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Abstract

Productivity gains from soil and water conservation (SWC) have empirical support in research stations. Previous empirical results from on-farm adoption of SWC are, however, varied. This study investigated the impact of soil conservation investment on farm productivity in three regions in Kenya. Using plot-level survey data, we focused on land productivity on plots with and without SWC. We tested the overall soil conservation hypothesis that increased SWC is beneficial for yield, as well as more specific hypotheses that SWC affects levels of inputs, returns from these inputs, and crop characteristics. The results showed a mixed picture where plots without SWC generally have higher yield values per hectare. However, plots with SWC are significantly steeper and more eroded than plots without SWC. A more careful analysis of a two-stage random effects–switching regression estimation comparing three SWC technologies to plots without SWC indicated that SWC increased the returns from degraded plots and sometimes from other inputs. A simulation exercise based on these estimations also showed that, in most cases, adoption has been beneficial for those who have done it and would be beneficial for those who have not.

Key Words: Kenya, soil conservation, switching regression, rural households, yields

JEL Classification: Q12, Q16, D61

Contents

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Introduction

Agriculture offers great promise for growth, poverty reduction, and environmental services making the sector a unique instrument for development (World Bank 2008). In particular, economists stress increased agricultural productivity as an essential component of a successful rural development strategy for several reasons. First, rising productivity in food production makes it possible to feed an inevitably growing population. Second, surplus production can be sold in rural and urban markets generating incomes for the majority of the rural poor. Increases in food availability have beneficial impacts on the urban poor. Finally, an increase in agricultural productivity releases labor and savings from agriculture into other sectors of the economy (Gollin et al. 2002). Thus, policy makers see improvements in agriculture as critical to poverty alleviation and a precondition for economic growth, particularly in sub-Saharan Africa (World Bank 2001; 2008).

Yet, agricultural productivity is threatened by land degradation, defined as the decline in the land's actual or potential productivity (Blaikie and Brookfield 1987). Soil erosion and nutrient depletion are two particularly common sources of declining agricultural productivity. Empirical studies have linked low and declining crop yield to the existence of soil erosion (Troeh et al. 1991; Pagiola 1994). Yields decline partly because essential organic matter and plant nutrients are lost. Eroded soils also suffer from moisture deficiency. Subsoil does not contain as much organic matter as topsoil and has smaller particle sizes, and is thus less permeable to water and less capable of storing moisture. Although the decrease of agricultural yields, to a certain degree, can be compensated for by an increase in fertilizer inputs, this option is not available for many poor farmers. Living at barely subsistence levels, most farmers do not have the economic capacity to use fertilizers. Also, fertilizers, if not properly used, may aggravate negative environmental externalities, such as pollution of surface and ground water.

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In Kenya, soil erosion has been the subject of concern since the 1930s (Pretty et al. 1995). Construction of physical soil and water conservation structures (SWC) was the first public response to the problem of soil erosion. These programs involved constructing terraces using forced labor, but were soon abandoned with the 1963 independence. Alarmed by the adverse effects of continued soil erosion, the government established a program to deal with the problem in 1974. An important feature of the program was the World Bank-sponsored training and visit (TV) system of extension for soil conservation. This system was meant to include interactive farmer–extension participation, coupled with intensive publicity and field and farmer demonstrations (Harding et al. 1996).

Another approach to stimulating adoption has been to give incentives to farmers. Incentives are, in this case, inducements from an external agency (government or donor) meant to motivate the local population individually or collectively to adopt SWC aimed at improving natural resource management (Laman et al. 1996). Politicians stress that these incentives should be available to all farmers because of the "public good" nature of soil conservation. They view incentives as legitimate payments for off-site benefits of soil conservation enjoyed by society (Stocking and Tengberg 1999). Given the persistence of land degradation, one conclusion that can be drawn is that these efforts have not been sufficient.

The nature and extent of soil loss may suggest that current levels of SWC adoption are socially and even privately inefficient. Although current practices may offer high short-term yields, they diminish the soil's future productive capacity. From a private agent's economic viewpoint, justifications for incentives for SWC include high short-term costs, compared to economic benefits in terms of improved yields that may be delayed for several years before they are realized. Additionally, poor households that lack capital to finance productive investments may be unable to undertake lump-sum investments like SWC, regardless of their expected returns.

Other broader social concerns, especially regarding yield decline, negative downstream externalities, and the adverse effects on rural farm incomes and food supplies for consumers, make soil conservation an important policy issue. Alleviating poverty is a public policy issue which, therefore, must involve land management. This is also important for overall economic growth as well as for equity considerations. Future generations have a right to a viable soil resource and the government as a custodian of the land has an obligation to ensure that it happens. The cost of land degradation to the Kenyan economy is substantial. Recent estimates of costs of soil erosion in Kenya have been estimated to be equal in magnitude to national electricity production or agricultural exports (equivalent to US$ 390 million annually or 3.8

percent of gross domestic product (Cohen et al. 2006). Finally, the country in addressing land degradation will be meeting some of its global environmental obligations as evidenced by the signing and ratification of various environmental conventions.[1]

Disentangling productivity differences between adopters and non-adopters is crucial for understanding household level responses to land degradation and for designing appropriate policy interventions. Nonetheless, few attempts have been made to examine the effect of SWC on crop productivity in non-experimental settings. The neglect is probably due to methodological difficulties and weak data. An econometric evaluation to establish whether SWC techniques indeed offer higher returns and merit promotion is complicated. First, there is limited literature on the empirical evaluation of SWC projects conducted at the farm level. Farmers and policy makers have relied heavily on research station trials in order to establish how different farm technologies affect yield. Yet, farm surveys consistently show that small farm holders fail to achieve the physical yields obtained in research stations (Evenson and Gollin 2003). Second, adoption of technology may be positively influenced by the current level of productivity (Feder and Slade 1984), although economic theory suggests that technology affects productivity. Thus, technology adoption and productivity appear to be jointly determined. Therefore, estimating a single equation *ex post* productivity with technology adoption as an explanatory variable is subject to simultaneity bias. Establishing *ex post* the true gains attributable to a technology, especially under farmer conditions, is thus a difficult proposition. This is an important empirical question, not only for understanding SWC promoting policies, but also for poverty alleviation through agricultural growth.

Past work has tried to clarify the relationship between investment in soil capital and productivity, but does not allow us to reach an empirical consensus. For example, Place and Hazell (1993), using data from Ghana, Kenya, and Rwanda, found that land-improving investments were insignificant determinants of yield. Hayes et al. (1997) reported similar results for Gambia. In contrast, Byiringiro and Reardon (1996) examined the effects of soil conservation on farm productivity in Rwanda. They found that farms with greater SWC investments had much better land productivity than others. Adgebidi et al. (2004) reported significant positive productivity effects of soil conservation, but only after controlling for household specific constraints. Similarly, Kaliba and Rabele (2004) found a positive and statistically significant

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[1] These include the United Nations Convention to Combat Desertification (1997), Convention on Biological Diversity (1992), and United Nations Framework Convention on Climate Change (1994).

association between wheat yield and soil conservation for Lesotho. This study, however, did not control for plot characteristics, which could lead to biased results in the event of correlation between plot quality and conservation. Using data from the Ethiopian highlands, Menale et al. (2008) applied a number of methods to control for selection and endogeneity bias to estimate returns to soil conservation. They found soil conservation structures to be beneficial only in water-stressed areas. This study, although carefully formulated, restricted its analysis to bunds, yet farmers apply different structures to different plots. While the other studies assumed that the same set of factors equally affected both adopters and non-adopters, Menale et al. (2008) is an exception. Consequently, the studies do not account for endogeneity of technologies and potential self-selection bias. In addition, the few studies dealing with the productivity implications of SWC adoption in Africa, and the conflicting results, warrant further examination of the issue.

This study, therefore, assessed the impact of SWC on the value of crop production per hectare with and without SWC in Kenya. Barrett et al. (2004) suggested a switching regression model to evaluate the impact of technology adoption on rice production in Madagascar. Our study took this approach a step further by investigating the impact of SWC adoption on conditional yield. In addition, we decomposed estimated yield differences into components that can be interpreted economically. To tackle these questions, we considered the performance of plots with and without SWC, carefully addressing plot and household heterogeneity, among other factors.

Our study differs from the previous literature in two respects. First, the nature of the data, multiple plots per household allowed us to control for unobserved household heterogeneity that may impact adoption and production decisions. The data were particularly well suited to such an analysis as they revealed the SWC status of each plot owned by the household. Second, the data pertained to a period when there was no direct donor or government support of SWC in the country.[2] More importantly, the adoption was driven and achieved by farmers without hand-out incentives. The lessons learned may have wider applicability not only in Kenya but also in other countries facing comparable problems of land degradation. However, one limitation that our study shares with other studies is the lack of longitudinal data. Plot-level longitudinal data offer detailed information that overcomes difficulties inherent in a single cross section. Our key

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[2] In the mid 1990s, donor support was withheld due to mismanagement and governance problems. Faced with budgetary pressures on public expenditures, the government reduced the number of extension agents.

findings were that SWC increased the returns from degraded plots and sometimes from other inputs. A simulation exercise based on these estimations also showed that, in most cases, adoption has been beneficial for those who have done it and would be beneficial for those who have not.

The rest of the paper is organized as follows. Section 1 presents the nature of the evaluation problem and a description of the analytical framework, including the hypotheses to be tested. Section 2 motivates the estimation methodology and section 3 introduces the data and variable definitions. Section 4 presents the results of the data analysis (including salient yield and input differences between plots with and without SWC), econometric estimates, and main findings. In the last section, we conclude the paper and discuss the implications for policy.

1. Conceptual Framework and Hypotheses

In the literature, there are several theoretical approaches of modeling farm technology adoption decisions. (For a survey, see Feder et al. 1985.) In this study, we saw two important issues that we needed to address in a model describing farmer behavior. These issues have been addressed in previous studies, but only separately and not jointly. First, farmers' SWC adoption and production decisions may be simultaneous (Feder and Slade 1984). This simultaneity may also be due to unobserved variables correlated with both adoption and production decisions. Second, households do not make adoption decisions randomly; instead, they are based on expectations of how their choices affect future crop performance. Consequently, adopters and non-adopters may be systematically different. These differences may also manifest themselves in farm productivity and could be confounded with differences purely due to SWC adoption. The results would be biased if we did not address this self-selectivity problem (Greene 2000).

Whether or not a household adopts SWC technology depends on the costs and benefits of each technology (Shiferaw and Holden 2001). The assumption we made is that a household maximizes utility when choosing technology. However, we did not observe its utility, but only its choice of technology. In the analysis, we therefore applied a random utility model (McFadden 1973). The utility of each alternative was in turn determined by a set of exogenous variables, *Z*, and an error term. The exogenous variables are both household variables and plot characteristics. Adoption is assumed to occur if the utility of the soil conservation alternative is higher than the utility of the other alternative; i.e., if $I_{hp}^{*} = I_{hp}^{sc} - I_{hp}^{nsc}$ or if $Z_{hp}\gamma + u_{hp} > 0$. (The indices *h* and *p* refer to household *h* and plot *p*.) If the variable I_{hp} reflects the soil conservation adoption decision and equals 1, and if there is a SWC structure by household *h* on plot *p* and otherwise equals zero, then we can write:

$$\begin{aligned} I_{hp} &= 1 \quad \text{if} (Z_{hp}\gamma + u_{hp}) > 0 \\ &= 0 \quad \text{if } (Z_{hp}\gamma + u_{hp}) \leq 0 \end{aligned} . \qquad (1)$$

Hence, the adoption decision Z_{hp} is a vector of the exogenous variables, including land size, market characteristics, human capital, and social characteristics (Feder, Just, and Zilberman 1985; Rogers 1995); γ is a vector of parameters; and u_{hp} is an error term. The error term includes measurement error and factors unobserved to the researcher but known to the household. The variable I_{hp} is a dichotomous choice variable and can be consistently estimated using a limited dependent variable model, such as binary probit (Maddala 1983).

To examine the impact of SWC adoption on farm productivity, one has to estimate yield functions for plots with and without SWC as a simultaneous system. Since plots with and without SWC are mutually exclusive, they cannot be observed simultaneously on a particular plot. Adoption of SWC may affect and even alter input use patterns and decisions (Kaliba et al. 2000). The households may also be both adopters and non-adopters if they have more than one plot. Therefore, we specified two separate yield functions for plots with and without SWC:

$$y_{hp1} = \mu_1 + X_{hp}\beta_1 + \eta_h + \varepsilon_{hp1} , \quad (if \quad I^*_{hp} > 0) \text{ , and} \qquad (2a)$$

$$y_{hp0} = \mu_0 + X_{hp}\beta_0 + \eta_h + \varepsilon_{hp0} , \ (if \ I^*_{hp} \leq 0) \ . \qquad (2b)$$

The variables y_{hp1} and y_{hp0} are continuous variables, representing the value of output per hectare if I_{hp} equals 1 or 0, respectively. X_{hp} is a vector of explanatory variables and β_1 and β_0 are vectors of unknown parameters. Finally, η_h is an unobserved household specific plot invariant effect and $(\varepsilon_{hp0}, \varepsilon_{hp1})$ are error terms.[3] This error structure allows control for unobserved effects, such as farming ability and intra-household correlation due to unobserved cluster effects.

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[3] Although random effects models are usually applied to cross-sectional time series data, these methods also apply for a single cross section when we have multiple plot-level observations within the household.

SWC can affect farm productivity positively in at least three ways. First, there could be an increase in farm yields per hectare through increased soil depth and water retention capacity, etc. Second, adoption of SWC may reduce input costs. For instance, increased soil fertility through accumulated soil organic matter could decrease the need to apply fertilizers. Third, the productivity of factor inputs may increase. However, there may be several other reasons for investment in soil conservation. To organize our empirical work, we relied on the above arguments, which suggest the following hypotheses to be tested.

Some empirical studies have suggested that the impact of SWC on agricultural productivity is positive (Byriringiro and Reardon 1996), while others have suggested that it is negative (Place and Hazell 1993). We, therefore, first had to test the hypothesis that SWC has a positive effect on agricultural productivity.

Second, the decision to invest in conservation may create differences in input demand (Pitt 1983). Inputs in the agricultural system, such as land, labor, and fertilizer, are explicit arguments in the yield functions. There may be differences in production costs between plots with and without SWC. For instance, one may expect that there are savings in fertilizer costs with SWC practice through reduced run-off and nutrient loss. Yesuf (2004) found, for example, in Ethiopia that adoption of SWC led to a reduced use of fertilizers. Thus, the hypothesis to be tested is whether adoption of SWC actually leads to significant reductions in other input factors such as labor, fertilizers, and manure.

Finally, a change in soil quality may also affect the productivity of the mentioned inputs (Kaliba et al. 2000). The hypothesis tested here is whether SWC actually increases the returns from land and other input factors.

While testing for these hypotheses, we needed to be aware of the fact that there are effects of SWC other than on productivity. For example, there might be other intangible benefits, such as scenic beauty and even social status associated with conservation (Swinton and Gebremedhin 2003). The latter suggests that preferences and behaviors of other community members affect individual farmer behavior, in particular if there are social norms regarding who is a good farmer. Any deviations from this norm may entail private costs, such as low self-esteem or low prestige, making over-investment plausible.

We also needed to take into consideration that specific farm attributes, such as land quality and slope, might influence adoption decisions and costs. Many farmers with fragile and hilly slopes may be preoccupied with SWC to avoid future crop yield losses, suggesting that adoption benefits cannot be solely assessed in terms of current crop yields.

We thus estimated yield functions to investigate the impact of soil conservation practices on yield and factor returns (Antle 1983; Antle and Capalbo 1993). This approach accounts for the fact that yield depends on inputs used in production and current or past soil conservation activities. Empirical studies of agricultural productivity have used a variety of estimation strategies. Some argue that direct estimations of production functions are likely to give biased parameter estimates because input use may be endogenous to production decisions (Berndt 1991). As the season progresses, farmers may adjust input amounts depending on weather, availability of credit, or pest conditions. As an alternative, estimation of the dual form of the production, i.e., a cost or profit function, has been suggested. However, this is difficult in the absence of good estimates of factor prices for labor and land. Moreover, the endogeneity problems of using the primal are specific to the plot, but since we controlled for plot-specific characteristics, they are likely to be modest. These effects are certainly bound to exist and must be kept in mind when interpreting results. Furthermore, a direct estimation of production functions is justified if farmers maximize expected yield value instead of actual yield value, as discussed in Zellner et al. (1966). They argued that when the random disturbance term represents factors, such as weather, and input quantities are chosen before the realization of this disturbance, then estimates are consistent because input quantities are independent of the error term. Coelli (1995) argued that these conditions are typical of agriculture, and so we adopted the primal approach in this study.

In this study, we attempted to estimate yield functions with a flexible quadratic form, a so-called translog production function. Second order terms included squares of each input and interactions of inputs and productivity shifters (e.g., fertilizer and SWC investment, plot characteristics, etc.). However, due to excessive multicollinearity, interaction terms needed to be dropped. What remained, therefore, was a reduced form translog function.

Our methodology is similar to that of Byiringiro and Reardon (1996), Holden et al. (2001), and Adegbidi et al. (2004), but still differs in some important respects. First, instead of using dummy variables to represent soil conservation investment, we used area shares to measure the intensity of use. Thus, we did not assume that SWC only had an intercept shift in productivity. Second, we estimated productivity for two regimes, which avoids loss of information entailed in correcting for non-adoption alone. A t-test was used to test for significance of differences in input use intensities between the two regimes.[4] Finally, yields under the major SWC technologies were estimated separately.

2. Estimation

Estimation of the separate production functions (2a) and (2b) with selected samples is accomplished with an endogenous switching regression model (Lee 1978; Maddala 1983). To account for household heterogeneity over plots, we used a random effects model (Wooldridge 2002). Sample selectivity was treated as a missing variable problem accounted for by including selectivity correction regressors in equations (2a) and (2b). This made the coefficient estimates of yield obtained from the two-stage procedure consistent (Maddala 1983). The correction instruments were derived from the first stage probit model, which provided estimates of γ used to estimate the correction terms, as follows:

$$E(\varepsilon_{hp1} \mid X_{hp}, I_{hp}^{*} > 0) = \sigma_{u1}\frac{\phi(Z_{hp}^{'}\gamma)}{\Phi(Z_{hp}^{'}\gamma)}\ ; \tag{3a}$$

and similarly for ε_{h0}, :

$$E(\varepsilon_{hp0} \mid X_{hp}, I_{hp}^{*} \le 0) = \sigma_{u0}\frac{-\phi(Z_{hp}^{'}\gamma)}{1-\Phi(Z_{hp}^{'}\gamma)}\ , \tag{3b}$$

where ϕ and Φ are the density function and the distribution function of the standard normal evaluated at $Z'\gamma$. The conditional expected yields were computed as:

$$E(y_{hp1} \mid X_{hp}, I_{hp}^{*} > 0) = \mu_1 + X_{hp}^{'}\beta_1 + \sigma_{u1}\frac{\phi(Z'\gamma)}{\Phi(Z'\gamma)}\text{, and} \tag{4a}$$

$$E(y_{hp0} \mid X_{hp}, I_{hp}^{*} \le 0) = \mu_0 + X_{hp}^{'}\beta_0 - \sigma_{u0}\frac{\phi(Z'\gamma)}{1-\Phi(Z'\gamma)}\ . \tag{4b}$$

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[4] The test statistic was calculated as $t = (X_{ip}^{sc} - X_{ip}^{nsc}) / \sqrt{Var(X_{ip}^{sc}) + (X_{ip}^{nsc}) - 2\operatorname{cov}(X_{ip}^{sc}, X_{ip}^{nsc})}$.

The coefficients σ_{u1} and σ_{u0} represent the estimates of the covariances. If these covariances are nonzero, then estimates of equations (4a) and (4b) would be biased due to sample selectivity. The signs of the covariance terms σ_{u1} and σ_{u0} have an intuitive economic interpretation. If $\sigma_{u1} > 0$ and $\sigma_{\mathrm{u0}} < 0$, then unmeasured returns are positively correlated with unobservable plot characteristics that are valued in the adoption of SWC. In that case, as the selection hypothesis proposes, plots of high return capabilities are selected for adoption. The reverse case, $\sigma_{u1} < 0$ and $\sigma_{u0} > 0$, casts doubt on the relevance of the selection hypothesis.

The two-step method does not guarantee correct standard errors for the coefficients because the imputed unobservable variables used in the second step are generated regressors rather than the true value. A common problem is that the standard error in the two-step model is smaller than the corrected values because the corrected variance-covariance matrix of the coefficients has an additional positive definite matrix from the first-step procedure. If the standard errors are not corrected, then hypotheses testing may be incorrect. Murphy and Topel (1985) offered a simple formula to correct the covariance matrix of the estimates. We used the correction factor to correct the standard errors in the second step, to generate the correct t-statistics (Greene 2000).

3. Data and Variable Description

The data came from a sample of Kenyan households in the Kiambu, Meru, and Machakos districts. These districts have contrasting SWC regimes, even in the same household, making them suitable for a comparison of productivity performance. The data pertain to the 2001–2002 farming season and cover the household socio-economic characteristics, crops, yields, and SWC status at the plot level. The households were interviewed two months after the maize harvest for optimal input-use recall on the recent crop.

Table 1 gives the summary statistics for the model variables. There are two dependent variables. A separate model for SWC adoption is included. We included some variables related to the SWC adoption decision. *Conserve* is a binary dummy variable indicating whether there is an SWC structure on the plot or not. Next we considered some of the variables used in this estimation. The human capital of the household is indicated by the years of education of adult males and females in the household and age of household head. On average, household heads were 52 years of age, suggesting that farming households tend to be late in their life cycle. The dependency ratio was derived as the number of dependants (aged below 15 years and above 65 years of age) divided by the number of those aged between 15 and 65 years. Scarcity of land is

Table 1 Descriptive Statistics

Variable	Units	Mean	Std. dev.	Min.	Max.
Conserve	dummy	0.86	0.33	0	1
Output value per hectare	Ksh	7590	24595	1400	42000
Soil and water conservation technology					
Bench area share	share	0.046	0.081	0	0.68
Bund area share	share	0.014	0.049	0	0.40
Ridge area share	share	0.026	0.085	0	0.80
Inputs					
Family labor	days/hectare	61	71	0	180
Hired labor use dummy	dummy	0.43	0.50	0	1
Hired labor	days/hectare	1.3	1.5	0	6
SWC maintenance labor	days/hectare	9.4	15	0	12
Fertilizer use dummy	dummy	0.32	0.47	0	1
Amount of fertilizer	kg/hectare	30	67	0	600
Manure use dummy	dummy	0.30	0.57	0	1
Amount of manure	kg/hectare	1040	1980	0	8000
Plot characteristics					
Plot area	hectares	0.36	0.46	0.1	6.83
Slope					
Light slope	dummy	0.34	0.47	0	1
Medium slope	dummy	0.40	0.49	0	1
Steep slope	dummy	0.24	0.42	0	1
Erosion status					
Lowly eroded	dummy	0.06	0.13	0	1
Moderately eroded	dummy	0.15	0.36	0	1
Highly eroded	dummy	0.18	0.38	0	1
Soil depth					
Shallow (<25 cm)	dummy	0.12	0.33	0	1
Moderate (25-50cm)	dummy	0.54	0.49	0	1
Deep (>50cm)	dummy	0.34	0.47	0	1
Household factors					

Average education	years	7.0	2.6	1	21.75
Value of livestock	Ksh	45200	51250	28800	118600
Farm size	hectares	1.43	1.24	0.5	8.3
Per capita land	share	0.26	0.29	0.01	0.77
Prior adoption	proportion	0.68	0.81	0	1
Age of household head	years	52	13.2	23	72
Dependency ratio	share	0.32	0.19	0.01	0.8
Off-farm income	dummy	0.62	0.54	0	1
Perennial crops income	Ksh	1249	2688	640	6428
Share transport cost to sell price	share	0.27	0.23	0.014	0.98
Distance to market	minutes	41	30	2	119
Social capital					
Associations	index	3.02	1.27	0	16
Trust	index	4.36	1.03	2	18
Community attachment	index	0.99	0.37	0	1.4
Information	index	3.11	1.06	-4	13.6

Note: Ksh = Kenya shillings

given by the per capita land available which is land size weighted by the household size. The average per capita land under maize cultivation was 0.26 hectares, a finding consistent with official publications. The physical capital of each household is indicated by the value of livestock and availability of off-farm income. On average, 62 percent of the households had access to off-farm income.

Output is the aggregated value of maize (Zea mays) and beans (Phaselous vulgaris) produced per hectare. We departed from the tradition of using a single crop yield for two reasons. First, maize and beans are both staple foods in Kenya and make up the dominant crop mix for small and medium farms. Second, the crops cannot be viewed separately, since they are grown simultaneously on the same plot, and there is the added advantage of minimized recall errors for such a dominant crop mix. The decision to aggregate over the two crops forced us to work with values because quantities cannot be aggregated directly.

There were a number of soil conservation measures used by farmers in our study. In the literature, the practice is to choose one or two specific soil conservation measures as an indicator of investment (see Kazianga and Masters 2001). The ratio of adopted practices to total number of conservation measures available has also been used to define the soil conservation variable for each farmer (Nowak 1987), which is simple, but ignores intensity of use. This study used the share of land covered by each measure as the intensity of SWC measure on a plot, that is, the proportion of plot area devoted to the measure.

On each plot, there was a predominant SWC structure whose measurements were used in this analysis. The structures include benches and *fanya juu* terraces,[5] both referred to here as *benches*. The other measure is contoured earth or stone bunds for soil-erosion control or water harvesting, conveniently called *bunds* here. In many places, farmers stabilized the bunds with Napier grass, which was also used as animal fodder. The last category is *ridges*, which also includes micro-basins, known as pits. (The decision to group these together was based on the amount of labor time needed to construct them.) Consistent with other studies of soil conservation in Kenya (Oosterndorp and Zaal 2002), our data suggested that the average intensity of use of benches is the highest with five percent of the area, followed by ridges and bunds with three and one percent, respectively.

With respect to inputs, *labor* is measured as the total amount of full labor days used for land preparation, seed bed preparation, planting, weeding, fertilizer and manure application, and harvesting. Family and hired labor are separated in conformity with other studies that found differences in their respective productivity. We noted that the average number of days of family labor is higher than the average number of days of hired labor. This could result from careful timing of the use of hired labor. Family labor is applied throughout the year, while hired labor is typically employed during peak labor-demand periods, such as planting and harvesting. The average family labor used per hectare is 60 days with a maximum of 180 days. While there are disagreements over labor demands associated with SWC, most observers seem to agree that SWC increases labor demand in construction and maintenance. On average, households with SWC spent nine days per hectare annually on maintenance.

Fertilizer and manure use averaged 29 and 1,000 kilograms per hectare, respectively. Although these amounts are far below those recommended for maize and beans, they are consistent with other findings from Kenya (Omamo et al. 2002). Because there are zero values for some households, it is not possible to use a simple logarithmic transformation for these

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[5] "*Fanya juu* terraces are made by digging a trench along the contour of the land and throwing the soil uphill to form an embankment. The embankments are stabilized with fodder grasses. The space between the embankments is cultivated. Over time, the *fanya juu* develop into bench terraces." (IIRR website, n.d., "Conserving Soil and Water," in *Sustainable Agriculture Extension Manual*, 84-92, http://www.iirr.org/saem/page84-92.htm)

variables. Following Battese (1997), we included a dummy variable for positive amounts to allow for an intercept shift for households with zero values for some inputs, as well as the logarithm of inputs for households with positive input levels. The log transformations reduced problems with non-linearity and outliers, improving robustness of the regression results (Mukherjee et al. 1998).

Plot-specific attributes, such as land quality and slope, may influence both adoption decision and productivity. Arguably, many farmers with fragile and hilly slopes may be preoccupied with SWC to avoid future crop yield losses. It is therefore important to control for the impact of plot characteristics on yield. However, measuring such soil quality characteristics is both complicated and costly. Consequently, we resorted to using approximate indicators, such as slope, erosion status, and soil depth.

The benefits of SWC depend on how much value the farmer realizes from the sale of produce. The cost of transportation relative to local market price is a coarse measure of the degree to which prices must be forgone in order to sell the output in local markets. High transport cost reduces the returns to crops production and is therefore expected to negatively affect the value of yield.

High-value perennial tree crops (coffee, tea) may contribute to agricultural productivity in various respects. On one hand, poor farmers in rural areas are unable to purchase productivity-enhancing inputs, such as fertilizers, due to capital and credit constraints, but incomes from such crops present an avenue for reducing such constraints. In addition, these cash crops have institutional input/output marketing arrangements that may benefit farmers (Jayne et al. 2004). On the other hand, there are concerns that cash crops compete with staples for labor and scarce land, jeopardizing the ability of households to feed themselves in the event of market failure. We included share of revenue from tree crops per land holding to investigate its impact on the value of maize and beans.

Finally, we included indicators of social capital to explain the adoption of SWC. Many arguments have been advanced in the literature as to why social capital may improve adoption of SWC. Some of these include solving collective-action problems, reducing monitoring problems, and developing revolving credit schemes to overcome incomplete or non-existent capital markets and information flows. Revolving credit schemes involve all members of a group contributing an agreed sum of money each period to the fund. The money can then be borrowed by one member each period, if required, for financing SWC or buying equipment. The success of such schemes requires that members do not free ride, which in turn demands trust. Networks and memberships of groups may also help overcome the impediments of information flows due to social divergence. Using principal components analysis, we constructed the indices of social capital and also analyzed their relationship to soil conservation. These are constructed from variables, such as membership in organizations; degree of involvement; and participation in water projects, soil erosion control, etc. (Nyangena 2007).

4. Results

4.1 Use of Soil and Water Conservation, Yields, and Inputs

One of our hypotheses was to test whether there were significant differences in input use between plots with and without SWC, with the expectation that SWC adoption would lead to savings of other inputs. Table 2 reports results for the mean differences in various characteristics for plots with and without SWC investments, using the t-test to test the null hypothesis of equality of means. It is apparent that plots without SWC have a higher and significant yield value. In line with previous studies (Pagiola 1994), there are significant differences in mean value of crop yield for plots without SWC investments in comparison with plots with SWC.

Table 2 Differences for Plots with and without SWC

Variable	Without SWC	With SWC	Difference	P-value
Value of crop yield (Ksh)	11320	8670	2650	0.002***
Inputs				
Family labor/hectare	65	56	9	0.641
Hired labor/hectare	4.6	4.2	0.4	0.046**
Average household education	7.5	6.8	0.7	0.064
Amount of fertilizer/hectare	36	41	-5	0.718
Amount of manure/hectare	870	1030	-160	0.011**
Plot characteristics				
Erosion status				
Slightly eroded plot	0.057	0.19	-0.133	0.006***
Moderately eroded plot	0.086	0.16	-0.078	0.005***
Highly eroded plot	0.014	0.07	-0.056	0.073
Slope				
Low slope	0.543	0.308	0.235	0.000***
Medium slope	0.371	0.407	-0.036	0.573

Steep slope	0.071	0.243	-0.172	0.000***
Soil depth status of plot				
Soil depth (<25 cm)	0.314	0.098	0.216	0.000***
Soil depth (25–50 cm)	0.429	0.549	-0.12	0.059**
Soil depth (>50 cm)	0.257	0.352	-0.095	0.118
Household factors				
Share value of tree crops/hectare	1.18	1.26	-0.08	0.024***
Presence of off-farm income	0.246	0.258	-0.012	0.012***
Market distance	1.15	1.1	0.05	0.109
Value of livestock owned	8.07	7.83	0.24	0.513
Plot size (in hectares)	1.72	1.39	0.33	0.042**

Notes: *** Significant at 1% level; ** significant at 5% level; Ksh = Kenya shillings

Plots with SWC have a significantly lower mean value of crop yield. This was further analyzed in the multivariate analysis. With regard to input use, we did not find clear differences with respect to family labor and fertilizer inputs. Plots without SWC on average hired more labor compared to those with SWC. There were statistically significant differences in the amounts between plots with and without SWC. Plots with SWC used much more manure compared to those without. Soil fertility is partly an endogenous variable; hence, large amounts of manure application might suggest that farmers applied more manure to plots with depleted soils. This may lend credence to the observation that SWC is used on eroded land, which may suggest that plots with SWC have low fertility and, hence, require more nutrient augmentation from manure.

Plot characteristics seemed to determine whether to choose to invest in SWC or not. About 55 percent of plots with a soil depth of between 25 and 50 cm had SWC, compared to 43 percent without SWC. In addition, there were statistically significant differences in the proportion of plots found on steep slopes with SWC, compared to those without. One would expect a direct positive relationship between SWC and yield. However, when a difference in yield between plots with and without soil conservation is observed, the underlying reason for the difference is not straightforward. On one hand, it is plausible that more productive plots attract SWC investment to retain or further augment the productivity. On the other hand, SWC investments may be adopted on eroded land in order to restore productivity that may have been lost due to erosion. One reason for this ambiguity could therefore be that there are differences in plot characteristics between plots with and without SWC investments. We used the Mann-

Whitney test (a non-parametric version of the independent t-test) to test whether there were significant differences with respect to plot characteristics for plots with and without SWC for each of the categories. Table 3 presents the results.

Table 3 Differences in Plot Characteristics with and without SWC

	Slope	Erosion status	Soil depth
	H0: $Slope^1$=$Slope^0$	H0: $Erosion^1$ =$Erosion^0$	H0: S-Depth ^{1}=$S\text{-}Depth^0$
Z	4.60	6.00	-1.324
P-value	0.000	0.000	0.2210

Note: Superscripts 1 and 0 represent with and without SWC, respectively.

We reported the overall differences for the plots. We rejected the hypotheses of equal slopes between the plots with and without SWC. Plots with SWC measures seem to be, on average, more steeply sloping than other plots. As with erosion status, we found a statistically significant difference between plots with and without SWC, indicating that plots with SWC were more eroded than those without. Arguably, plots that suffer from high erosion, low water retention, and low fertility would be strong candidates for SWC investments and, according to table 3, this appears to be the case. One may also argue that late SWC adoption may be a response to erosion rather than a preventive measure. Our comparisons thus far were pair-wise and did not control for other pertinent factors. Given the systematic differences identified in this descriptive section, we now turned to a multivariate analysis attempting to control for these differences in input intensities and plot characteristics, while analyzing yield values from plots with and without SWC.

4.2 Results of Estimations

The estimation was conducted in two stages. The results of the probit estimates of equation (1) are presented in table 4. The fitted values of the probit model are used to construct the selectivity variables whether a plot has SWC or not, corresponding to equations (3a) and (3b). The coefficients indicate the direction of likelihood of adoption of a given independent variable.

Table 4 Estimated Probit Results for SWC Investment Decision

Variable	Coefficient	P-value
Farm characteristics		
Plot soil factors		
Deep soil(>50 cm)	-0.128	0.074
Highly eroded	0.194	0.007
Steep slope	0.781	0.003
Perceived tenure security (reference HIGH)		
Medium	0.252	0.326
Low	-0.376	0.046
Geographic location (reference KIAMBU)		
Machakos	0.544	0.148
Meru	0.357	0.397
Behavioral characteristics		
Human capital		
Education	-0.160	0.0001
Age of household head	0.081	0.098
Age squared	-0.006	0.208
Socio-economic		
Dependency ratio	0.247	0.642
Hired workers	0.921	0.047
Off-farm income	-0.211	0.246
Per capita land	0.734	0.093
Perennial tree crops	-0.66	0.025
Distance to market	-0.003	0.081
Prior adoption	0.083	0.373
Social capital		
Associations	0.121	0.097
Trust	0.146	0.055
Community attachment	-0.029	0.751
Information	0.212	0.011
Intercept	-1.973	0.199
Concordant predicted probabilities	84.21%	

Discordant predicted probabilities	15.79%	
Overall correctly classified	81.70%	
Sample size	388	
Pseudo R^2	0.201	
Log-likelihood	-146.02	
Pearson chi square (361)	587.08	(0.000)

A more in-depth analysis of the adoption decision is given in section 5. However, for the following analysis on the differences in productivity between plots with and without SWC, it is interesting to confirm, as indicated in the previous section, that increased erosion status and slope significantly increased the probability of adopting SWC. Also, the negative sign of the coefficient for soil depth supported the notion that farmers with deep soils are less likely to adopt SWC. The pattern of adoption is thus significantly affected by plot and soil characteristics, with plots typically considered to be worse being more likely to have SWC. This explains the findings by Shiferaw and Holden (1998) and Gebremedhin and Swinton (2003). In addition, it gives further evidence of why one would not *a priori* expect higher productivity on land with SWC than on land without SWC.

This study confirmed many of our expectations and previous adoption studies, for instance, by pointing out the disincentive created by distance to market and the importance of social capital (Nyangena 2007). As would be expected, low tenure security discourages long-term investments, such as SWC, although in some situations, SWC investment may be a strategy to secure tenure on insecure land. Other variables, such as education and age of the head of household, also had unexpected signs.

Table 5 below presents the coefficients of the regressions with the selectivity correction for SWC adopters and non-adopters. Initially we included both quadratic and interaction terms in the yield functions. However, this specification contained inflated standard errors and led to insignificant parameter estimates with unexpected signs for some inputs. The lack of significance seemed to be due to excessive multicollinearity. A likelihood ratio test also rejected the less restrictive specification ($p<0.732$). We therefore turned to a less flexible reduced form translog specification, which resulted in most coefficients being significant and signs consistent with economic theory. Moreover, dropping interaction terms also increased degrees of freedom. We conducted an F-test for the possibility of pooling the data from the two samples, but this was decisively rejected ($p<0.01$).

Table 5 Log Value/Hectare Function Estimates: Random Effects Estimates for Switching Regression with and without SWC

Variable	NONE *Coefficient*	BENCH *Coefficient*	BUND *Coefficient*	RIDGE *Coefficient*	POOLED *Coefficient*
Soil conservation					
Bench area share					-0.863*
Bund area share					0.478
Ridge area share					0.967***
SWC maintenance labor/ hectare					0.051
Inputs					
Family labor/hectare	0.102***	0.024	0.101***	0.054	0.034***
Square of family labor/hectare	-0.641***	-0.292	-0.633***	-0.641	-0.242***
Hired labor use dummy	0.784***	0.679***	0.103	0.448*	0.004
Hired labor/hectare	1.172***	0.613***	0.475***	0.642***	0.325***
Fertilizer dummy	0.119	0.305	1.097**	-0.131	0.724***
Amount of fertilizer/hectare	0.408***	0.209	0.791***	-0.165	0.319***
Square of fertilizer/hectare	-0.074	-0.008	-0.079**	0.031	0.004
Manure dummy	0.698**	0.982***	0.974	2.723***	0.944***
Amount of manure/hectare	0.074	0.167***	0.159	0.259***	0.125
Plot characteristics					
Erosion status					
Moderately eroded plot	-0.091	0.538*	0.283	0.723***	-0.191
Highly eroded plot	-0.108	0.047	-0.112	-0.233	-1.344**
Slope					
Medium slope	-0.699	0.051	-0.343	0.444*	0.117
Steep slope	-1.566**	0.398***	-0.487	0.183	0.019
Soil depth status of plot					
Soil depth (25-50 cm)	0.213	0.107	0.431	-0.107	0.151
Soil depth (>50 cm)	0.729	0.301	0.635	0.199	0.517*
Household factors					
Share value of tree crops/ hectare	0.972***	0.524***	0.605***	0.673***	0.654***
Off-farm income	-0.011	-0.001	-0.086	-0.132	-0.133**

Market distance	-0.012***	-0.002	-0.003	-0.004	-0.004***
Farm size (hectares)	-0.132*	-0.096*	0.031	-0.023**	0.184
Value of livestock owned	0.186**	0.019	0.063	0.022	0.035**
Plot area (in hectares)	0.615***	0.223**	0.335*	0.143	0.747***
Selectivity correction	-1.358**	0.508***	-0.521	-0.746**	-0.786***
Intercept	10.031***	6.829***	7.537***	9.857***	6.395***
Rho	0.165	0.622	0.792	0.654	0.199
Regression diagnostics					
R-square					
Within	0.47	0.66	0.72	0.76	0.46
Between	0.29	0.45	0.57	0.56	0.36
Overall	0.43	0.47	0.62	0.46	0.42
Wald chi-square	181(23)***	261(23)***	145(23)***	166(23)***	218(27)***
Number of plots	70	259	102	96	457

Note: ***, **, and * significant at the 1%, 5%, and 10% levels.

The coefficients on selectivity correction factors from equations (3) and (4) provide some evidence that the selection model was necessary. For instance, self-selection occurred in the adoption of BENCH and RIDGE, since the selection terms for the adopters were statistically significant at 1 and 5 percent levels, respectively. These results suggested that if left uncorrected, self-selection would have biased the estimates of log value of yield equations associated with BENCH and RIDGE.

The results for plots with soil conservation investments are reported for BENCH, BUND, RIDGE, and the POOLED sample in table 5. In the analysis of the results, we will utilize this disaggregation and focus on the differences in coefficients between the various regimes. These variations represented, of course, the respective contributions of the explanatory variables to agricultural yield in the different regimes. They thus helped shed some light on our two hypotheses that SWC increases the agricultural yield and positively affects the productivity of other inputs.

We started with a comparison of the coefficients of the NONE and POOLED samples. In the POOLED estimation, we included the *area shares* of benches, bunds and ridges. These variables would capture any independent impact of the respective SWC structures. Only the coefficient for *ridge area share* had the expected positive and significant coefficient. Unlike benches and bunds, ridge structures are constructed annually, involving the removal of old structures and the construction of new ones. This process ensures that soil is churned and well aerated, unlike bunds and benches, which excavate infertile subsoil. The ridges are built perpendicular to the slope, so that rain water is directed away safely without destroying crops.

As opposed to the *ridge area share*, the impact of *bench area share* on the log value of farm production was negative, although only significant at the 10 percent level. We found no statistically significant effect of *bund area share* on farm productivity. The results from BENCH and BUND may partly be a reflection of the fact that these structures imposed additional costs by occupying otherwise productive land, at least in the short term (Pagiola 1994). Similar findings are reported in the literature (Shiferaw and Holden 1998; Adegbidi et al. 2004). The types of studies quoted above did not deal with our concern, since they used data that combine all SWC structures. Our approach to analyzing the impact of SWC structures on value of yield utilized data at the level of the individual SWC treatments.

Our second interest was the impact of SWC on the productivity of other inputs. In general, there were significant differences in determinants of log value of output across the SWC treatments.[6] *Family labor* had almost identical impact on the log value of yield for NONE and for BUND, but was not found to have statistically significant impacts for BENCH and RIDGE. Similarly, households with higher *Fertilizer* application earned the highest log values of yield for only BUND and then for NONE, while the coefficients were small and insignificant for BENCH and RIDGE. Households with more *Hired labor* earned higher log yield values for all SWC structures, but the impact was even larger for NONE. The returns from *Manure* application were positive and significant for NONE, but higher for BENCH and RIDGE, controlling for other factors. The largest impact was for RIDGE, which suggests that they are more suited to manure application. Thus no clear-cut picture emerged regarding the impact of SWC on the productivity of different input factors. The results suggest that the impact of inputs for SWC adoption may be context dependent. This suggests that efforts to promote SWC adoption should focus on understanding these contexts.

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[6] Various Chow tests were made to test the hypothesis that coefficients for pairs of treatments are the same. For all tests, the hypothesis that the coefficients are the same was rejected.

Since we found that SWC was overrepresented on steep and eroded soils with lower productivity, it was important to control for such plot characteristics. These variables also gave us an opportunity to analyze which technology is best suited for which land category. Ideally, this should be done by running separate production functions for the most important land categories. Unfortunately, the data did not permit this. Still, the existing results indicated that BENCH and RIDGE treatments may successfully increase the productivity on moderately eroded plots. Similarly, while steep slopes affected the log value of output negatively on plots without SWC, this was not the case if a BENCH treatment was applied on such steep slopes.

Turning to household factors, we found a number of other interesting results. First of all, high returns from *tree crops* consistently improved the log value of maize and beans production across the various regimes analyzed. This could be capturing the effect of a reduced capital constraint. Alternatively, it could be the effect of more integration in the input and output markets including credit (Jayne et al. 2004). Thus, tree crops could provide a win-win situation, in which the trees boost incomes and forest products (such as fuelwood) at the same time as they increase food production. Subsequently, there appears to be a case for profitable expansion of tree crops.

The effect of *Farm size* on log value of yield was negative and consistent with much of the literature on farm size productivity effects (Benjamin 1995; Heltberg 1998). This held for plots without SWC and for BENCH and RIDGE treatments. On plots without SWC, one can think of more use of other inputs. Since we controlled for land quality, labor input, and other factors, our result suggests that smaller farmers attain not only higher land productivity but also higher total factor productivity. As would be expected, *Plot area* had a positive and significant effect on crop value, both with and without SWC.

Distance to markets had a significantly negative impact on the log value of output, particularly for plots without SWC. However, combined with the result from the probit analysis that market distance decreased SWC adoption, it indicated the importance of improving market access for remote farmers.

4.3 Robustness Checks

We investigated the robustness of our estimation results in two ways. We allowed for the possibility that the SWC investments could have a longer life span than previously assumed. We therefore included plots with soil conservation investments up to 10 years old. Some would argue that experience should improve productivity through learning-by-doing effects.

Furthermore, there are studies that have shown that crop yields on terraces less than 10 years old are higher than those that are older (Figueiredo 1986). We then introduced an age variable for the SWC structure and an interaction term between SWC structure and age. The age variable was not statistically significant for all the SWC structures. The null hypothesis that age interaction terms in the model are jointly equal to zero could not be rejected for all structures. The F-statistics for joint significance of the interaction terms for BENCH, BUND, and RIDGE all had P-values greater than 0.7. We also tested whether there were district differences in the productivity of SWC measures. The P-values of the interaction terms between SWC measures and district dummies all indicated that these interactions were insignificant.

4.4 Productivity Decompositions

Our results so far appeared inconclusive with regards to the impact of various SWC structures on value of output. We also saw that there were systematic differences in plot characteristics and input quantities between plots with and without SWC. Of interest was the effect of adoption on the value of output when consideration was given to use of inputs and plot characteristics with and without SWC. Specifically, it would be interesting to know what percentage of production is due to changed plot status. Answers to this question may be useful to formulate scenarios that contribute to a better understanding of the role of SWC in agricultural production.

We therefore conducted two simulations based on the following scenarios. The first involved exploring the differences between SWC adoption on the log value of output and what the same households would have earned if they were non-adopters. This could be interpreted as the “SWC effect” on the value of output of adopters. Using the estimated parameters $(\hat{\beta})$ of the yield function in table 5, evaluated at their respective sample mean values, we decomposed the differences in value of output. Let the subscripts 0 and 1 indicate non-adoption and adoption status, respectively.

By employing a decomposition technique suggested by Oaxaca (1973), the estimated coefficient and the means of the two groups can be used to calculate SWC adoption/non-adoption yield value differences. Mean log yield differences can be written as:

$$\begin{aligned}\widehat{\overline{\ln Y_1} - \overline{\ln Y_0}} &= \sum \bar{X}_1 \hat{\beta}_1 - \sum \bar{X}_0 \hat{\beta}_0 \\ &= \sum (\bar{X}_1 \hat{\beta}_1 - \sum \bar{X}_1 \hat{\beta}_0) + \sum (\bar{X}_1 \hat{\beta}_0 - \sum \bar{X}_0 \beta_0) \\ &= \sum \bar{X}_1 (\hat{\beta}_1 - \hat{\beta}_0) + \sum \hat{\beta}_0 (\bar{X}_1 - \bar{X}_0) \quad . \qquad (5)\end{aligned}$$

The first term is the difference between adopter yield value and what the same farmers would have earned if they were non-adopters. This can be interpreted as the "SWC" effect on the yield value of adopters. The second term indicates the endowment effect between adopters and non-adopters or what non-adopters would have gained if they had the characteristics of adopters. Adoption of SWC may not change features such as slope, but may change plot attributes such as soil depth, soil organic matter, and degree of erosion. These biophysical factors act in concert with other factors, such as inputs to shape-cropping outcomes through maintenance of water balances and control of run-off (Turner and Brush 1987).

The estimated mean (log) value difference between adopters and non-adopters varies between structures. In estimating the predicted differences, we followed Lee (1978) and exclude the selectivity terms from the set of variables that predict $\widehat{\ln Y_1}$ and $\widehat{\ln Y_0}$. Results are reported in table 6.

Table 6 Decomposition of Impact Of SWC Adoption on Log Yield Value

	SWC effect			Endowment effect		
	BENCH	***BUND***	***RIDGE***	***BENCH***	***BUND***	***RIDGE***
Estimated difference	0.642	0.412	0.263	0.642	0.412	0.263
Inputs	-0.29	0.33	0.52	0.15	-0.14	0.14
Plot characteristics	0.39	-0.48	-0.28	0.49	0.20	-0.23
Household factors	0.33	0.18	-0.21	-0.13	-0.06	-0.06

We can attribute the value differences as those due to differences in input use amounts and those due to plot differences or quality. There are also those due to household characteristics, largely in terms labor endowments, cash income constraints, etc. All of these factors were evaluated at the sample mean variable input levels. By this method, we decomposed the productivity differences between the SWC structures. Overall, we noted that the differences were positive and largest for BENCH, followed by BUND. The productivity effect of adoption of BENCH was largest for plot characteristics, which may suggest their effectives in bringing steeply sloping land into cultivation. The productivity effect for BUND and RIDGE was negative (-0.48 and -0.28, respectively), which suggested that these structures may not be the most appropriate on degraded plots. However, with regard to input use, there was a positive effect for BUND and RIDGE (0.33 and 0.52, respectively), which suggested that adoption of these structures induced use of variable inputs. The observed and unobserved household effects were associated with positive yield gains for those adopting BENCH and BUND (0.33 and 0.18, respectively). This is consistent with the broader technology adoption literature, which finds that adopters are better farmers overall (Feder, Just, and Zilberman 1985).

Turning to the gains that non-adopters forfeit, we found that the largest returns came from plot factors for those adopting BENCH (0.49), followed by BUND (0.20). With regard to inputs use, there was an almost equal gain for adopters of BENCH and RIDGE, at 0.15 and 0.14, respectively. The estimated aggregate productivity effect of SWC adoption on household factors was negative, which may help explain limited uptake.

The results in this section go beyond the findings of previous studies in evaluating benefits of SWC under changing input, plot, and household characteristics. We found that SWC adoption appears to be useful in changing the impact of plot attributes on yield, although the contribution to predicted yield value is rather small. A natural extension of this analysis would be to calculate the profits per hectare with and without various SWC techniques, similar to the approach of Gebremedhin et al. (1999). However, this would demand detailed price information regarding the various inputs.

5. Summary, Conclusions, and Implications

This section outlines a methodology to estimate the impact of soil conservation adoption on crop yields. The method is general enough to be applicable to the adoption of any technology because it accounts for self-selection and simultaneity. The yield equation is theoretically consistent with a smallholders' production function.

Based on the expectation that SWC affects the welfare of adopting farmers through improvements in overall productivity, savings in inputs, and synergies with other inputs, these were framed as hypotheses and subsequently tested. The initial descriptive analysis, using two-sample t-tests and a Mann-Whitney (non-parametric) test, showed that plots without SWC had significantly higher value of yield per hectare and more hired labor than plots with SWC. However, plots with SWC used significantly higher amounts of manure. The higher mean value of yield on plots without SWC was expected to result from a negative selection, since it was found that plots with SWC had significantly steeper slopes and more erosion than the plots without SWC. This expectation was confirmed by the results of a probit that showed that SWC was positively correlated with steeper slopes, more erosion, and less soil depth.

In order to further analyze the productivity implications of SWC, random effects switching regressions were estimated for each of the three identified SWC technologies. The results showed, among other things, significantly different impacts on yield from plot characteristics and inputs, depending on which technology was used. Benches, for example, seemed to improve the productivity on steep slopes and ridges on moderately eroded plots. Regarding inputs, bunds seemed to increase the productivity of fertilizers, while ridges gave the highest return to manure.

The estimation results were then used in a decomposition analysis of how inputs and plot and household characteristics contributed to value of yield. We considered two scenarios: first, what the farmers would have earned if they were non-adopters; and second, what non-adopters would have earned if they had characteristics of adopters. The simulations indicated that the returns from plot characteristics increased with adoption. The return from other inputs given SWC was not as clear—possibly because of higher applications of inputs to compensate for the lack of SWC.

The evaluation of the hypotheses in this case study were thus less clear than expected, but did shed some light on the earlier, inconclusive literature regarding the impact of SWC on agricultural productivity. One cannot expect higher overall productivity on plots with SWC, since these structures are over-represented on plots with steep slopes and erosion problems. The relevant evaluation is, instead, whether such vulnerable and degraded plots have higher productivity with rather than without SWC. SWC can lead to savings in various factor inputs, but this is not a general finding and needs to be tested from case to case and input by input. SWC can lead to higher productivity of other inputs, but the evidence is inconclusive and seems to depend on complex relationships among technologies, plot characteristics, and inputs.

Methodologically, the paper has made some contributions. One contribution is pointing out the appropriateness of sample separation. Published literature has not analyzed the relationship between SWC and land productivity, separating between adopters and non-adopters. This study even divided the adopters into three different SWC practices. Econometrically, this was done by applying a two-stage random effects switching regression approach that handled the problems of self-selection and simultaneity. Finally, a simulation exercise was conducted to tease out the impact of adoption on some key areas of interest—plot characteristics and agricultural inputs.

Some of the results obtained here are supported by similar conclusions by Place and Hazell (1993), who did not find a significant impact of land investment on productivity. They observed that where investment fails to lead to greater productivity even if correlated to SWC, this may be because the purpose of investment is conservational rather than yield enhancing. In an analysis in Gambia, Hayes et al. (1997) found that some land investments enhanced yields, despite using a substantially different empirical strategy.

Other important positive determinants of farm productivity, besides traditional inputs, include plot size, livestock, and value of tree crops, while distance to market has a negative impact on the value of agricultural output. The empirical analysis indicated strong evidence confirming that in Kenya more tree-crop income increases agricultural productivity. The estimates were consistently highly significant and in the various specifications. Agroforestry initiatives thus seem to have great potential in these areas. Plot size is positively correlated to value of output, which indicates economies of scale. Further fragmentation of land in Kenya can therefore not be expected to raise per-hectare output. Finally, efforts to improve market access (e.g., through construction of rural roads) could in the long-run have broad implications on adoption of SWC and profitability of agriculture.

A limitation of this study is the incomplete modeling of the substitution possibilities between SWC and other purchased inputs, particularly fertilizers. This limitation is not attributable to the methodology, but is due to data limitations. As larger and possibly longitudinal data become available, the issue of substitutability and complementarities between SWC and other inputs may be addressed more thoroughly. Another natural extension of the simulation analysis, given availability of factor prices, would be to calculate the per-hectare profit levels with and without various SWC measures.

This analysis has focused on private adoption decisions and potential private returns from such decisions. However, it should be remembered that these decisions are also important from a societal point of view, since private decisions to conserve would also limit negative externalities with respect to downstream effects from erosion, such as sedimentation and pollution of rivers. Future research should investigate societal benefits of SWC adoption, since they could be the basis for public decisions to increase the incentives for private conservation.

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