Out of site out of mind: Quantifying the long-term off-site economic impacts of land degradation in Kenya

By

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Land degradation in sub-Saharan Africa (SSA) is a serious problem that is threatening livelihoods of the poor who depend on agriculture. The problem also poses a challenge to economic development since economies of most countries in the region are based on agriculture. Land degradation also leads to sedimentation of surface water bodies, runoff and flooding and other off-site effects (Pagiola, 1999; Scherr and Yadav, 1996; Schroeder, 1993; Unruh, et al., 1993) at local and national level. At global scale, land degradation has been identified as one of the factors that contribute to climate change and loss of biodiversity. Contribution of land degradation to climate change mainly results from emission of Greenhouse Gases (GHG) as a result of bush and crop residue burning and other processes that lead to disruption of the carbon cycle. Degraded land also loses vegetative cover that absorbs the shortwave radiation, leading to global warming (Glasdottir and Stocking 2005). Another effect of changes in vegetative cover is a change in albedo (reflectivity), which changes the absorption of energy. Albedo may have positive or negative effects on warming, depending on the albedo of what replaces the vegetation.

Soil erosion and soil nutrient depletion are the major forms of land degradation in SSA (Pieri, 1989; Oldeman, 1994; Oldeman, et al., 1991; Voortman, et al., 2000). In addition to contributing to fall in agricultural productivity and the consequent food and nutrition insecurity, soil nutrient depletion and erosion could also contribute to deforestation and loss of biodiversity since farmers may be forced to abandon nutrient-starved soils and cultivate more marginal areas such as hillsides and rainforests. Loss of biodiversity and poor water quality in turn could contribute to increase in pests and diseases (Scherr, 2000).

Given the real and potential on-farm and off-site negative impacts of land degradation discussed above, governments in SSA and their development partners have been designing strategies and policies to address the problem as part of their poverty reduction and environmental conservation efforts. This study was conducted with the purpose of determining the on-farm and off-farm economic impacts of land degradation in central Kenya.

Accounting for off-site effects of land degradation

There are many types of land degradation with equally numerous off-site effects. We will therefore focus on only two, namely soil erosion and degradation of vegetation on crop plots and their potential on-farm and off-site impacts. We analyze the offsite effects that we can attribute to land degradation unambiguously and those which we were able to get the costs and benefits data. We quantify the offsite impacts related to sedimentation and how it affects the cost of potable water production. We also analyze the amount of carbon stored in the planted trees, shrubs and grasses, and soil carbon saved due to soil and water conservation or lost due to soil erosion and other channels. Our study is based on a case study of Sasumua water treatment plant located in the Kinale/Kikuyu watershed, which is in the central provinces of Kenya.[1] We consider two scenarios, namely farmer practices that use what we call Sustainable Land Management (SLM) and those who do not practice SLM. The SLM practices considered in this study include:

(i) Agroforestry to help control soil erosion, increase carbon stock, improve soil fertility and other agroforestry benefits (see Sanchez, et al., 1997).

(ii) Application of organic and inorganic fertilizer and incorporation of crop residues

(iii) SWC practices to control soil erosion and to conserve moisture and water.

Though these technologies are highly interrelated, they are separated in this research to emphasize their importance. The SLM practices are assumed to address the offsite effects of soil erosion and degradation of vegetation.

We use the common indicators for economic returns, i.e. Net Present Value (NPV) and the Internal Rate of Return (IRR) to determine whether the SLM practices are profitable from the social perspective. The social Cost-Benefit Analysis (CBA) takes into account the on-farm and off-farm costs and benefits at farm level and at society (community, district, national, regional and global) level. The social NPV will be compared with the private NPV to reflect the benefits and costs that farmers realize when they ignore the off-site effects of production. Hence, comparing the social and private NPV will reflect the impacts of externalities of agricultural production on profit.

We do the social CBA by considering the market failures or policy-induced distortions might distort price signals perceived by agricultural producers; and externalities of land degradation, which might impose costs or benefits on the society.[2] Although the importance of off-site effects of land degradation is widely recognized, most studies focus exclusively on on-farm effects. This is mainly due to difficulties encountered in quantifying and valuing off-site effects. This study quantified the off-site effects of land degradation using data obtained from the Kinale/Kikuyu watershed in the central provinces of Kenya. We assess the cost and benefit with and without SLM practices over a 50 year period. Using a discount rate of 10% (see Pagiola, 1996),[3] the NPV of the costs and benefits is computed with and without soil fertility management, agroforestry and SWC structures, which are the three main components of the SLM considered in this study. If soil erosion is the major form of land degradation in the study area, the effects of continued erosion on agricultural productivity is estimated Using the returns to the investment, which are obtained by taking the difference between the streams of discounted costs and benefits, with and without the adoption of the soil conservation practices. This valuation technique is commonly called the ‘change of productivity approach’.[4] This approach will be used in this study. The approach estimates only the discounted returns to the specific conservation measure being examined.

Due to data availability problems, a simple, flexible and less data intensive model was used to determine the soil loss due to erosion. This model is the Revised Universal Soil Loss Equation (RUSLE) (Renard, et al., 1991). The RUSLE model relates soil loss from a field to the climate, type of soil, topography, and management variables as follows:

$A = RKLSCP$

Where A is the mean annual soil loss (metric tons per hectare), R is the rainfall erosivity index, K is the soil erosivity index, L is the slope length, S is the slope steepness, C is the crop factor, and P is the conservation practice factor.

The weakness of this approach is related to the fact that the crop yield response to soil erosion over time is complex hence controlling for all factors is difficult (Enters, 1998). Additionally, most soil erosion data are exaggerated since they are based on small plots and then extrapolated to larger areas such as a catchment, district, region, etc (Glasdottir and Stocking, 2005; Koning and Smaling, 2005). Even though the RUSLE results don’t account for redeposition, they give a reasonable order of magnitude estimate of on-site costs of erosion from highlands, since these areas are more sources than recipients of erosion. However, due to its parsimonious data requirement and simplicity, RUSLE remains one of the most widely used soil erosion prediction model and has been used in Kenya and many other SSA countries.

The quantity of soil eroded is related to the corresponding crop yield in order to determine the loss of crop productivity due to soil erosion. Since crop yield is determined by many factors, the best estimate is obtainable under experimental conditions, in which most of such factors are controlled. Once the functional relationship between crop yield and soil erosion is determined, the value of crop yield loss due to erosion is computed and used to determine the benefits and costs of investing in controlling soil erosion. Likewise, the value of loss of crop productivity due to soil fertility mining is determined using data from a long-term soil fertility experiment conducted in Kabete, Kenya. This value is also used to determine the benefits and costs of practicing soil fertility management technologies.

The impact of deforestation and reduction of carbon stock in general is estimated after determining the amount of lost carbon using various silvicultural methods. A value is then imputed on the quantity of carbon lost. Land degradation is often correlated with increased soil carbon dioxide emissions and a reduced ability to store carbon. However, as Pagiola (1999) notes, the links between land degradation and carbon dioxide emission are numerous and complex and hence difficult to quantify. Some actions which cause land degradation can increase carbon emissions directly, e.g. bush and crop burning. Some forms of degradation reduce soil carbon, since erosion carries away Soil Organic Matter (SOM). However, this does not necessarily lead to increased emissions, because much of the carbon carried away by erosion may be deposited under conditions where it may be well preserved (e.g. in riverbeds and reservoirs). Land degradation also affects the soil carbon cycle. Lower production of crops and pasture due to degradation will result in lower carbon inputs in subsequent periods. Due to these complex relations the effect of land degradation on soil carbon sequestration is difficult to quantify. Hence, we will use coefficients generated by previous studies and adapt them to the

Kenyan conditions. Once carbon sequestration (and emission) has been quantified for both with- and without SLM scenarios a value will be attached to the – most likely – reduced emissions. Other studies usually value the CO_2 emission reduction at US$ 3-4 per ton of carbon.

Analytical methods and data

Analytical methods

We quantify the impact of each of the three SLM practices and assess the profitability of adopting them. We begin by specifying the CBA model (profit function) and then specify the biophysical relationships that attribute the impact of SLM practices on agricultural productivity. Equation (1) and (2) specify the profit of adopting or not adopting the SLM practices:

Profit with SLM

$$(1)\quad \pi_t^c = Y_t^c (P_t - Z_t^c \pm \lambda_t^c)$$

Where: π_t^c = Profit with SLM practices in year t

Y_t^c = Crop yield with SLM practices in year t

P_t = Social price of output in year t

Z_t^c = Social cost of production of one unit of Y_t^c

λ_t^c = Off-site costs/benefits with SLM practices per unit produced in year t

Profit without SLM

$$(2)\quad \pi_t^d = Y_t^d (P_t - Z_t^d \pm \lambda_t^d)$$

Where: π_t^d = Profit without SLM practices in year t

Y_t^d = Crop yield without SLM practices in year t

Z_t^d = Cost of production of one unit of Y_t^d

λ_t^d = Off-site costs/benefits without SLM practices per unit produced in year t

The social NPV (NPV^s) of adopting SLM practices is therefore given by

$$(3)\quad NPV^S = \sum_{t=0}^{T} \rho^t (\pi_t^c - \pi_t^d)$$

Where T = farmers' planning horizon

$\rho^t = \left(\frac{1}{1+r}\right)^t$ = farmers' discount factor, where r is the farmer's private discount rate

Farmers will find it profitable to adopt SLM practices if NPV>0. However, farmers' decision to adopt SLM practices does not take into account the off-site costs and benefits that result from adoption or non-adoption of SLM practices. This also doesn't account for risk, credit constraints, size and irreversibility of investment. The literature on these issues also establishes that a positive NPV may be far from sufficient to induce investment (e.g., Pender 1996; Dixit and Pindyck 1994; Fafchamps and Pender 1997).

Following its definition, the IRR is given by:

$$(4)\quad NPV = \sum_{t=0}^{T} \left(\frac{1}{1+IRR}\right)^t (\pi_t^c - \pi_t^d) = 0:$$

The greater the IRR, the higher the rate of returns to investment.

The first step to computing equations (1) through (3) is to find how crop yields (Y_t^c and Y_t^d) are affected by the SLM practices, namely, soil fertility management, agroforestry and SWC structures. Ideally, we need data from an experiment that included all three SLM types and conducted over many years to capture the long-term biophysical changes and the corresponding crop yield changes. To the best of our knowledge, there is no such experiment in SSA or other countries with biophysical characteristics similar to Kenya. However, there are three sets of long-term and short-term experiments conducted in Kenya that investigated separately the response of crop yield to (i) organic and inorganic fertilizer and crop residue management, (ii) SWC structures and (iii) agroforestry (Calliandra and Napier grass) treatments.[5] We will use the results of these experiments to establish the relationship between crop yield and the three SLM practices.

To simplify the modeling approach, we assume that crop yield is affected by soil moisture, soil quality (chemical and biophysical characteristics such as soil nutrients present in the soil, bulk density), and topsoil depth. In low external input agriculture -- such as the study area, agronomists use topsoil depth to determine SOM and soil fertility in general (Koning and Smaling, 2005; Mantel and van Engelen, 2000; Nkonya, 1999).

$$(5) \quad \textit{Crop yield} = f(\textit{soil moisture, soil quality, topsoil depth, } \varepsilon_t)$$

Where ε_t is a random error.

Topsoil depth (x) may not be a good indicator of soil quality since two soils of the same topsoil depth may have quite different SOM levels due to its different uses. Hence we introduce the soil quality term to account for such possibility. All three SLM practices affect soil quality and topsoil depth. There are many attributes of soil quality that are not easy to model. Holding land management and biophysical conditions constant, these attributes will change over time if the farmer practices continuous cultivation. For example, in the long-term Kabete soil fertility trial, crop yield under continuous cultivation decreases largely due to decline in SOM over time even in treatments receiving the highest rates of organic and inorganic fertilizer (Nandwa and Bekunda, 1998).[6] This implies inorganic and organic fertilizers cannot replenish some nutrients required for increasing or maintaining crop productivity. Hence, holding land management and most biophysical conditions constant,[7] SOM will be strongly correlated with the number of years of continuous cultivation. Hence we assume that under controlled long-term soil fertility experimental conditions, the change in crop yield over years will largely be attributable to changes in the SOM. However, since researchers of the soil fertility experiments in Kenya did not control for rainfall changes (e.g., using irrigation), we need to control for rainfall amount. Controlling for soil depth (through effective control of soil erosion), the cumulative soil erosion, $x_t = 0$, hence the empirical model representing the impact of soil quality on crop yield with SLM practices over years is:

$$(6) \qquad Y_t^c = f(rainfall,\ yearly\ trend\ of\ changes\ of\ soil\ quality,\ \varepsilon_t)$$

The impact of rainfall on crop yield is likely to be positive exponential since crop yield response to rainfall will be very strong under moisture stress conditions but it will taper off when moisture stress decreases. Eventually, crop yield will not respond to rainfall when soil moisture reaches a certain threshold.

Exploratory investigation of the Kenyan long-term soil fertility trial showed that the maize crop yield declined exponentially over years.[8] Hence equation (6) is explicitly specified in the following model that also shows the expected signs:

(7) $$Y_t^c = e^{\beta_0 - \beta_1 t + \beta_2 h + \varepsilon_t}$$

where h = annual rainfall in mm, β_0, β_1, and β_2 are coefficients of the associated variables. Other variables are as defined previously.

Likewise, exploratory analysis of the soil erosion experimental data in Kenya also showed a negative exponential relationship between soil erosion and crop yield. Hence, the without SLM practices model (Y_t^d), with expected signs is:

(8) $$Y_t^d = e^{\beta_0 - \beta_1 t + \beta_2 h - \beta_3 x_t + \varepsilon_t}$$

Where x_t is the cumulative loss in soil depth in cm. Other variables are as defined previously. Under equation (8), we assume that the farmer does not apply any form of fertilizer, does not incorporate crop residues and does not control soil erosion.

The maize yield panel data are likely to be serially correlated. We therefore tested for the first order autocorrelation (AR(1)) for the with and without SLM models. Since we are using panel data with each replication forming a unique serial data, we test serial correlation for each replication. The Durbin-Watson test statistic for no SLM ranged from 1.67 to 2.43, which is in the region indicating no serial correlation. However, the SLM model Durbin-Watson statistic ranged from 0.31 to 1.65 indicating there is serial correlation within panels. Heteroscedasticity across panels was also a problem in the data. To address the potential serial correlation and heteroscedasticity, we used the feasible generalized least squares (FGLS) model, which addresses both problems.

Soil erosion is usually reported as an annual amount of soil that leaves the farm or plot per unit area (tons/ha/year). Hence we need to establish the relationship between amount of soil lost per unit area per year and the corresponding loss of depth of topsoil. This relationship was established in Kenya by Mantel and van Engelen (2000) as follows:

$$(9) \qquad x = \left(\frac{E}{10^4} * \frac{T}{B} \right) * 100$$

Where: x = topsoil loss (cm)

E = Soil erosion risk in kg $ha^{-1}yr^{-1}$.

T = number of years in the planning horizon. In this study we seek to understand the loss of topsoil depth in 50 years.

B = bulk density of topsoil in kg m^{-3}.

Since agroforestry is one of the technologies for controlling soil erosion and improving of soil quality, it is implicitly incorporated into equation (7) and (8). However, its impact will be explicitly specified when estimating equations (1) through (3). Details on how we treated agroforestry are given in the next (data) section.

Data

The data section describes how we computed the costs and benefits with and without SLM practices. We use data from the Kinale/Kikuyu watershed, which is located in the central provinces. The watershed is one of the sources of potable water for the city of Nairobi, which is the capital city of Kenya. To capture the long-term response of crop yield to SLM practices, this study uses mainly data from maize experiments conducted at Kabete and Embu research stations in Kenya. The stations are in the Kinale/Kikuyu watershed. Both stations are located in the high potential areas of the Kinale/Kikuyu watershed. The Kabete long-term soil fertility trial has been running for the past 30 years (since 1976). This trial combines three levels of inorganic fertilizers and farm yard manure and two types of crop residue management. All possible combinations of farm yard manure (0, 5, & 10 tons/ha), nitrogen and phosphorus (0, 90, & 180 kgNP/ha) and crop residue management (incorporation or no incorporation) were combined to form a total of 18 treatments, which were planted in four replications each year.

To analyze the with and without SLM scenarios, we use only two treatments of this trial that reflect recommended fertilizer rates in the study area:

(i) Application of 90kgN/ha plus 30kgP/ha of inorganic fertilizers, 5 tons of farm yard manure and incorporation of crop residues.

(ii) No application of inorganic and organic fertilizers and no incorporation of crop residues. This is the control treatment that reflects the without soil fertility management practice that leads to soil nutrient depletion.

This experiment is the longest running soil fertility trial in Kenya. Hence it captures the long-term impact of soil fertility management practices on crop yield. Thus, the data of this trial will be used as benchmark for SLM practices considered in this study.

Data from two experiments conducted at the Embu agricultural research station were used to quantify the impact of SWC structures and agroforestry practices on maize. The first Embu experiment sought to determine the impact of multipurpose shrubs, namely Calliandra and Napier grass strips and a combination of the two on crop yield. This experiment was conducted for five years (1993-1997). This is a short period, hence not reflecting the long-term impacts of the agroforestry practices. To address this problem, we will use the Kabete fertility trial to compute the long-term crop yield trend but modify this trend to reflect the yield increase due to increase of SOM and other yield enhancing attributes of agroforestry practices. This approach is based on the fact that the Kabete agroecological conditions are similar to those at Embu. Studies by ICRAF (2005) in western Kenya have shown that agroforestry practices have the potential to increase crop yield by two to four times the yield on plots that receive no organic or inorganic fertilizers and without agroforestry practices. However, the impact of agroforestry practices on crop yield is likely to be much smaller on plots with high SOM or those that receive organic and/or inorganic fertilizers. Hence in this study, we will assume that the agroforestry practices have no significant impact on crop yield in the first few years of the with SLM scenario. In the later years, we introduce a coefficient that adds a certain percent of crop yield to reflect the agroforestry potential to maintain high crop yield on continuously cultivated plots. However, we will use the results from the Kabete experiment as the benchmark since the Embu agroforestry trial was conducted for only few years and does not give the long-term impact of agroforestry on maize yield.

Let Y_t^a = crop yield with SLM practices including agroforestry in year t,

$\hat{Y}_t^c$ = estimated crop yield with SLM practices in year t

Equation (7) then becomes

$$Y_t^a = \hat{Y}_t^c \alpha_t \tag{10}$$

Where α_t is the rate of crop yield increase due to agroforestry practices in time t. As discussed above, $\alpha_t = 0$ in the first few years (five years according to the Embu experiment).

The objective of the second Embu experiment was to determine the impact of soil erosion on maize grain yield. The experiment was conducted for five years from 1993 to 1997.[9] The experiment was set at plots with slope ranging from 15% to 20%, which reflects the average slope of the Kinale/Kikuyu watershed.[10] Hence for the case of the without SLM scenario, we also use the Kabete experiment but reduce estimated crop yield by a certain percentage to reflect the impact of soil erosion on crop yield.[11] Results from the experiment showed that maize yield declined at an average of 5% per centimeter of soil lost.[12] This is in the range of estimates provided by Weibe (2003) based on an exhaustive review of experimental studies of soil erosion impacts. He found that most studies showed yield reduction of 0.01 – 0.04% per ton/ha. Of soil lost, and generally lower in temperate regions. Assuming that soil has a bulk density of 1.3 tons/m^3, one cm of soil is equal to 130 tons/ha, and this converts to 1.3 – 5.2% yield loss per cm of soil lost.

In addition to increasing crop yield, agroforestry practices have other benefits that affect the profitability of SLM practices. These benefits are considered in computing the benefits and costs in equation (1):

(i) Calliandra and Napier grass are used to stabilize SWC structures and/or replace them in moderately sloping areas. Hence, planting of shrubs and grass on SWC structures reduces their maintenance costs.[13] Discussion with soil scientists conducting agroforestry and soil erosion in Kenya revealed that planting Calliandra hedgerows and Napier grass strips could reduce labor for maintaining SWC structures by 75%. Accordingly, we reduced the labor for maintaining SWC structures by 75% for the with SLM practice scenario.

(ii) Calliandra biomass is harvested and used to prepare dairy meal and Napier biomass is used as fodder. The prices of the dairy meal and Napier fodder are reported in table 1.

(iii) Calliandra and Napier biomass above the ground has the potential to absorb carbon dioxide from the atmosphere (Unruh, et al., 1993; Woomer, et al., 1998; Sanchez, et al., 1997) while the underground biomass (roots and stems) store carbon (Batjes, 2004). To account for these global benefits, we impute a value equivalent to the benefits of sequestration offered by the agroforestry practices. As mentioned earlier, studies of carbon sequestration impute a value of US$3.5 per ton of carbon biomass stored above or below the ground (table 1). Raw data of the Embu agroforestry experiment show that Calliandra and Napier grass biomass left on the ground after harvesting is about equal to the amount of biomass harvested. Calliandra and Napier grass grow after their biomass is harvested. During the growing time, which lasts approximately four to six months, they provide the environmental services of storing carbon and absorbing carbon dioxide. The underground carbon (roots and other stem tissues) not harvested continue providing such services throughout the year.

(iv) When agroforestry trees, shrubs and grass are planted in crop plots, there is potential competition with crops for space, light, nutrients and moisture (Ibid; Unruh, et al., 1993). The Embu trial showed that Calliandra and Napier did not cause a statistically significant change in maize grain yield for the first five years. This is probably due to the rich SOM on the experimental site that led to poor response to nitrogen fixation and the organic matter added by the Calliandra and Napier in the first few years.[14] Another possible explanation for this is the low competition for nutrients, water and light during the first few years in an agroforestry system, and limited competition for water and nutrients due to the high rainfall and good soils of the area. Competition for nutrients was minimized since Calliandra releases nutrients from decomposition of the leaves/roots and fixes atmospheric nitrogen. Researchers also added inorganic fertilizer. Annual harvesting of Calliandra above ground biomass also reduced the competition for light. To account for the area lost to planting Calliandra hedgerow and Napier grass strip, we reduce the maize grain yield by 3% as explained below. There were five Calliandra hedgerows or Napier grass strips per hectare.

Each row occupies a space of 0.6m each and is 100 m long. Hence, the space taken up by Calliandra hedgerows and Napier grass is about 3% of one hectare of maize. The costs of establishing the agroforestry practices and other costs are considered and reported in table 2.

To allow Calliandra and Napier to grow, their biomass was not harvested in the first year after planting. Their biomass increased for the first three years and leveled off in the fourth year.

Table 1: Prices of outputs with and without Sustainable Land Management Practices

Output	Price (KES/ton)
Maize grain: Private price	10,750
Social price	10,556
Calliandra biomass (dairy meal)[1]	17,000
Napier biomass[1]	833
Maize biomass (which farmers without SLM feed to livestock)	833
Carbon stock[1] (accumulated due to control of soil erosion) ($3.5/ton)	255.5

[1] Carbon accumulation due to SWC and soil fertility management is 0.2 to 0.7 tons C/ha/yr (Vagen, et al. 2005, Gachene, 1997), which is an average of 0.5 tons C/ha/yr. Higher carbon sequestration rates are realized for agroforestry practices planted without crops. Woomer, et al. (1998) estimated that agroforestry trees could accumulate an average of 3.3 tons of carbon per hectare per year.

Note: Prices of biomass are not regulated, hence private prices = social prices

After estimating Y_t^c and Y_t^d and how they are influenced by SLM practices or lack of it using the experimental data, we estimate equations (1) to (3) using crop production budgets. These are estimated using different levels of input use that reflect practices in the areas being studied. Table 2 reports the maize production costs with and without adoption of SLM.

Since we are analyzing social CBA, we account for the input and output price distortions. Kenya imports all of its inorganic fertilizer. Fertilizer is classified by the Kenya Revenue Authority as an essential import, hence does not attract an import tax**.** This implies the Kenya fertilizer price is not distorted. Kenya produces most of its maize seed locally and the government does not regulate the maize seed price, suggesting that both inputs (fertilizer and seeds) have negligible price distortions. However, the government participates in the maize market, contributing to market distortions. For example the National Cereal and Produce Board (NCPB), which is a government institution, bought 0.18 million tons of grain in the 2005/06 season, representing about 6.7% of the maize demand in Kenya. NCPB buys maize grain at KES 13.33/kg but the maize market price is KES 10.56/kg. However, NCPB price is paid only to 6.7% of maize consumed in Kenya. Hence the weighted average price of maize after government intervention is KES 10.75 (13.33*0.067+10.56*0.933) per kg suggesting that the estimated price distortion is around KES 0.19/kg or KES 190/ton. Prices of Calliandra, crop residues, and Napier grass are not regulated or taxed, hence have no distortions.

Kenya does not import a large volume of maize under normal circumstances. For example, only a net of about 10,000 tons of maize was imported in 2003 (CBS, 2004) at a tariff of 50% of CIF. Since only a small volume of maize was imported into the country, we do not introduce the import tariff distortion in this analysis.

Estimation of off-site costs of land degradation is always difficult due to lack of data. As discussed earlier, there are many potential local, national and global off-site effects of land degradation. Our study will focus on the off-site effects related land management practices that affect soil erosion and carbon stock on cropped farmland. The major off-site effects of soil erosion include sedimentation of surface water bodies such as lakes, ponds, reservoirs and waterways. Siltation increases the costs of water facility maintenance and replacement, and purification and treatment of potable water, (Moore and McCarl, 1987). Soil erosion also affects soil organic carbon and above ground vegetation. However, contribution of agriculture to anthropogenic soil erosion is not well-known. Other anthropogenic activities such as roads could cause significant soil erosion (Pagiola, 1999).[15] Soil eroded from agricultural land also gets deposited elsewhere within the farm or in neighboring farms while soil reaching waterways could be deposited on the streambed. Hence the share of eroded soil reaching surface water bodies and reservoirs is always very small. For example in large watersheds, sediment delivery ratio, the sediment that exits the watershed as share of the gross erosion, is only 0.05 (Stocking, 1996).

In this study we estimated the costs of potable water production from Kinale/Kikuyu water catchment is the siltation of the water reservoir at Sasumua water treatment plant, which supplies around 20% of Nairobi city potable water. The Sasumua water treatment plant staff estimated that the costs of water treatment and purification during the dry season reflect the costs of water treatment and purification when all farmers effectively control soil erosion such that water production is not affected significantly by soil erosion and other agricultural activities that pollute water. The water treatment and purification costs with land degradation were simulated using the rainy season. The nature of the potable water problem is siltation and pollution. Untreated and unpurified water is characterized by higher turbidity due to solids such as soil, crop residues, animal droppings, etc., higher bacterial count and pH, coloration and agrochemical loading. To address these problems, water has to be treated and purified using greater amount of alum (aluminum sulphate) - a coagulant - to purify water and chlorine to disinfect the water (table 3).

Table 2: Production costs with and without Sustainable Land Management (SLM)

Particulars	Material input			Labor input		Total cost
	Quantity	Units	Price	labor days/ha	pay/day	
			KES		KES	KES
Land preparation				35	100	3500
Maize seed & labor for seeding	32	Kg	130	20	100	6160
Napier grass planting material & labor for planting*	5000	cuttings	2	2	100	10200
Calliandra seedlings & labor for planting*	6665	seedlings	5	2	100	33525
Construction of SWC structures (fanya juu)*				32	100	3200
Maintenance of SWC structures**				22	100	2200
Fertilizer: Nitrogen + labor for application	60	Kg	76.47	0.5	100	4638.24
Phosphorus + labor for application	30	Kg	57.14	0.5	100	1764.29
Manure transportation & application	5	Tons	142.86	20	100	2714.29
Weeding x2				45	100	4500
Harvest maize grain				15	100	1500
Harvest & transport maize biomass				5	100	500
Total variable labor input with SLM				162		
Total variable labor input without SLM				120		
Total one time initial costs with SLM					46925	
Initial cost as % of total cost (initial & variable cost) of SLM					64%	
Total variable costs (with SLM)						26976.81
Total variable costs (without SLM)						15035

* Cost incurred in the first year only.

** When farmer reinforces the SWC structures by planting Calliandra and Napier, their maintenance costs drop by 75%.

Due to elevated use of alum, there is sludge buildup that requires frequent backwashing. This process requires use of a large amount of water that has to be disposed of after backwashing. The buildup of silt in the water reservoirs and intakes is also cleaned by dredging. It is estimated that use of alum, chlorine, backwashing and removal of siltation has increased water production cost by KES 9,904,041 per year.

Table 3: Increase in the cost of water treatment and purification due to land degradation

Type of treatment/purification	Treatment agent	Cost without SLM (Million KES per 7 months)	With SLM (Million KES per 5 months)	Incremental cost (Million KES/year)
Purification of water	Alum	8.30	1.78	5.81
Treating water	Chlorine	0.39	0.16	0.17
Sludge removal	Flush with water	0.53	0.11	0.43
Cleaning siltation	Dredge sediments			3.50
Total incremental cost				**9.91**

Notes: The incremental costs are computed by multiplying additional costs of water treatment during the wet season times the number of wet season months, rather than the difference of costs with and without SLM.

Results

Figure 1 shows that maize yield declines for both the with and without fertilizers and crop residues. Figure 1 also shows the regression results of the crop yield model. The rate of decline for the without fertilizer and crop residue is much faster than the case with SLM practices, and the intercept is also lower without SLM. The predicted maize yield of the two scenarios (figure 1) shows that in a 100 year period, maize yield with fertilizer and crop residue in the first year was 5.5 tons/ha but will decline at a rate of 2.5% annually, which is equivalent to about 135 kg of grain yield reduction from yield in the previous year.. However, this rate of decline decays over time as yield decreases. The corresponding rate of maize yield decline for the without fertilizer and crop residue scenario is 3.8% per year. The crop yield trend shows the long-term impact of land degradation resulting from continuous cultivation, which is a common problem in areas with high population density.

Economic viability of SLM practices

An analysis was done to evaluate the economic viability of SLM practices namely application of the recommended inorganic and organic fertilizers, incorporation of crop residue, and use of SWC structures and stabilizing them with Calliandra hedgerow and Napier grass. .We first consider the private and social NPV and IRR of SLM practices. We do this by examining the NPV per hectare for all the SLM practices and the contribution of offsite costs and benefits to NPV. There are two options that a farmer could take to implement the initial investment. The first option involves implementing all initial investments in the first year, namely constructing SWC structures and stabilizing them with Calliandra and Napier grass. The second option is staggering the initial investment over a period of time that gives the farmer the opportunity to stagger the expensive initial investments. Investigation of the two options showed that staggering the initial investment was more efficient than the option of investing in all technologies in the first year.

If a farmer takes the first option by adopting all SLM practices in the first year, she will realize a total 50 year private NPV of KES 152.31/ha. The corresponding total social NPV is KES 176.05/ha. The initial fixed costs account for 64% of the total cost (fixed and variable cost) of SLM practices in the first year (table 3). Almost 50% of the initial cost is contributed by Calliandra seeds, suggesting that the legume is likely to be one of the most important barriers to adoption if its planting material is not made cheaper and more easily available. The high initial cost underscores the barrier to adoption of SLM practices that farmers are likely to face in the initial SLM investment. This barrier may be difficult to address for poor households.

Figure 1: Regression equation lines showing maize yield with and without SLM based on the Kabete fertility experiment.

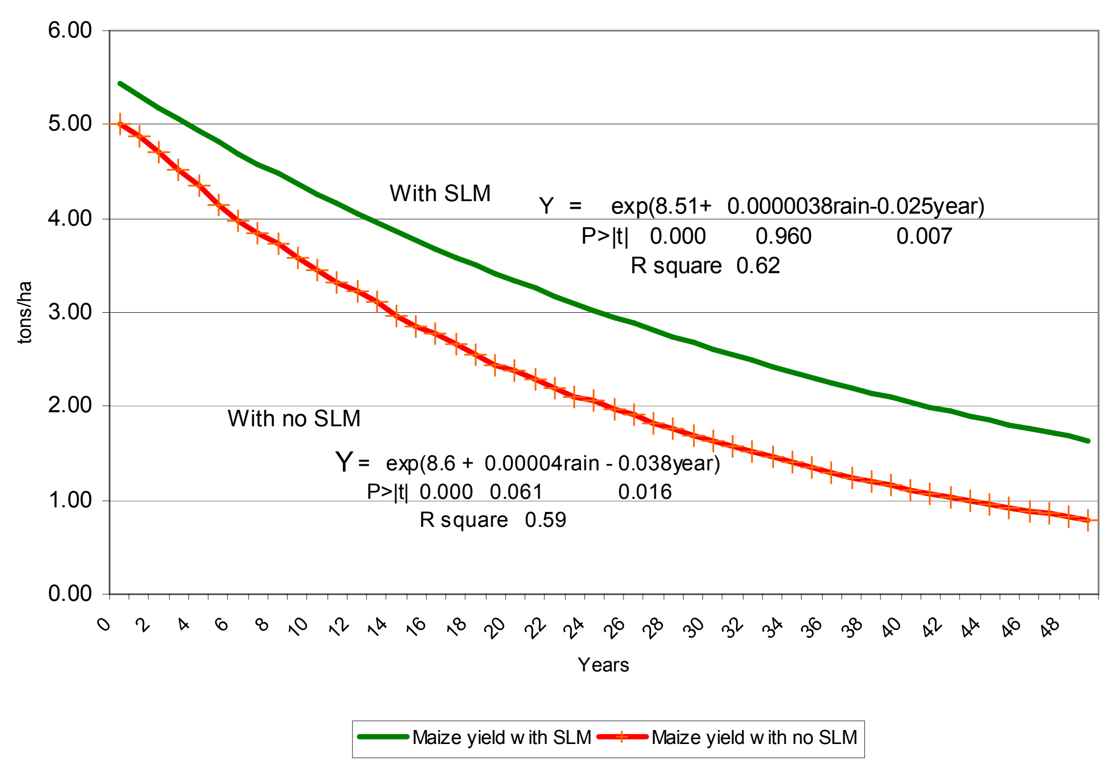

Table 4: Fifty year social and private NPV, IRR and off-site benefits and costs

	Private	Social
Total NPV (‘000 KES/ha)	152.31	176.05
Average NPV/year (‘000 KES/ha)	3.05	3.53
Value of carbon sequestered as % of NPV		10.00
Cost of water treatment and purification as % of NPV		4.79
IRR (%)	30.70	39.00

Notes: (i) The total water treatment costs were divided by the total area cultivated in the catchment
(ii) Carbon sequestered include carbon saved in the crop plot due to control of soil erosion (0.5 tons/ha/year) and Calliandra and Napier underground and above ground carbon

Staggering investment lowered significantly the losses incurred if a farmer follows a one time investment plan from around KES 50,000/ha for the private NPV to total of only KES 15,430/ha if initial investments are staggered over a period of four years. The IRR rates obtained in this study (39% for the social NPV and 30.7% the private NPV), are comparable to those obtained in other SWC studies conducted in Central America and the Caribbean, where SWC IRR ranged from 11% to 84% (Lutz, et al., 1994). The social NPV and IRR results suggest that holding all else constant, adoption of SLM practices is profitable. The private NPV and IRR also show that this is true even when we ignore the offsite costs and benefits.

The social NPV is higher than the private NPV due to valuation of the carbon stock resulting from biomass production of Calliandra and Napier grass and due to imputing costs of the off-site negative impact of soil erosion for the without SLM scenario (table 4). The global benefits resulting from carbon sequestration account for about 10% of the total NPV/ha and the costs due to water treatment and purification was about 5% of the social NPV. The contribution of offsite costs and benefits is significant and indicates the large costs that farmers may have to pay to account for costs that they do not have direct benefits. Farmers and other land users always receive no compensation for the environmental services they provide to the public. This contributes to their common attitude of disregarding the externalities of their production and sub-optimal land use. In The case of Kenya, Payment for Environmental Services (PES) is still limited to services related to game parks. Most environmental services offered by farmers do not receive compensation.

To understand the robustness of the results, we need to analyze the sensitivity of the NPV and IRR to changes in the input and output prices.

Sensitivity analysis

We analyze the sensitivity of the NPV and IRR to input and output prices and to presence or absence of a dairy sector. We halve the maize price and double the fertilizer price and analyze the response of NPV and IRR to such changes. In table 5, we take a pessimistic scenario whereby the price of maize falls by 50% from KES 10,750 to KES 5,375 per ton. This leads to a 25% drop in the social 50 year total NPV from KES 176,050 to 131,990 per hectare for farmers with SLM practices (table 5). The private NPV drops by 28% while the private and social IRRs drop only slightly. The drop of NPV for the farmers who practice SLM is cushioned by the revenue from Calliandra and Napier biomass, suggesting that adoption of agroforestry practices involving multi-purpose trees and shrubs reduces risk exposure.

If the fertilizer prices double, the social and private NPV decreases to levels comparable to those experienced after the 50% fall in maize price. If fertilizer prices double and maize price falls by 50%, the total 50 year social NPV for adopting SLM practices will fall by about 50% but the corresponding IRR for adopting SLM practices will be greater than the discount rate of 10% (table 5). These results suggest that adoption of SLM practices is profitable over a wide range of output and input prices.

We investigated the feasibility of adopting the SLM practices in an area with no economic use for the Calliandra and Napier biomass. Such areas could have weak or no dairy production activities. Table 5 shows that if Calliandra and Napier grass biomass are not used for dairy production, the total 50 year social and private NPV drop dramatically to KES 39,190 and KES 7,790 per hectare respectively. The corresponding IRR is 10% for the social scenario and about 1.9% for the private scenario (table 5). These results demonstrate that profitability of the SLM practices heavily depends on the dairy sector or other synergistic benefits of the SLM practices. Without dairy production, the NPV and IRR for adopting SLM practices are also very sensitive to changes in input and output prices. A 50% decrease in maize price leads to negative 50 year total NPV for both private and social scenarios. In general changes of all input prices leads to negative social and private NPV. The results suggest that in areas with weak or no dairy production or other enterprises that have synergies with some practices, SLM practices have low returns and are risky and hence not likely to be adopted. Hence in the absence of PES or other incentives, farmers in areas with weak or no dairy production are not likely to adopt the SLM practices analyzed in this research and consequently prevent the negative offsite effects of land degradation. This is a major concern that needs to be addressed while promoting adoption of the SLM practices in areas with weak or no dairy production.

Table 5: Sensitivity analysis of NPV and IRR with no dairy sector, double fertilizer prices

Change	Social NPV (KES ‘000)	Private NPV (KES ‘000)	Social IRR (%)	Private IRR (%)
Baseline (no change)	**176.05**	**152.31**	**39.00**	**30.70**
Half maize price	131.99	109.03	42.0	29.5
Half maize price and double fertilizer price	90.29	67.33	25.0	15.8
Fertilizer prices rise by 50%	134.55	110.61	27.0	19.7
No dairy	39.19	7.79	10.0	1.9
No dairy, half maize price	-4.86	-35.49	-	-
No dairy, double fertilizer price	-2.51	-33.91	-	-
No dairy, double fertilizer price, & half maize price	-46.52	-77.19	-	-

Conclusions and implications

This study investigated the private and social returns to the Sustainable Land Management (SLM) practices with an objective of finding practices that will reduce the on-farm and off-farm negative effects land degradation. The Net Present Value (NPV) of the SLM practices was much greater than zero indicating SLM practices are profitable when they are complementary. In particular, use of Soil and Water Conservation (SWC) structures and reinforcing them with agroforestry practices are profitable when the agroforestry practices (Calliandra and Napier) are used as fodder for dairy cows. These results suggest that SLM practices have the potential to be adopted in areas with a strong dairy production. This will address both the on-farm and off-farm negative impacts of land degradation.

One of the major concerns for widespread adoption of SLM practices is the high initial investment cost required to establish SWC structures and reinforce them with multipurpose agroforestry shrubs and grass. This concern comes from the fact that most farmers have limited capacity to invest and consequently high private discount rates. The initial costs account for 64% of the total cost of maize production in the first year. If a farmer decides in the first year to adopt all the SLM practices, she will incur a loss of about Kenyan Shillings (KES) 50,000/ha in the first year, which is about a third of the household income in Kenya. The initial investment cost is certainly a barrier to adopting SWC structures and agroforestry and this explains their low adoption. One strategy that farmers are likely to use to address this constraint is to stagger the initial investments over several years. Even after staggering the initial investment costs over a period of three to four years, the farmer will still incur initial losses of about KES 15,430/ha over the four year investment period, implying that some farmers may not be able to adopt SLM practices even if they have the option to stagger the initial investment.

These results have important implications for addressing the off-site impacts of land degradation. There is need to facilitate availability of credit in the operational areas to help farmers' finance these initial investment costs. However, credit in the form of cash may not work due to the fungible nature of cash. In kind credit, such as providing agroforestry planting materials could help farmers to obtain them easily. Establishment of commercial agroforestry nurseries will greatly help the largest initial cost of buying Calliandra and Napier or any other agroforestry tree/shrubs/grasses in the first year.

To reflect the biophysical and socio-economic diversity in the study area, we investigated the profitability of SLM practices in areas that have a weak or no dairy production sector. The results show that in areas with weak or no dairy production, the SLM practices to be promoted by this project are risky when agricultural prices change significantly. These results suggest the need to promote SLM practices that complement each other and other farm enterprises. This also implies that promoting a package of complementary technologies is likely to make them more profitable and less risky. As discussed above however, a package of technologies implies high initial fixed costs or variable costs, and hence the need to promote financing services. In the quest to promote a package of technologies, stepwise adoption (Byerlee, et al., 1986) of components of the technologies should be expected. For example, SWC structures need to be planned such that they involve agroforestry practices that have alternative uses such as dairy, firewood, etc. Our study has shown that promotion of agroforestry practices for the sake of control of soil erosion and its off-site effects only may not work.

If promotion of a mix of complementary enterprises is not feasible, high value crops are likely to make SLM practices more profitable (Place, et al., 2002). However, risk and access to market are likely to be of concern for high value crops.

In areas where SLM practices are not profitable, promotion of alternative livelihoods is necessary. For example, non-farm activities are likely to give farmers alternatives to their land degrading agricultural activities. For example, a study in Uganda showed that farmers who had non-farm activities were more likely to fallow than those without (Nkonya, et al., 2005).

Another approach that could increase the feasibility of adoption of SLM practices is Payment for Environmental Services (PES). For PES to be sustainable it needs to be win-win, i.e. it increases returns to SLM practices and also helps downstream communities to avoid or minimize the off-site effects of land degradation. For example, if the Sasumua Water Treatment Plant were to pay farmers to adopt soil and water conservation technologies, it could reduce its potable water production costs and help farmers to realize profit by adopting SLM practices. The project will need to explore the possibility of PES since such environmental service payments are not necessarily feasible or economic wherever there are off-site costs, considering the costs of establishing and monitoring such a payment system.

Endnotes:

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[1] The Sasumua dam, located on Chania river, receives water from a catchment of around 128 km^2 (Annandale, 2002).

[2] As it will be shown later, the price distortions relevant for this study are negligible.

[3] Other studies report higher private discount rates (for example Holden, et al., 1998 for evidence from Ethiopia, and Pender, 1996 for evidence from south India).

[4] Alternative valuation techniques include the ‘hedonic pricing approach’ and the ‘replacement costs approach’. However, the ‘change of productivity approach’ is the most commonly applied and widely accepted tool (for more details on the various tools see Enters, 1998).

[5] More details of these experiments are given in the data section below.

[6] In addition to depleting SOM, continuous cultivation even with adequate N, P, and K inorganic fertilizers could lead to depletion of nutrients other than N, P, and K, and degradation of biological physical properties of the soil.

[7] Except rainfall that is controlled for in equation (5), and (6).

[8] More details in the data section.

[9] Since Embu is located in the high potential area as most of the watersheds, these soil erosion trial data reflect better the biophysical environment of the selected watersheds than the Machakos soil erosion experimental results that were used by Pagiola (1996). Machakos is located in much drier areas with different soil characteristics.

[10] The Kenya Agriculture Act (Cap 318) of 1980 prohibits agricultural activities on land with slope exceeding 35%. The law also requires that farmers must have SWC structures on crop plots with slope of 12% to 35% (Government of Kenya, 1986).

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[11] The experiment at Kabete is established on plots with very small slope that does not require any form of SWC structure. Hence it reflects the yield of crops planted on steep slopes but with SWC structures that effectively control soil erosion.

[12] Results from a similar experiment conducted at Machakos Kenya showed that one cm loss of soil topsoil depth led to a loss of 0.13 tons of maize grain yield/ha (Pagiola, 1996), which was equivalent to about 7% of the yield with zero soil loss. The rate of loss of crop yield due to erosion is less in more fertile soils such as volcanic soils (andosols and nitisols) that are rich in nutrients (Mantel and van Engelen, 2000).

[13] Agroforestry practices also increase soil nutrient inputs; enhances internal flows; decrease nutrient losses and other provide environmental benefits (Sanchez, et al., 1997)

[14] Maize yield in the Kabete long-term soil fertility trial also showed poor response to fertilizers in the first few years, probably due to the same reason (high SOM on plots after opening a virgin land). The agroforestry trees and shrubs are likely to show stronger impact on yield of crops grown on land with low SOM and soil nutrients (Sanchez, et al., 1997; Woomer, et al., 1998). Hence it was expected that maize yield in the Embu agroforestry trial will show a greater response to the agroforestry treatment in the subsequent years.

[15] Ecological erosion can also contribute significantly to soil erosion. It is estimated that ecological erosion of undisturbed forest area is about 20 – 30 t/km^2/year (Shepherd, et al., 2000).

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