Impact of Alternative Land Management Options on Soil Fertility and Erosion in Uganda

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Abstract

Using a data set collected in eight districts of Uganda, this study investigates how investment in soil fertility management (SFM) and conservation practices may affect natural resource outcomes, particularly the extent and level of soil erosion and soil nutrient loss. The study used ordered probit models and the results suggest that investment in SFM and conservation practices greatly improves soil fertility and reduces soil erosion. From a policy perspective, public investment to encourage use of SFM and conservation technologies would help the country achieve sustainable agricultural production.

Keywords: Land Management, Soil Fertility, Ordered Probit, Erosion

1. Introduction and motivation of the study

Policy makers in many developing countries and Uganda in particular are faced with the daunting task of enhancing agricultural productivity, and protecting the resource base on which agriculture depends. Inadequate policies to manage these productive resources may lead to land degradation. In fact land degradation is a major concern to policy makers in Uganda and the rest of sub-Saharan African (SSA).

Land degradation in Uganda is mainly manifested in the form of soil erosion and soil nutrient loss. Incidentally, Uganda has one of the highest rates of soil nutrient loss and soil erosion in SSA (Stoorvogel and Smaling, 1990; Wortmann and Kaizzi, 1998). If unattended to, land degradation may lead to low agricultural productivity, and hence low household incomes. Already, Deininger and Okidi

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(2001) have shown that the major cause of low incomes in Uganda's rural areas has been stagnating agricultural production.

Agriculture remains the key economic activity in Uganda (contributing 40% of the GDP, 85% of export earnings and 80% of employment) and the main source of livelihood for the vast majority of the population. The sector is dominated by a large subsistence segment pointing to the importance of agriculture's performance for food security and poverty reduction (Government of Uganda, 2004 and NEMA, 2002) and hence the need to invest in improving the productivity of land through efficient farming practices.

Adoption of more efficient farming practices and technologies that conserve the resource base are instrumental for achieving economic growth, food security and poverty alleviation. Adoption of soil fertility management (SFM) and conservation technologies will enhance productivity and quality of soil resources in a number of ways. For instance, investment in soil conservation practices reduces soil erosion and this can lead to improved yield, through increased soil depth and water retention capacity. Secondly, use of conservation practices may reduce input costs. For instance, increased fertility through accumulated soil organic matter could decrease the need for adding inorganic fertilizers. Surprisingly, despite the extent of land degradation and the importance of these technologies, adoption of most soil conservation and SFM technologies in Uganda is still below 30 percent (Nkonya et al., 2004). These levels of adoption are so low and are clearly socially inefficient. Thus land degradation and consequently poverty are expected to continue worsening unless intervention policies are effected.

Policy design to encourage adoption of these practices requires good understanding of determinants of adoption and their economic and environmental implications. In response to this need, a number of studies have investigated factors that determine adoption of soil and water conservation (SWC) and SFM techniques (see Feder et al., 1985; Shiferaw and Holden, 1998; 2001 for a complete review). In Uganda studies have shown that the low adoption is explained by institutional, household and farm characteristics (Pender et al., 2004; Nkonya et al., 2005; Birungi, 2007). For instance, poor farmers with credit and capital constraints are not able to use purchased inputs such as inorganic fertilizer to enhance farm productivity or pay for labour to invest in labour intensive conservation technologies.

Although research on determinants of adoption of SFM and conservation technologies has been carried in Uganda, research on impact of these practices on the severity of land degradation and comparative analyses of their effectiveness is lucking. Using data collected by the World Bank and the International Food Policy Research Institute (IFPRI), this paper investigates the impact of adoption of different SFM and conservation practices on land degradation in Uganda. Specifically, the study intends to investigate:

(i) How investments in alternative conservation practices affect soil erosion, and
(ii) How investments in alternative SFM practices affect soil nutrient loss

The rest of the paper is organised as follows: the analytical model is presented in section two and section three discusses the empirical model. Section four describes the study area, data, and choice of variables. Section five presents the results of the empirical analysis and section six draws conclusions and policy implications.

2. The analytical framework

This paper adopted the analytical framework used by Swinton and Quiroz (2003) depicted in figure 1. This two step framework assumes first, that a farming household chooses the agricultural practices/technologies that maximise the expected utility subject to limitations imposed by the available economic and natural resources, as well as parameters imposed by the larger economy. The first stage therefore would require understanding the factors that influence the decision to adopt particular agricultural practices/technologies. Using the same data set, an earlier study by Birungi (2007) has shown that choice of such technologies in Uganda are influenced by factors such as poverty, property rights, institutional factors, farm and operator specific characteristics.

In the second step, the chosen farming practices/technologies in turn combine with the natural environment and random environmental changes to create final natural resources outcomes. Equation (1) expresses the processes of figure 1 into algebraic form. The final natural resource outcome (FNR_i) depends on initial natural resource (NR_i) status as well as changes brought about by a vector of agricultural practices (x) as conditioned by other natural characteristics (S) and random effects (ε_i).

$$FNR_i = NR_i + f(x, S) + \varepsilon_i \qquad (1)$$

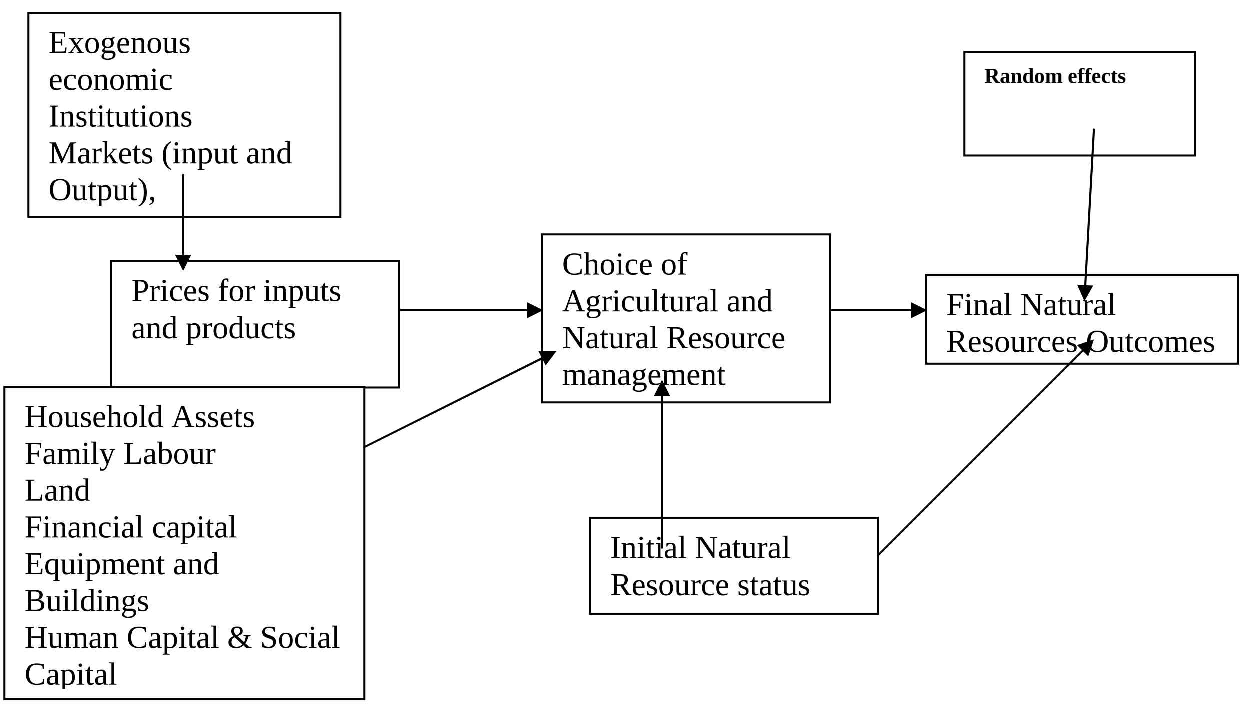
This in turn implies that;

$$\Delta NR_i = f(\Delta x, \Delta S\ ) + e \quad (2)$$

Where $\Delta NR_i = FNR_i - NR_i$

These natural resource outcomes, positive or negative shape farmers subsequent choices in future periods. The natural characteristics include land suitability characteristics such as elevation, slope, and soil types as well as other location and climatic characteristics governed by the geography of the area. This means that most of the variables incorporated in S are exogenous to the decision making process. Our interest in this study therefore will mainly be on the farming practice variables (x) that are chosen by farming households and can be influenced by policy. The studied practices include terracing, fallowing, organic fertiliser and inorganic fertiliser use.

Figure 1: Flow chart of links between household assets, farming practices, and natural resource outcomes



Source: Adapted from Swinton and Quiroz (2003)

3. The Empirical Model

Finding appropriate data on measures of natural resource outcomes such as plot level soil nutrient loss, soil loss due to soil erosion in tons per acre, etc. in developing countries is a major problem. More over longitudinal data that would capture feedback effects of the natural resource status is hard to come by. This study therefore relied on farmers perceptions of changes in land degradation. Perception on extent and changes of land degradation are important in Uganda because they drive decision making on investment in conservation activities. This is because of the lack of scientific investigation and dissemination of information on extent of degradation that would have otherwise informed farmers' decisions.

The impact of adoption of SFM and conservation practices on two natural resource outcomes namely soil erosion and soil nutrient loss are analysed. Respondents provided their perceptions of changes in soil erosion and soil fertility over a period of ten years. The perceptions were measured as ordinal responses with three levels. Perception of soil erosion was captured through a scale that increases with severity of the problem (i.e. 1 for no erosion, 2 for mild erosion and 3 for severe erosion). On the other hand, soil fertility loss was captured by a scale that decreases with fertility (i.e. 1 for highly fertile, 2 for moderately fertile and 3 for infertile).

Given the ordered nature of the responses, ordered probit models are used. Using OLS would not be appropriate given the non-interval nature of the dependent variable. Which means the spacing of the outcomes choices can not be assumed to be uniform. For instance, linear regression would assume that the difference between severe erosion and mild erosion response is the same as that between mild erosion and no-erosion, yet these responses simply reflect ordinality. The ordered probit model may be specified as follows (Long, 1997; Green, 2000);

$$y_i^* = x_i\beta + \varepsilon \qquad (3)$$

Where, the observed y is related to y^* according to the following measurement models.

i) Soil erosion

$$y_i = \begin{cases} 1 \Rightarrow & no & erosion & if & -\infty < y_i^* < \tau_1 \\ 2 \Rightarrow & mild & erosion & if & \tau_1 < y_i^* < \tau_2 \\ 3 \Rightarrow & severe & erosion & if & \tau_2 < y_i^* <= \infty \end{cases} \quad (4)$$

ii) Soil nutrient loss

$$y_i = \begin{cases} 1 \Rightarrow & highly & fertile & if & -\infty < y_i^* < \tau_1 \\ 2 \Rightarrow & moderately & fertile & if & \tau_1 < y_i^* < \tau_2 \\ 3 \Rightarrow & & infertile & if & \tau_2 < y_i^* <= \infty \end{cases} \quad (5)$$

Where τ_m represents the *thresholds* or *cut points.* Interpretation of the results in ordinal probit models is not straight forward. Long (1997) suggests computing partial changes in the probability of an outcome for a given change in each independent variable. For a continuous variable, a marginal change in the predicted probability of the outcome *m* (i.e. in the interval τ_{m-1} to τ_m) for a change in an independent variable x_k at the mean of each variable is given by:

$$\frac{\partial \Pr(y = m \mid \bar{x})}{\partial x_k} = \beta_k \left[f(\tau_{m-1} - \bar{x}\beta) - f(\tau_m - \bar{x}\beta) \right] \quad (6)$$

For discrete explanatory variables, the estimated results are reported in terms of the probability of an outcome given that the dummy changes from 0 to 1, other factors constant. The predicted probability of outcome *m* therefore, as a particular explanatory variable x_k changes from x_0 to x_1 (other variables constant) is given by:

$$\frac{\Delta \Pr(y = m \mid x)}{\Delta x_k} = \Pr(y = m \mid x, x_k = x_0) - \Pr(y = m \mid x, x_k = x_1) \quad (7)$$

4. The data and study area

The data used in this study are drawn from a survey conducted by the International Food Policy Research Institute (IFPRI) in cooperation with the World Bank and the Uganda Bureau of Statistics (UBOS). It is part of the main UBOS national household survey that was conducted in 2002/2003. The survey covered eight districts: Arua, Iganga, Kabale, Kapchorwa, Lira, Masaka, Mbarara, and Soroti. These were chosen to represent different agro-ecological zones, poverty levels, farming systems and endowment of natural resources at the district level.

The study area extends over a wide range from the highlands of Kabale and Kapchorwa to the low lands of Soroti and Lira districts. The sites in Masaka and Iganga districts as well as the highland areas are located in highly favourable agro-climatic zones with two rainy seasons. The climate changes and becomes quite dry as one moves further north (Lira and Soroti districts). Levels of rainfall vary significantly between these districts. Population densities also vary, ranging from 67 people per square kilometre in Kapchorwa district to a high of 250 in Kabale and 288 in Iganga districts. Different land tenure systems are also found in the study area. Capturing diversity in tenure is important for evaluating the role of ownership and user rights. The districts covered also show diversity in farming systems and terrains. There are large variations in crop types grown and the importance of livestock.

A stratified two-stage random sampling was used to draw a sample from the Uganda National Household survey (UNHS) in 2002. The IFPRI data were derived from a sample of 126 enumeration areas. The survey collected detailed data on farm management practices, property rights, institutions and infrastructure at fine spatial scales. Specifically, farm level characteristics, production technologies, inputs and outputs, and marketing activities were covered. Information that was not covered in this survey such as education and household expenditure was sourced from the UNHS, since the two data sets had common identifiers.

Summary statistics for all the variables used are presented in Table 1. The table shows that on average, 4.2 percent of the households use inorganic fertilizer. This is despite the fact that 47.8 percent of the sample reported to have observed nutrient problems on these plots. In fact in Uganda the culture of fertilizer use is very poor. Use of fertilizer is only common in large-scale plantations or where it is subsidized and directly supplied to the farmers by certain institutions. An example is the British American Tobacco (BAT) supplying fertilizers to Tobacco farmers in Arua and Kapchorwa commercial maize farmers association. However, farmers use traditional means of enhancing nutrient such as fallowing (27.9%). Adoption of soil conservation technologies is also very low. For instance only 9.5 percent reported to have adopted terracing.

About 80 percent of the plots had long-term tenure security with a right to bequeath the land to the next generation. Only 28 percent have received extension services and the average period in school for the household head is about 5.8 years. The mean distance to the nearest seasonal road is 0.63 kilometers.

Table 1: Summary statistics for the sample variables

Variable	Mean	Std. Dev.	Min	Max
Tenure security (right to be bequeath, Yes=1, no=0)	0.80243	0.39826	0	1
Dist. from plot to Seasonal Road (Kms)	0.63547	1.35870	0	35
Extension (dummy)	0.28173	0.44994	0	1
Age of household head (Years)	41.62871	13.64	19	89
Education of household head (Years)	5.75853	4.07509	0	17
Household size (number)	6.18767	2.62283	1	17
Sex of head of household	0.82583	0.37934	0	1
Non-Farm income (Ush [a])	408,984.7	88,1621.1	0	12,000,000
Terracing (dummy)	0.09496	0.29323	0	1
Tree plant (dummy)	0.26508	0.44147	0	1
Use of Inorganic fertiliser (dummy)	0.04140	0.19927	0	1
Fallowing (dummy)	0.27903	0.44862	0	1

a. Ugandan Shilling (One USD = 1780 Ush)

5. Econometric estimations and results

It is hypothesized that natural resource outcomes (high soil fertility and low soil erosion) are positively related to investment in farming practices such as fallowing, terracing, organic and inorganic fertilizer applications. Other variables included in the estimation based on the literature are plot specific characteristics, institutional and policy factors as well as household and area characteristics[3].

Before model implementation, the independent variables were first scrutinised for possible correlations since multi-colinearity is a common problem with such data sets. A number of variables that were found to be strongly correlated with others were dropped. The models were then estimated in their reduced forms.

[3] Appendix 1 provides a list of all variables used in the model, and how they are measured

The Huber-White sandwich estimator was also used to correct for possible heteroscedasticity of unknown form (White, 1980).

Table 2 shows the changes in the predicted probabilities of the different outcomes (three for each model) and appendix 2 presents estimates of the coefficients of the ordinal probit model. Most of the variables have the expected signs and are consistent with expectations. In the erosion model, we find that investment in tree planting and terracing, increases the probability of having no erosion and reduces the probability of having mild and severe erosion. Investment in soil conservation structures therefore is associated with reductions in soil erosion.

Also in the soil fertility model, we also realize that the use of SFM technologies is associated with high fertility of soils and low soil nutrient loss. Results show that the use of both inorganic fertilizer and fallowing increase the probability of having fertile soils. The impact of inorganic fertilizer was however not significant. This could be explained by the low use of inorganic fertilizer (4.2%) in the country. These results suggest that government programs to encourage investment in SFM and conservation technologies should be revitalized.

Though the extension variable had the correct signs, its impact was not significant. The weak relationship between extension and natural resource outcome might be attributed to inadequate and sometimes complete absence of extension services. About 28 percent of the sampled households have had a single extension visit in a year. The policy implication of these findings are that, first, there is need to open up the existing extension system to take into consideration traditional conservation and SFM technologies. Second, public investment in extension services would of paramount importance to curb soil erosion and nutrient loss.

Table: 2: Changes in predicted probabilities (Ordered probit model)

Variable Name	Soil Erosion model			Soil Fertility model		
	No erosion	Mild erosion	Severe erosion	Fertile	Moderately Fertile	Infertile
Education of household head(Years)	0.0082***	-0.0046***	-0.0037***	0.0034*	-0.0006	-0.0028*
Age of household head (Years)	0.0026***	-0.0015***	-0.0012***	0.0005	-0.0001	-0.0004
Non-Farm income (Ushs)	0.0369***	-0.0205***	-0.0164	0.0015	-0.0002	-0.0012
Sex (dummy, %ge of males)	0.0097	-0.0053	-0.0043	-0.0493**	0.0134	0.0359**
Extension (dummy)	0.0299	-0.0168	-0.0130	0.0081	-0.0015	-0.0067
Dist. from plot to Seasonal Road (Kms)	-0.0029	0.0016	0.0013	0.0023	-0.0004	-0.0019
Use of Inorganic fertiliser (dummy)	-	-	-	0.0237	-0.0058	-0.0179
Fallowing (dummy)	-0.0115	0.0063	0.0051	0.0446**	-0.0107*	-0.0339***
Tree plant (dummy)	0.0920***	-0.0533***	-0.0387***	-0.0289*	0.0033	0.0255*
Terracing (dummy)	0.1286***	-0.0795***	-0.0491***	-0.0327	0.0017	0.0311
Tenure security (Dummy-right to be bequeath, Yes=1, no=0)	-0.0386	0.0221	0.0165	0.0011	-0.0002	-0.0009
Household size (number)	-0.0050	0.0028	0.0022	0.0024	-0.0004	-0.0020

*, **, and *** represent the level of significance at 10, 5 and 1 percent respectively

The soil erosion model also shows that education measured is significantly and positively related to improvement in resource condition. Education increases the probability of having no erosion and reduces the probability of having mild and severe erosion. Education was also found to increase the probability of having fertile soils and reduce the probability of having infertile soils. This could be explained by the fact that better educated households manage their resources better because they are better placed to acquire information and to take advantage of such information to increase production opportunities. These findings suggest that continued public and private investment in education opportunities for the rural poor may reduce problems of soil erosion and soil nutrient loss.

Age of household head is also positively associated with better resource outcomes (soil erosion and soil nutrient loss). This may be due to experience gained in production and therefore proper management of the resources. Availability of non-farm income also increases the probability of having no erosion and reduces the probability of having mild and severe erosion. Non-farm income also increases the probability of having fertile soils. This is again as expected since non-farm income may be used to purchase the required inputs such as labour, inorganic fertilizer among others. Surprisingly, the gender variable (sex) suggests that being a male-headed household is associated with less probability of having fertile soils. On the other hand, male-headed households are associated with a high probability of having no erosion and reducing probability of having mild and severe erosion. This result could be explained by the differences in labour needs for conservation suggesting that women manage less labour intensive SFM technologies.

6. Conclusions and implications of the study

The goal of this paper was to investigate the impact of investment in SFM and conservation practices on land degradation: Specifically, we were interested in establishing how investment in SFM and conservation practices may affect soil erosion and soil nutrient loss. An ordered probit model was fitted to a data set collected in eight districts in Uganda by IFPRI and the World Bank.

The results indicate that investment in SFM and conservation techniques would reduce soil erosion and improve soil fertility. For instance we find that investment in soil conservation structures such as terraces increase the probability of having no erosion while reducing the probability of having mild or severe erosion. Other important factors that may positively affect natural resource outcomes include education, age of household head, and availability of non-farm income. From a policy perspective, investment in soil fertility management and conservation technologies would be important to achieve sustainable agricultural production. Investment in farmer education is also of high importance for improving natural resource outcomes and hence the wellbeing of the rural poor.

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Appendix 1: Coefficients for the ordered probit resource outcomes model

Variable Name	Soil Erosion model		Soil Fertility model	
	Coefficients	P-Level	Coefficients	P-Level
Education of household head(Years)	-0.0206***	0.0010	-0.0140*	0.0970
Age of household head (Years)	-0.0066***	0.0000	-0.0019	0.4370
Non-Farm income (Ushs)	-0.0927***	0.0020	-0.0062	0.8620
Sex (dummy, %ge of males)	-0.0242	0.6920	0.1935**	0.0230
Extension (dummy)	-0.0752	0.1450	-0.0336	0.6280
Dist. from plot to Seasonal Road (Kms)	0.0072	0.2940	-0.0095	0.3220
Use of Inorganic fertiliser (dummy)	-	-	-0.0946	0.6810
Fallowing (dummy)	0.0288	0.5810	-0.1781**	0.0120
Tree plant (dummy)	-0.2330***	0.0000	0.1236*	0.0770
Terracing (dummy)	-0.3310***	0.0000	0.1450	0.1870
Tenure security (Dummy-right to be bequeath, Yes=1, no=0)	0.0975	0.1360	-0.0045	0.9590
Household size (number)	0.0125	0.1740	-0.0098	0.4210
/cut1	-0.3163		-1.1100	
/cut2	0.8848		1.0733	
Number of obs	2661		1523	
LR chi2(12)	67.04		20.15	
Prob > chi2	0.0000		0.0064	
Log likelihood	-2472.4606		-1187.4533	

*, **, and *** represent the level of significance at 10, 5 and 1 percent respectively