15$	$1.7^b \pm 0.02$	$0.5^{b,c} \pm 0.02$	$17.1^{c,d} \pm 0.25$	$70.3^a \pm 3.11$
Calliandra + napier	$4.6^d \pm 0.02$	$3.9^c \pm 0.20$	$1.3^{d,e} \pm 0.09$	$0.4^c \pm 0.05$	$16.8^d \pm 0.16$	$71.8^a \pm 7.46$
Leucaena + napier	$4.8^c \pm 0.03$	$4.0^c \pm 0.08$	$1.6^{b,c} \pm 0.03$	$0.5^{b,c} \pm 0.02$	$17.6^{b,c,d} \pm 0.27$	$70.3^a \pm 4.07$
After 22 months of experimentation (time 22 months)						
Control	$4.9^c \pm 0.09$	$3.8^c \pm 0.10$	$1.0^e \pm 0.16$	$0.2^d \pm 0.03$	$18.3^{b,c} \pm 0.26$	$26.6^d \pm 3.40$
Calliandra	$5.2^b \pm 0.06$	$4.7^b \pm 0.12$	$1.5^{b,c} \pm 0.04$	$0.6^b \pm 0.05$	$21.7^a \pm 0.82$	$38.7^{b,c} \pm 0.85$
Leucaena	$5.1^b \pm 0.03$	$4.6^{b,c} \pm 0.21$	$1.5^{b,c,d} \pm 0.04$	$0.7^a \pm 0.03$	$20.8^a \pm 0.76$	$43.7^b \pm 0.26$
Napier	$4.7^d \pm 0.13$	$3.3^d \pm 0.07$	$1.3^{d,e} \pm 0.13$	$0.4^c \pm 0.06$	$18.2^{b,c} \pm 0.15$	$27.4^d \pm 0.22$
Calliandra + napier	$5.3^a \pm 0.04$	$5.5^a \pm 0.22$	$1.7^b \pm 0.11$	$0.4^c \pm 0.04$	$20.7^a \pm 0.29$	$31.6^{c,d} \pm 3.17$
Leucaena + napier	$5.2^{a,b} \pm 0.05$	$5.1^a \pm 0.10$	$1.8^a \pm 0.07$	$0.6^b \pm 0.09$	$18.6^b \pm 0.22$	$30.0^{c,d} \pm 0.27$

Means within a column followed by different letters indicate significant difference based on Fisher's protected LSD test ($P = 0.05$); values are means ± SE

Table 3 Effect of vegetative hedges on soil losses on 5–40% slopes

Slope category (%)				
Treatment	5–10	10–20	20–30	30–40
Soil loss from two seasons old hedge plots (t ha^{-1})				
Control	16.80[a]	79.50[a]	77.40[a]	67.53[a]
Calliandra	15.52[a]	37.53[b]	34.87[b]	26.47[b]
Leucaena	14.70[a]	46.63[b]	37.50[b]	29.60[b]
Napier	12.64[a]	20.87[c]	22.90[c]	20.62[b]
Calliandra + napier	13.57[a]	30.57[b]	26.50[b,c]	26.58[b]
Leucaena + napier	14.17[a]	35.18[b]	33.73[b]	21.78[b]
Soil loss from four seasons old hedge plots (t ha^{-1})				
Control	16.48[a]	79.61[a]	79.25[a]	78.90[a]
Calliandra	11.00[a]	26.14[b]	28.92[b]	22.18[b]
Leucaena	12.31[a]	29.68[b]	28.62[b]	23.50[b]
Napier	10.10[a]	10.21[c]	11.90[c]	9.67[c]
Calliandra + napier	12.83[a]	17.70[b,c]	14.15[c]	11.55[c]
Leucaena + napier	10.66[a]	17.67[b,c]	13.38[c]	12.98[c]

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

losses ($P = 0.004$) than the fifth season (represents the effect of the four seasons old hedges) for treatments with hedges and vice versa for the control (Table 3). Soil losses from plots on 5–10% slope had a narrow range (10–17 t ha^{-1} yr^{-1}) for different treatments and seasons in comparison to other slopes, and there were no significant differences between treatments ($P < 0.05$).

During the third season, we observed significantly lower ($P < 0.001$) soil losses in plots with hedges relative to the control on slopes exceeding 10% but with the exception of napier, no significant differences among different types of hedges. Consistent significant erosion differences between hedges were observed during the fifth season on slopes exceeding 10% ($P < 0.05$). Napier hedges were the most effective at reducing erosion losses in both seasons (Table 3). We observed significantly lower soil losses from the four seasons old combination hedges than individual tree hedges ($P = 0.012$). Soil loss on 10–20% slope category was higher than soil loss on any other slope category ($P = 0.043$). In an attempt to understand this seemingly unusual phenomenon we analyzed our particle size data while treating slope categories as factors and particle size/soil texture as variates. The soil textural characteristics for different slope categories were characterized by significantly lower ($P < 0.001$) clay content on the 10–20% slope relative to 20–30 and 30–40% slope (Table 4).

The presence of hedges had very little impact on maize crop yields during the first season (Table 5). Sole napier hedges suppressed yields during this season, but not during the fourth. The effects of the hedges were more apparent during the fourth season. A number of treatments resulted in significant increases in yields, particularly when N-fixing trees were part of the system. Maize yield was higher during the fourth season than the first season for all the treatments with vegetative hedges, but lower on the control.

Table 4 Soil textural characteristics at different slope categories in Kirege

	Particle size (g kg^{-1})		
Slope category (%)	Sand	Silt	Clay
5–10	318.6[a]	284.9[a,b]	396.5[a]
10–20	304.3[a]	310.1[a]	385.6[a]
20–30	299.6[a]	279.8[b]	420.5[b]
30–40	299.5[a]	290.5[a,b]	411.0[b]

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

We observed significantly lower grain yield when cumulative soil loss exceeded 150 t ha^{-1} yr^{-1} ($P = 0.01$) and significantly lower plant height and stover weight when cumulative soil loss exceeded 150 t ha^{-1} yr^{-1} ($P < 0.0001$) (Table 6).

Household Characteristics of Adopters and Non-adopters of Contour Hedges

A higher percentage of male-headed households than female-headed households had adopted contour hedge technologies on their steep arable land (Table 7). Adoption rose with the level of formal education from 0–1 year of education category to 8–12 years of

Table 5 Maize yield at Chuka farms in plots served by various vegetative hedges during the first and fourth seasons of the trial

Treatment	First season of trial	Fourth season of trial	Treatment mean
	....................Maize grain (t ha^{-1} ± 1 SE).................		
Control	2.2^{a} ± 0.5	2.0^{a} ± 0.3	2.1^{a}
Calliandra	1.9^{a} ± 0.4	2.9^{b} ± 0.4	2.4^{a,b}
Leucaena	2.1^{a} ± 0.6	3.1^{b} ± 0.5	2.6^{a,b}
Napier	0.9^{b} ± 0.1	2.1^{a} ± 0.4	1.5^{c}
Calliandra + napier	2.2^{a} ± 0.7	3.4^{b} ± 0.8	2.8^{b}
Leucaena + napier	2.3^{a} ± 0.8	3.6^{b} ± 0.6	2.9^{b}

For each column, means followed by different letters indicate significant difference based on Fisher's protected LSD test ($P = 0.05$); values are mean yield ± SE

Table 6 Relationship between observed soil erosion classes with selected maize growth parameters in Chuka farms

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	1.9^{a} ± 0.2	247.3^{a} ± 5.0	7.0^{a} ± 0.2	10.2^{a} ± 0.5
100–150	1.5^{a} ± 0.2	259.0^{a} ± 8.5	7.3^{a} ± 0.2	4.1^{b} ± 0.3
150–200	1.5^{a} ± 0.2	226.2^{b} ± 8.6	5.6^{b} ± 0.5	3.2^{b,c} ± 0.1
>200	0.9^{b} ± 0.3	190.1^{c} ± 2.8	3.3^{c} ± 0.2	1.6^{c} ± 0.1

For each column, means followed by different letters indicate significant difference based on Fisher's protected LSD test ($P = 0.05$); values are means ± SE
TAGB – total aboveground biomass

Table 7 Household characteristics of adopters and non-adopters of contour hedge technology in Chuka division, Kenya (used $N = 120$)

Variable	Parameter	Non-adopters ($n = 60$)	Adopters ($n = 60$)
House head sex	Male (%)	45	55
	Female (%)	64	36
Education (%)	0–1 year	64	36
	1–4 years	51	49
	5–8 years	45	55
	8–12 years	40	60
	>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

education category and then declined sharply beyond that point. The adopters had on average more livestock than non-adopters. Adoption was highest among the farmers who had bought their land, low among the farmers who had inherited land, and lowest among those farmers who were on land rent arrangements.

Farmers' Adaptation of Contour Hedges

A number of adopters (55%) modified the originally demonstrated contour hedges (double interlocking hedges of calliandra, leucaena, and napier) with adaptations of their own (Table 8). Such adaptations ranged from changes in the type of trees used in contour hedges and contour hedge patterns to frequency of pruning of contour hedge trees. Majority of contour hedge modifiers cut the hedge trees at a height that was higher than the one that was demonstrated. High in the list of common modifications also were reduction in inter-row spacing and introduction of *Tithonia diversifolia* into the hedges (Table 8). Approximately 3% of the adopters left hedges to grow to trees. We found that such farmers were keen on using hedge species for fuelwood and as seed orchards.

Determinants of Adoption of Contour Hedges

The Logit model was significant at the 10% level. The model correctly predicted 72% of both adopters and non-adopters. Eight variables were significant in

Table 8 Percentage of adopters making modifications in their management of contour hedges in Chuka division, Kenya ($N = 120$)

Farmers' modification	Responses	Percentage
Inter-row spacing expanded	10	8
Inter-row spacing reduced	20	17
Introduced *Tithonia diversifolia* species into the double rows	18	15
Planted hedge as single row instead of double rows	9	8
Planted more than two rows in the same hedge	6	5
Height of tree cut back higher than demonstrated	25	21
Often allowed goats to graze on the hedges directly	4	3
Left hedges to grow into trees before cutting	4	3

Table 9 Econometric model results of factors affecting farmers' adoption of contour hedges in Chuka division, central highlands of Kenya

Variable	Estimate	Standard error	*t*-Statistic	*P* value
SEX	1.062	0.512	1.09	0.05
AGE	−0.03	0.031	1.31	0.06
FSIZE	0.152	0.127	1.71	NS
RISK	−0.302	0.533	0.59	NS
EDUC	3.39	1.12	2.91	0.005
LVST	1.59	0.821	1.93	0.02
FINC	1.61	0.512	1.95	0.01
NFINC	−0.191	0.622	0.46	NS
CONTACT	1.83	0.523	3.12	0.001
GOCOOP	2.43	0.921	2.753	0.05
SLOPE	0.66	0.473	1.25	NS
PERCEPTION	0.53	0.330	0.27	NS
AREA	−1.53	0.723	1.84	0.02
Intercept	−7.43	2.12	−3.56	0.005
Percent correct predictions	72.3			
Log of likelihood function	−54.21			

Source: Ruxton and Neuhauser (2010)

explaining the adoption of contour hedge technology at 5–10% level (Table 9).

They were farmers' contact with extension agents which was significant at 0.1%, level of education at 0.5% level, farm income at 1% level, livestock and land size at 2% level, membership to group or cooperative and sex at 5% level, and age at 6% level. The other variables did not significantly influence adoption of contour hedges. The coefficients for land size and age were negative and significant at 2 and 6% levels, implying that these two variables were inversely related to contour hedge adoption. Other variables like perception of soil erosion occurrence, slope, family size, and risk perceptions were not important in explaining contour hedge adoption behavior in this region.

Discussion

Soil Analytical Characteristics

The increase in soil pH on plots with tree hedges can be attributed to an increment in exchangeable bases (Ca^{2+} and Mg^{2+}). Increased calcium and magnesium react 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 (Loomis and Connor, 1992). The high total soil organic carbon in the hedge plots after 22 months was most likely a result of transfer of hedge pruning into the plots.

Low inorganic N concentration at 22 months relative to initial levels can be attributed to weather and sampling time differences. The first sampling was done toward the end of September after a long dry spell and during land preparation for planting, while the second sampling (time 22 months) was done in July after the March to May rains (long rains) and July drizzles and at maize tasseling stage. So probably a lot of nitrate had been immobilized, leached, denitrified, or even taken up by the growing crop at the time of sampling. Maize has the highest demand for N at the tasseling stage (Karlen et al., 1988), so nitrogen would be locked in maize plant tissues at this time.

Soil Conservation and Maize Crop Performance

Lower soil losses during the fifth season on the contour hedge plots in comparison to the third season can be attributed to hedge species differences in stage of growth and natural terrace formation. During the fifth season, hedges were more mature and therefore formed a more intact barrier to sufficiently obstruct runoff and enhance deposition of the sediment load carried downslope by the runoff. Natural terraces form along contour hedges, advance, and become more effective in obstruction of soil movement with time due to entrapment of washed off soil on the upslope side of the hedge (Lal, 1989).

Napier hedge 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 many tillers within a short time, forming an intact hedge. Lower soil loss values on combination hedge plots as compared to single tree species hedge could partially be attributed to presence of napier component and the positive interaction between napier and leguminous tree species which recycle and fix N (NRC, 1983; Young, 1997).

The lower soil loss in the 20–30 and 30–40% slope categories relative to 10–20% slope confirms Angima et al.'s (2003) observation of lower soil losses on 40% slope than on 20% slope. It is probable that the low soil clay content we observed in the 10–20% slope relative to higher slopes explains this observation. High soil clay content leads to surface sealing resulting in low soil particle detachment (Morgan and Rickson, 1995). 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, the ability of soil to resist detachment by runoff flow energy was probably higher than on the 10–20% slope category.

The inverse relationship between maize crop growth parameters and soil loss can be attributed to loss of topsoil, which is the most favorable soil for crop growth. The loss of topsoil inevitably reduces soil productivity, which in turn deters crop growth because the topsoil is usually the most fertile, containing natural plant nutrients, humus, and any fertilizers that farmers have applied (Lal, 1989). 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 sloping landscapes.

Farmers' Behavior and Adoption of Contour Hedges

Farmers' adaptation of contour hedges can be attributed to farmers' attempts to make contour hedge technologies more applicable to their local/individual conditions. Though we would have expected a strong and positive relationship between perception of soil erosion and slope with farmers' uptake of contour hedges, the two variables though positive did not significantly influence adoption of contour hedges. It is probable that steep landscapes increased farmers' risk index, hence negatively affecting farmers' willingness to invest their time and other resources in such land. Farmers' age was significantly related to likelihood of adoption at the 10% level of significance. The negative sign on AGE suggests that contour hedges are more likely to be adopted by younger farmers. This is probably because, as shown by a number of studies elsewhere, younger people are often better disposed to trying new innovations and have longer planning horizons to justify investments in tree-based technologies (Adesina et al., 2000; Adesina and Sirajo, 1995; Ervin and Ervin, 1982). The positive sign on land tenure suggests that the possession of rights over trees has positive influence on likelihood of contour hedge technology adoption. While the coefficient for farm income (FINC) was positive and significant, the coefficient of non-farm income (NFINC) though not significant was negative. This implies that farmers who made more resources from agricultural activities were more likely to adopt biological contour hedges than those that made less. On the other hand, farmers with higher non-farm income were more unlikely to take up contour hedges relative to those who did not have non-farm income or those with lesser non-farm income. Though risk perception was not a significant determinant of contour hedge adoption, the coefficient for risk was negative, indicating that farmers with a higher risk index were more unlikely to adopt contour hedges relative to those with lower risk index.

Conclusions

We conclude that contour hedges are capable of reducing soil losses and improving crop production. The farmers' level of education, age, land size, risk perception, farm income, and number of livestock are important variables in as far as adoption of contour hedgerows is concerned in the central highlands of Kenya.

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