CHAPTER VII: MODELLING ADOPTION OF SOIL FERTILITY MANAGEMENT AND CONSERVATION PRACTICES

This chapter describes the approach adopted by the study to model adoption of soil fertility management and soil conservation practices by smallholder farmers in the Central highlands of Ethiopia. The first section presents the analytical framework and the empirical models are specified in section two. The last section describes the factors hypothesized to influence adoption behavior of smallholder farmers.

7.1 Analytical framework

The decision whether or not to use a new technology could be considered under the general framework of utility or profit maximization (Norris and Batie, 1987; Pryanishnikov and Katarina, 2003). It is assumed that economic agents including smallholder subsistence farmers use a technology only when the perceived utility or net benefit from using a technology is significantly greater than would be the case without the technology. While utility is not directly observed the actions of economic agents are observed through the choices they make. Suppose that Y_j and Y_k represent a household's utility for two choices, which could be denoted by U_j and U_k, respectively. Following Green (2000) and Pryanishnikov and Katarina (2003) the linear random utility model could be specified as

$$U_j = \beta_j^{'} X_i + \varepsilon_j \text{ and } U_k = \beta_K^{'} X_i + \varepsilon_K \tag{7.1}$$

where U_j and U_k are the perceived utility of technology j and k, respectively, X_i is a vector of explanatory variables that influence the perceived desirability of the technology, β_j and β_k are parameters to be estimated and ε_j and ε_k are the error terms, assumed to be independently and identically distributed. In case of soil fertility and soil conservation technologies, if a household decides to use option j on the ith plot, it follows that the perceived utility or benefit from option j is greater than the utility from other options (say k) depicted as:

$$U_{ij}(\beta_j^{'}X_i + \varepsilon_j) > U_{ik}(\beta_k^{'}X_i + \varepsilon_k), k \neq j \tag{7.2}$$

The probability that a household will adopt option j among the set of soil fertility and soil conservation practices could then be defined as:

$$\begin{aligned} P(Y = 1 \mid X) &= P(U_{ij} > U_{ik}) \qquad (7.3) \\ &= P(\beta_j^{'}X_i + \varepsilon_j - \beta_k^{'}X_i - \varepsilon_k > 0 \mid X) \\ &= P(\beta_j^{'}X_i - \beta_k^{'}X_i + \varepsilon_j - \varepsilon_k > 0 \mid X) \\ &= P(\beta * X_i + \varepsilon^* > 0 \mid X = F(\beta^* X_i) \end{aligned}$$

where P is a probability function, U_{ij}, U_{ik} and X_i as defined above, $\varepsilon^* = \varepsilon_j - \varepsilon_k$ is a random disturbance term, $\beta^* = (\beta_j^{'} - \beta_k^{'})$ is a vector of unknown parameters which can be interpreted as the net influence of the vector of independent variables influencing adoption, and $F(\beta^* X_i)$ is the cumulative distribution function of ε^* evaluated at $\beta^* X_i$. The exact distribution of F depends on the distribution of the random disturbance term, ε^*. Depending on the assumed distribution that the random disturbance term follows, several qualitative choice models such as a linear probability model, a logit or probit models could be estimated (Pindyck and Rubinfeld, 1997; Green, 2000).

Qualitative choice models are useful to estimate the probability that an individual with a given set of attributes will make one choice rather than an alternative (Pindyck and Rubinfeld, 1997; Green, 2000). Of the three functional relationships often specified, the linear probability model is computationally simpler and easier to interpret parameter estimates than the other two models. However, its specification creates estimation problems involving the application of ordinary least squares (OLS) such as heteroscendasticity error terms, predicted values may fall outside the (0,1) interval, and non-normal distribution of the error term. Although, transformation could provide homoscedastic disturbance terms and then apply weighted least square procedures, there is no guarantee that the predicted values will lie in the (0,1) probability range. These difficulties with the linear probability model compelled econometricians to look for alternative model specifications (Pindyck and Rubinfeld, 1997; Green, 2000).

The two most popular functional forms used in adoption modelling are the probit and logit. These models have got desirable statistical properties as the probabilities are bounded between 0 and 1 (Pindyck and Rubinfeld, 1997; Green, 2000).

Apparently, adoption models could be grouped into two broad categories based on the number of choices or options available to economic agents (Pindyck and Rubinfeld, 1997; Green, 2000). In a setting where there are only two technological choices or options designated by $J_i=1$ if agent i adopts and $J_i=0$ otherwise would give rise to binomial adoption models whereas choice sets with more than two alternatives would give rise to multinomial adoption models.

As noted earlier, smallholder farmers in the highlands of Ethiopia use a mix of soil fertility management and soil conservation practices. However, most previous technology adoption studies in the country focusing on production technologies did not give due consideration to soil conservation and soil fertility management practices albeit a few soil conservation adoption studies by Shiferaw and Holden (1998) in the Andit Tid area, Central highlands, Gebremedihn and Swinton (2003) in Northern highlands and Bekele and Drake (2003) in Eastern highlands of Ethiopia. Most soil fertility adoption studies in the country focused on inorganic fertilizers either as a component of a package of crop production technologies treating the package as a unit or the components of the package as separate units (Waktola, 1980; Kebede et al., 1990; Yirga et al., 1996; Alene et al., 2000; Dadi, et al., 2001; Regassa, 2001). To smallholder farmers, however, commercial fertilizer is one technological option among the menu of soil fertility management options available. Furthermore, most previous soil fertility management studies were limited by the analytical methods employed in analyzing the adoption behavior of smallholder farmers. Despite the fact that the adoption decision of soil fertility management involves choices among several soil fertility management decisions making the adoption decision inherently multivariate, most studies employed binomial logit/probit and Tobit regression models to investigate the factors determining the adoption decision and the intensity of use of inorganic fertilizers, respectively. Binomial logit and probit models applied at a household or farm level when in fact input use decisions are made at a plot level (due to non-homogeneity of plots managed by households) may not be appropriate. Dorfman (1996) pointed out that the use of bivariate models when in fact the adoption decision involves a set of several technological options excludes useful information contained in interdependent and simultaneous adoption decisions. Furthermore, as has been argued earlier, most previous adoption studies attempting to model the adoption decision assumed the same explanatory variables influence the adoption decision and intensity of use in a similar fashion. In other words, most previous adoption studies assumed a variable that increase (decrease) the probability of use also increase (decrease) intensity of use of a technology. However, Nakuma and Hassan (2003) and Gebremedhin and Swinton (2003) found evidence that the factors determining the decision to adopt and the factors determining intensity or extent of use of a soil conservation technology might be different. Similarly, Katchova and Miranda (2004) showed that farm characteristics affecting decisions to adopt marketing channels differ from those affecting decisions regarding quantity, frequency and contract type. Accordingly, recognizing the fact that soil fertility management and soil conservation practices involve choices among several technological options, this study, applied a multinomial logit model for discreet dependent variables involving several choices. The study also recognized that factors affecting the adoption decision and the intensity of use of soil fertility management practices might be different hence adopted a Tobit model for continuous dependent variables to model the intensity of inorganic fertilizer and stone/soil bund use by smallholder farmers in the highlands of Ethiopia. Furthermore, taking into account that smallholder farmers input use decisions are made at a plot level due to non-homogeneity of plots managed by households, the study modeled the adoption decision at a plot level.

7.2 Soil fertility and soil conservation technologies in the study area

According to what was discussed in preceding sections, in this study, incidence of use of soil fertility management or a soil conservation practice is measured by the proportion of sample households using one management practice or a combination of practices simultaneously on a plot or parcel of land. Similarly, intensity of use of a certain type or mix of soil fertility management or soil conservation practices are measured by mean use rates or proportion of crop area under each option or mix of options (e.g. amount of inorganic fertilizer or length of soil conservation structures constructed per unit area).

The menu of soil fertility management options that smallholder farmers in the highlands could choose from can be categorized into two: introduced or modern (inorganic fertilizers consisting of DAP and Urea) and traditional[24] including seasonal fallowing (weedy fallows), crop rotations involving legume crops, long-term[25] fallowing (*guie*) and animal manure. Noteworthy is that these soil fertility management practices differ considerably in terms of their attributes, timing of costs and benefits. While animal manure and inorganic fertilizers are productivity enhancing inputs that may be applied at various intensities every year, seasonal fallowing and legume rotations could be considered investment decisions with two years of maturity. Smallholder farmers' soil fertility management strategies on a certain plot, therefore, involve a choice among these inputs and agronomic practices either independently or in some combinations. It should be noted that the use of traditional soil fertility management practices unlike inorganic fertilizers do not involve immediate cash outlays by the household but require substantial opportunity costs in terms of foregone output (e.g. seasonal fallowing, planting less productive legume crops) or require additional family labor inputs to transport manure. Therefore, the decisions to fallow a certain plot or include legumes as rotation crops involve weighing current costs against anticipated benefits in the second cropping season.

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[24] A traditional soil fertility management refers to a technological option that has been well recognized as a soil fertility amendment or enhancement practice and used by smallholder farmers for a long period of time.

[25] The use of long-term fallowing, which once was the most important soil fertility management practice particularly in the upper highlands has now declined due to land shortages and hence this practice will not be considered in this modeling endeavor.

Although it is hardly possible to claim that smallholder subsistence farmers actually make marginal calculations in the literal sense, it is apparent that a household deciding to fallow a plot (practice chiflik)[26] this year, incurs costs in terms of foregone output and extra plowings required for land preparation. Likewise, the decision to plant a legume this year involves weighing tradeoffs between foregoing current benefits from planting a preferred, possibly high yielding cereal crop this year against anticipated productivity improvements in the following year as a result of improved soil quality due to investments in legumes the first year. It is, therefore, hypothesized that different factors may condition the use of traditional soil fertility management practices by smallholder farmers.

Similar arguments could also be made on the adoption of inorganic fertilizers or the combined use of inorganic fertilizers with a traditional practice(s). The decision whether or not to use inorganic fertilizer and how much inorganic fertilizer to use among other things depends on the soil fertility management practices used the previous year (whether a plot was fallowed, had manure or planted to a legume) as well as farmer perceptions of inorganic fertilizer as a possible substitute or complementary input to the traditional fertility management practices and inputs. It is therefore hypothesized that the factors that influence the likelihood and intensity of use of inorganic fertilizer by smallholder farmers may differ from those that appear to be significant when several soil fertility management practices are analyzed as a group. In this study, therefore, based on the above framework two soil fertility adoption models are specified. The first model focuses on factors determining the use or non-use of alternative soil fertility management practices (both traditional and modern) on a cropland (plot). Accordingly, alternative soil fertility management options considered include:

i. Seasonal fallowing (SF) alone

ii. Legume rotations (LR[27]) alone

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[26] Seasonal fallowing also referred to as *chiflik* or *worteb* is a traditional soil fertility management practice in which part of the land is fallowed for one season and used for crop production the following season.

[27] Legume rotations refer to the practice of growing leguminous crops such as faba beans and field peas in the upper highlands and chick pea, rough pea, lentil and faba bean in mid highlands in rotation with other crops (non-leguminous).

iii. Animal manure (AM) alone
iv. Animal manure in association with SF
v. Animal manure in association with LR
vi. Inorganic fertilizer (IGF) alone
vii. Inorganic fertilizer in association with options one, two or three (IGF+SF/LR/AM)
viii. Continuous cropping without any soil fertility amendment practice (no adoption)

The second model is targeted at determining the factors associated with the intensity of inorganic fertilizer use among smallholder farmers measured in terms of amount of inorganic fertilizer applied per hectare regardless of the use of traditional soil fertility management practices.

Soil conservation practices used on cultivated lands in the highlands include traditional ditches (*boyi*), cut-off drains (*golenta*) and stone and soil bunds. Among these practices, traditional ditches, though widely practiced, are considered more of a production practice for draining excess runoff from a plot than a soil conservation practice and hence excluded from further consideration. Soil and stone bunds constructed by piling earth mounds and rocks (stones), respectively, are viewed to have similar effects. The choice of a stone against a soil bund largely depends on availability of stones in the vicinity. In this study, therefore, both soil and stone bunds are treated as one category. Like the case of soil fertility management, smallholder farmers have to choose from the various soil conservation practices. Hence, the appropriate econometric model would be a multinomial adoption model. Accordingly, choice sets considered in the soil conservation multinomial adoption model include:

i. The use of traditional cut-off drains (*golenta*) only
ii. Terraces (stone and soil bunds) with or with out cut off drains
iii. No soil conservation practice (no adoption)

The models listed above are presented in the following sub-sections.

7.2.1 Multinomial logit models for the adoption of soil fertility and soil conservation technologies

As pointed above, the choice (dependent) variables: soil fertility management and soil conservation practices are discrete with J+1 alternatives (j=0, 1, 2…J). The appropriate econometric model would, thus, be either a multinomial logit (MNL) or multinomial probit (MNP) regression models. Indeed, both MNL and MNP models estimate the effect of explanatory variables on a dependent variable involving multiple choices with unordered response categories (Dorfman, 1996; Long, 1997; Green, 2000). Multiple response (polychotomous) choice models such as MNL and MNP are more desirable compared to their counterparts of binomial logit and probit models in two respects (Wu and Babcock, 1998). It allows exploring factors conditioning both specific management practices (e.g. inorganic fertilizer alone, farmyard manure alone, etc.) as well as combination of management practices (e.g. integrated soil fertility management such as inorganic fertilizer in association with fallow or legume rotations). It also takes care of self-selection and interactions between alternative practices. However, the probit counterpart of a MNL model is rarely used in empirical studies due to estimation difficulties imposed by the need to solve multiple integrations related to multivariate normal distributions (Wu and Babcock, 1998; Pryanishnikov and Katarina, 2003). In this study, therefore, a MNL specification was adopted to model soil fertility and conservation adoption decision behavior of smallholder farmers' involving discrete dependent variables with multiple choices.

Let M_j be the j^{th} soil fertility or soil conservation management technology that a household chooses to use on the i^{th} plot. M_{ji} could then take the value of 1 if the j^{th} practice or option is adopted on the i^{th} plot, 0 otherwise. The probability that a household with characteristics X adopts technology j on the i^{th} plot is specified as (Green, 2000):

$$P_{ji} = \Pr ob(M_{ji} = 1) = \frac{e^{x'\beta}}{1+\sum_{j=1}^{J} e^{x'\beta}}, j = 1 \ldots J \qquad (7.4)$$

where β is a vector of parameters which satisfy $\ln(P_{ij}/P_{ik}) = X'(\beta_j - \beta_k)$ (Green, 2000).

Unbiased and consistent parameter estimates of the MNL model in equation (7.4) require the assumption of independence of irrelevant alternatives (IIA) to hold. More specifically, the IIA assumption requires that the likelihood of using a certain soil fertility or soil conservation practice on one plot by a household need to be independent of alternative soil fertility and conservation practices on other plots (i.e., P_j / P_k is independent of the remaining probabilities). The premise of the IIA assumption is that of independence and homoscedastic disturbance terms of the basic adoption model in equation (7.1). Wu and Babcock (1998) indicated that the IIA assumption, though, a convenient property with regard to estimation imposes a restriction on farmer behavior. This is particularly true for the study sample where the management decisions made by the same farmer on different plots under his/her management are unlikely to be independent rendering the error terms to correlate.

The validity of the IIA assumption could be tested using Hausman's specification, which is based on the fact that if a choice set is irrelevant, eliminating a choice or choice sets from the model altogether will not change parameter estimates, systematically. The statistics of Hausman's specification is given by (Green, 2000):

$$\chi^2 = (\hat{\beta}_s - \hat{\beta}_f)'[\hat{V}_s - \hat{V}_f]^{-1}(\hat{\beta}_s - \hat{\beta}_f) \tag{7.5}$$

where s indicates the estimators based on restricted subsets, f indicates the estimator based on the full set of choices, and $\hat{V}_s$ and $\hat{V}_f$ are the respective estimates of the asymptotic covariance matrices.

Alternative models and econometric procedures have been suggested to overcome the limitations of the IIA assumption in the MNL model. Two of such models discussed in the literature are the nested logit and multinomial probit models (Wu and Babcock, 1998; Green, 2000; Heinrich and Wenger, 2002). The nested logit model is widely used in transport and marketing research where the implied decision choices allow specification of a nesting structure or sequencing of decisions. In this study, however, the nested logit model could not be used for there is no a priori specification of a nesting structure of the decision choices made by households. The MNP model, on the other hand, does not require either nesting nor impose no correlation of error terms. However, the computational difficulties involved with estimation limit its application. Heinrich and Wenger (2002) based on a review of the works of James J. Heckman and Daniel L. McFadden suggested a practical way of overcoming the IIA problem in empirical estimation of the MNL model would be to redefine or restructure the choice variables by collapsing closely related choices into distinct groups. In the absence of alternative specifications, this study used the MNL specification to model smallholder farmers' adoption behavior of soil fertility and conservation management practices in the highlands of Ethiopia.

Provided that the IIA assumption is met, the maximum likelihood estimators are asymptotically normally distributed with a mean of zero and a variance of one for large samples (Long, 1997). Nonetheless, the use of cross-section data to estimate model parameters may still introduce heteroscendasticity problems. Upon ascertaining the validity of the IIA assumption, the Huber/White/sandwich estimator of variance instead of the traditional variance estimators can be used to account for possible heteroscendasticity of unknown form. Further improvements of parameter estimates could also be achieved by correcting the variance-covariance (VCE) matrix of the estimators for possible correlation of errors within groups (clusters). Significance of estimators is tested with z-statistics and goodness of fit of the model is assessed by the likelihood-ratio (LR) tests comparing the log-likelihood from the full model (the model with all the explanatory variables) with a restricted model where only the constant is included.

Parameter estimates of the MNL model provide only the direction of effect of the independent variables on the dependent (response) variable but estimates neither represent actual magnitude of change nor probabilities. Differentiating equation (7.4) with respect to each of the explanatory variables, however, provides marginal effects of the explanatory variables given as:

$$\frac{\partial P_j}{\partial x_k} = P_j(\beta_{jk} - \sum_{j=1}^{J-1} P_j \beta_{jk}) \qquad (7.6)$$

The marginal effects or marginal probabilities are function of the probability itself which when multiplied by 100 measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable (Long, 1997; Green, 2000; Ersado et al., 2004).

7.2.2 Tobit and Heckman's two-step regression models for the intensity of use of inorganic fertilizers and stone/soil bunds

The intensity of use of inorganic fertilizers and stone/soil bund measured as the sum[28] of diamonium phosphate (DAP) and Urea fertilizers applied per unit of cropped area and length of stone/soil bunds, respectively, are censored continuous variables. As discussed above, this censoring arises due to the fact that not all sample households use inorganic fertilizers or stone/soil bunds. Even those households who reported having used inorganic fertilizer and constructed stone/soil bunds may not have done so on all of the plots under their management. Application of ordinary least square (OLS) to such censored data renders the estimates biased. Two approaches suggested and often used in the literature to overcome the problem are Heckman's two-step procedure (and its extensions thereof) and the Tobit model (Winship and Mare, 1992; Long, 1997; Vella, 1998). This study, therefore, adopts these approaches to model the intensity of inorganic fertilizer and stone/soil bunds among smallholder farmers in the Ethiopian highlands.

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[28] DAP and Urea are considered as complementary inputs that should be used in certain combinations depending on crop type and soil characteristics. Despite research recommendations emphasizing use of recommended rates of both DAP and Urea for maximum yield, most smallholder farmers prefer DAP to Urea and use more DAP than Urea but at sub-optimal levels.

The Tobit model, a more general case of probit, besides the probability of adoption as in the probit model estimates the value of the continuous response for the case when

$$y_i^* = \beta' x_i + \varepsilon_i \tag{7.7}$$

Where X_i is an N * 1 vector of explanatory factors, β is a vector of coefficients, and ε_i are independently and normally distributed error term with mean zero and variance, σ^2. If y_i^* is negative, the variable that is actually observed, the rate of commercial fertilizer or length of stone/soil bund, y_i is zero. When y_i^* is positive, $y_i = y_i^*$.

Following Long (1997) and Green (2000), the probability that the rate of inorganic fertilizer or stone/soil bund used is zero in the Tobit model could be specified as:

$$P(y_i = 0) = \phi(-\frac{\beta' x_i}{\sigma}) \tag{7.8}$$

and the density function for the positive values of Y_i is

$$f(y_i / y_i > 0) = \frac{f(y_i)}{P(y_i > 0)} = \frac{\frac{1}{\sigma}\phi(\frac{y_1 - \beta' x_i)}{\sigma}}{\phi(\frac{\beta x_i}{\sigma})} \tag{7.9}$$

where $\phi(\bullet)$ is the standard normal probability density function. Equation (7.8) is a probit model representing the adoption decision whereas equation (7. 9) represents a truncated regression for the positive values of the continuous decision of how much soil fertility inputs to use $(y_i > 0)$. The Tobit model is preferable to OLS for it allows the inclusion of observations with zero values. Both the probit and Tobit models require maximum likelihood methods (MLE) to estimate the coefficients of the adoption equation. The log-likelihood for the Tobit model consists of the probabilities for the non-adoption decision and a classical regression for the positive values of Y_i (Long, 1997) given by:

$$\ln L = \sum \ln \phi(-\frac{\beta' x_i}{\sigma}) + \sum \ln[\frac{1}{\sigma}\phi(\frac{y_i - \beta_i' x_i}{\sigma})] \qquad (7.10)$$

The estimated coefficients, β, do not represent the marginal effects of a unit change in the independent variable on E(Y) or E(Y^*). Based on the works of McDonald and Moffit, Long (1997), Green (2000) and many others showed the following decomposition of the marginal effects of the Tobit model:

$$\frac{\partial E(Y/X)}{\partial X_j} = \Pr(Y > 0)\frac{\partial E(Y \mid Y > 0)}{\partial X_j} + E(Y/Y > 0)\frac{\partial \Pr(Y > 0)}{\partial X_j} \qquad (7.11)$$

where Pr(Y>0) is the probability of an observation being uncensored given X. The above decomposition shows that the total change in the unconditional expectation is disaggregated into the change in conditional intensity of use weighted by the probability of adoption and the change in the probability of adoption weighted by the conditional intensity of use.

A major concern with the ML estimators of the Tobit model is its sensitivity to violation of the basic assumptions of homoscedasticity and normality of the errors (Long, 1997; Vella, 1998; Green, 2000). Violation of these assumptions renders the Tobit estimates biased and inconsistent (Long, 1997; Vella, 1998; Green, 2000). The incidence of heteroscendasticity in the Tobit model could be detected using a likelihood ratio and/or a Lagrange multiplier test (Green, 2000). As recommended for the MNL model, in the Tobit model too, the Huber/White/sandwich estimator of variance could be used to correct for possible heteroscendasticity of unknown form.

Test for the non-normality of the disturbance terms in the Tobit model, however, is not straightforward. Green (2000) suggested alternative approaches to deal with the non-normality of the error distribution in the Tobit model. One way is to assume alternative forms of the error distribution (exponential, lognormal and Weibull) and compare results. Another approach is to use robust estimators less sensitive to changes in the distribution of the error terms such as least absolute deviations (LAD) and censored least absolute deviations estimators (CLAD). Empirical application of semi parametric models, however, is limited due to computational complexity and hence is not pursued in this study.

A second concern in the proposed Tobit model particularly for the intensity of fertilizer use is endogeneity. Besides household, farm, plot and institutional variables hypothesized to condition inorganic fertilizer use, soil fertility management practices used the previous season (fallow, legume or farmyard manure) are believed to be important in explaining variations in inorganic fertilizer use among smallholder farmers. These variables are thus included as explanatory variables in the Tobit model. One would argue inclusion of these variables in the right hand side of the equation might result in biased and inconsistent parameter estimates due to endogeneity. In principle, the endogeneity problem could be adequately dealt with a two-stage model or using instrumental variable technique (Hassan, 1996). The problem for our data, however, is not expected to be serious as the decision to use inorganic fertilizer and other soil fertility management practices are not made at the same time. As has been noted earlier, the decisions whether or not to use inorganic fertilizer and how much inorganic fertilizer to use on a plot given the farmer has decided to cultivate the plot in question is made at planting. On the other hand, the decisions to fallow, use legume rotations or apply farmyard manure are already taken prior to plating either in the previous season or during the off-season.

A third concern with the Tobit specification is whether or not it adequately fits the data. The Tobit model is based on the assumption that there is no sample selection problem. In the presence of self-selction, however, results of the Tobit model are biased and inconsistent (Winship and Mare, 1992; Vella, 1998). Furthermore, the Tobit model assumes that a variable that increases the probability of adoption will also increases the mean amount of inputs used (Lin and Schmidt, 1984; Norris and Batie, 1987; Katchova and Miranda, 2004). The preposition that the same variables and the same parameter vector affect both the adoption decision and the intensity of use, however, has been questioned (Green, 2000; Gebremedhin and Swinton, 2003; Katchova and Miranda, 2004). Lin and Schmidt (1984) proposed a formal procedure to test the validity of the Tobit assumption. This test explores whether a censored Tobit model fits the data better compared to a separate probit and a truncated regression (a Tobit which only uses non-limit cases for the dependent variable) by computing the following likelihood ratio statistic (Lin and Schmidt, 1984; Green, 2000):

$$\lambda = -2[\ln L_T - (\log L_\mathrm{P} + \log L_{TR}) \qquad (7.12)$$

where λ is distributed as chi-square with R degrees of freedom (R is the number of independent variables including a constant), L_T is a likelihood function for the Tobit model with the same coefficients, L_P is a likelihood function for the probit model fit separately, and L_{TR} is likelihood for the truncated regression model fit separately. If the null hypothesis is rejected, Heckmans's (1979) two-step procedure, which allows for different factors to influence the adoption decision and intensity of use would be appropriate.

Hickman's two-step procedure described below involves estimation of the probability model for the adoption decision, calculation of the sample selection bias (the inverse Mill's Ratio) and incorporation of this selectivity bias variable into the outcome equation (intensity of use) and then apply OLS to estimate the intensity of use.

The first procedure in Heckmans's to step model is to estimate a probit model for the probability that Z=1 with all observations using a set of covariates (ω) to estimate a vector of coefficients (α) given by.

$$P_i(Z_i = 1) = \phi(\varpi_i^{'}\alpha) + e_i \qquad (7.13)$$

The second procedure would be to estimate the expected value of the outcome variable (Y) conditional on Z=1 and a set of covariates (X_i).

$$E(Y_i \mid z = 1, X_i) = X_i^{'}\beta + E(\mu_i \mid Z_i) \qquad (7.14)$$

The third procedure is to evaluate the conditional expectation of μ in equation (7.14) with respect to the variable, e, represented by

$$E(\mu_i \mid e_i)\omega_i^{'}\alpha = \rho\sigma_e\sigma_\mu \frac{\phi(\omega_i^{'}\alpha)}{\Phi(\omega_i^{'}\alpha)} \qquad (7.15)$$

Then, inserting equation (7.15) into equation (7.14) we get equation (7.16) as follows:

$$E(Y_i \mid z = 1, X_i) = X_i^{'}\beta + \rho\sigma_e\sigma_\mu \frac{\phi(\omega_i^{'}\alpha)}{\Phi(\omega_i^{'}\alpha)} \qquad (7.16)$$

Finally, we use OLS to regress Y on X and $\lambda_i \frac{\phi_i}{\Phi_i}$ given by:

$$E(Y_i \mid Z = 1, X_i) = X_i^{'}\hat{\beta} + \theta\hat{\lambda}_i \qquad (7.17)$$

7.3 Choice of variables and hypotheses to be tested

As noted above, the adoption behaviour of farmers could be traced from their utility functions. However, the fact that the arguments of the utility function are not well known makes selection of the determinants of technology adoption a difficult task (Norris and Batie, 1987; Shiferaw and Holden, 1998). Previous research on farmers' adoption of new technologies including soil conservation considered perception of the problem or constraint (soil degradation), profitability of the proposed technology, household and farm characteristics, attributes of the technology and institutional factors such as land tenure, access to markets, information and credit (Ervin and Ervin, 1982; Norris and Batie, 1987; Pagiola, 1996; Shiferaw and Holden, 1998; Hassan et al., 1998a; Hassan et al., 1998b; Lapar and Pandey, 1999; Kazianga and Masters, 2002; Bamire et al., 2002; Gebremedhin and Swinton, 2003; Nakhumwa and Hassan, 2003; Bekele and Drake, 2003). Shiferaw and Holden (1998) argued that the effect of most of these factors on adoption behaviour of farmers is conditioned by market imperfections prevalent in developing countries including Ethiopia. Where market imperfections are important the production and consumption decisions of smallholder farmers may not be separable making indispensable the inclusion of household characteristics, asset endowments, institutional factors and other variables impacting profitability of the proposed technology as explanatory variables in the adoption decision model (Shiferaw and Holden, 1998). Therefore, based on investment theory, previous studies and analysis of the agriculture sector of Ethiopia, a range of household, farm and plot characteristics, institutional factors and agro-ecology variations are hypothesized to influence adoption of soil fertility management and soil conservation technologies by smallholder farmers in the highlands of Ethiopia.

7.3.1 Household characteristics

Household attributes often considered to have differential impacts on the adoption decision include age, education level of the household head, family size and wealth (livestock ownership and type of house).

Several studies considered the effect of age of the farmer on adoption decision as a composite of the effects of farming experience and planning horizon. Many equated short planning horizons with older, more experienced farmers who may be reluctant to adopt soil conservation practices that may not yield immediate benefits whereas younger farmers being more educated on the average and having longer planning horizons may be more likely to invest in soil conservation (Norris and Bati, 1987; Lapar and Pandey, 1999). On the other hand, greater experience could lead to better knowledge of spatial variability of plots that could lead to more accurate assessment of adoption. Several studies in Ethiopia have shown a positive relationship between number of years of experience in agriculture and the adoption of improved agricultural technologies, Kebede et al. (1990), while a study by Shiferaw and Holden (1998) indicated a negative relationship between age and adoption of improved soil conservation practices. Hence, considering the above factors the effect of age of the household head, a proxy for years of experience in farming, cannot be signed in the empirical model a priori.

Higher education is believed to be associated with access to information on improved technologies and the productivity consequences of land degradation (Ervin and Ervin, 1982; Feder et al., 1985; Norris and Bati, 1987). Evidence from various sources indicates a positive relationship between the educational level of the household head and the adoption behaviour of farmers (Norris and Bati, 1987; Igoden et al., 1990; Lin, 1991), as well as literacy and adoption behaviour (Yirga et al., 1996). Farmers with higher levels of education, therefore, are more likely to adopt land augmenting soil fertility and soil conservation technologies than those who do not.

The influence of household size on the decision to adopt is ambiguous. Large family size is normally associated with a higher labor endowment that would enable a household to accomplish various agricultural tasks on timely bases. On the other hand, households with large family members may be forced to divert part of the labor force to off-farm activities in an attempt to earn income in order to ease the consumption pressure imposed by a large family size. In the highlands of Ethiopia, off-farm opportunities are rare especially during the slack period of the year after the main season harvest when conservation activities are expected to be performed implying low opportunity cost of labor during this period. Hence, we expect a household with large family size to be more likely to adopt land augmenting soil fertility management practices such as inorganic fertilizer and manure especially soil conservation practices involving labor-intensive constructions but inversely related to the use of seasonal fallowing.

Wealth is believed to reflect past achievements of households and their ability to bear risk. Previous studies in Ethiopia used the type of house a household owns (corrugated or grass roofed) and the number of livestock as a proxy for the wealth position of a household (Yirga et al., 1996; Shiferaw and Holden, 1998). Livestock plays a very important role in the mixed crop-livestock farming systems of the highlands. First, it serves, as a store of value, which could be easily traded to meet a household's cash needs in time of emergencies. Second, oxen being the major source of traction power play a crucial role in timely land preparation and planting that consequently improves the marginal productivity of soil fertility inputs. Third, livestock provides manure required for soil fertility maintenance. Therefore, the number of livestock owned is hypothesized to be positively associated with the adoption of soil fertility and soil conservation technologies.

7.3.2 Farm and plot characteristics

Farm characteristics hypothesized to influence adoption in this study are farm size, number of plots (parcels) owned and distance of plots from the homestead. Smallholder farmers in the highlands manage several plots of land scattered across a topo-location. These plots not only vary in size but also differ in soil types, fertility levels, degree of slope and other plot specific features. Obviously, adoption of soil fertility and soil conservation practices would be a function of plot characteristics as these factors influence actual and perceived levels of soil degradation as well as actual and perceived costs and benefits.

Norris and Batie (1987) indicated that farmers who own and cultivate larger farms are likely to spend more on conservation as it is associated with greater wealth and increased availability of capital, which makes investment more feasible. The impact of farm size could, however, vary depending on the type of soil fertility management and conservation practices considered. Households with relatively larger farm size may prefer seasonal fallowing to more intensive forms of soil fertility management and conservation practices while land scarce households might have incentives to adopt labor intensive management practices. A study by Negatu and Parrikh (1999) revealed a positive impact of farm size on adoption of improved wheat and maize varieties, respectively, whereas Yirga et al., (1996) reported no association between land per person and the use of crop technologies including commercial fertilizer. Hence, the impact of farm size on the adoption decisions could not be predicted a priori.

Other things being equal, the larger the plot slope the higher the erosion hazard. Slope of a plot is therefore expected to have a positive association with the use of soil conservation practices.

Ervin and Ervin (1982) and Norris and Batie (1987) noted perception of an erosion problem is the first step in the adoption process, which triggers subsequent adoption. Recognition of erosion has been found to positively influence conservation behavior in a number of studies (Shiferaw and Holden, 1998; Bekele and Drake, 2003). Hence, it is expected that households who manage marginal plots (plots with poor soil fertility) or face the most sever potential erosion problems are more likely to adopt soil fertility and soil conservation practices.

Distance of a plot from a household's residence may influence a households investment decisions in two ways. First, distance of a plot by raising the labor costs for hauling manure and the opportunity cost of labor (time lost traveling to and from a plot) may have a disincentive on investments in soil nutrient management and soil conservation technologies involving substantial labor inputs. Secondly, plots located far from farmers' residences are high-risk investments as the chance of loosing these plots is higher in the event of land redistribution. Hence, plot distance is expected to be negatively associated with the use of animal manure and legume rotations, which require at least two years to realize the benefits, but positively with the use of inorganic fertilizer.

The physical size of a plot may have a range of influence on the adoption decision of soil fertility and soil conservation practices. For instance, the area taken up by soil conservation structures might potentially reduce crop output and may eventually discourage adoption of soil conservation structures. On relatively large plots, a household may not be concerned with the potential area loss due to adoption of soil conservation and subsequent reduction of crop output compared to small sized plots. Physical structures on small plots of land also cause inconveniencies for using oxen during ploughing (Shiferaw and Holden, 1998). Hence, the potential impact of plot size on the adoption of soil fertility management and soil conservation would be different. Plot size is expected to be inversely related to the adoption of land augmenting soil fertility management practices (commercial fertilizer and manure use) but positively related to seasonal fallowing and soil conservation practices.

7.3.3 Institutional factors

Institutional factors often considered in empirical adoption decisions to have differential impacts on technology adoption by smallholder farmers are access to information, institutional credit, off-farm employment and land tenure. Direct government involvement in the construction of soil and water conservation structures on farmers field has also been cited to have a considerable impact on the adoption decision (Gebremedihn and Swinton, 2003; Bekele and Drake, 2003)

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Access to information on sources of new inputs is believed to contribute towards optimal use of scarce resources. Various studies in developing countries including Ethiopia reported a strong positive relationship between access to information and the adoption behaviour of farmers (Kebede et al., 1990; Yirga et al., 1996; Ghadim and Pannell, 1999; Herath and Takeya, 2003). In Ethiopia, agricultural extension services provided by the MOA is the major source of extension information in general and in the study area in particular. Hence, it is hypothesized that the greater the number of contacts a household has with extension workers, the more likely the adoption decision.

The role of off-farm income on the decision to adopt is not clear. It is observed that farmers with off-farm income are less risk-averse than farmers without sources of off-farm income. Off-farm activities may also reduce the management resources available for the adoption process, but access to outside information may have positive effects. Norris and Batie (1987) found a negative association between off-farm employment and adoption of conservation adoption in the US. Hence, the impact of off-farm income on adoption could not be predicted a priori.

There is mixed evidence about the impact of land ownership on incentives to adopt a new technology. Tenure status affects investments in soil conservation by altering the planning horizon (Lapar and Pandey, 1999). A number of studies showed that land ownership increase incentives by lengthening planning horizons and the share of benefits accruing to adopters while lowering the rates of time preference. Others argue that the effect of tenure on adoption depends on the type of technology in consideration. A technology with a high potential to conserve input use, reduce cost, and provide economic benefits such as conservation tillage could create incentives for adoption even among renters, part time renters and part time operators (Norris and Batie, 1987). Nonetheless, it is generally held that renters of farmland are less likely to invest in conservation practices because short-term leases reduce incentives to maintain the productivity of rented land (Norris and Batie, 1987; Soule et.al, 2000). In Ethiopia, despite the fact that land is a public property under the custody of the government, informal land markets have thrived where smallholder farmers either lease land in cash or on share cropping bases (Teklu and Lemi, 2004). Nevertheless, given past experience and the widely held view that land redistribution is a fact of life as long as land remains a public property, there still remains much uncertainty concerning tenure security. It is therefore hypothesized that adoption of soil fertility management practices that yield benefits over a couple of years such as animal manure and seasonal fallowing as well as conservation practices are expected to be used more likely on owned plots (plots allotted to a household directly by PA officials) than on rented or share cropped plots.

Liquidity constraint (cash shortages) is a typical feature of smallholder farmers operating in developing countries. Availability of agricultural credit by easing the liquidity constraint allows smallholder farmers to have access to external purchased inputs such as commercial fertilizer and other new agricultural technologies, which ultimately improve farm productivity. Studies by Zeller et al. (1996), Yirga et al. (1996), Hassan et al. (1998a) underscored the role of credit in enhancing adoption of agricultural technologies. It is therefore hypothesized that access to credit will have a positive impact on adoption of both soil nutrient and soil conservation technologies.

Soil conservation practices have been promoted and in some cases constructed by direct public interventions on farmers' fields. On-farm demonstrations of improved varieties with their associated cultural practices have also been held to demonstrate the superiority of improved technologies over traditional practices. Hence, it is hypothesized that households who benefited from direct public intervention or participation in demonstrations and extension package programmes may have developed a positive attitude towards improved soil management practices.

7.3.4 Agro-ecology

The highlands of Ethiopia are characterized by diverse climate, land use and settlement patterns. Within the central highlands a number of sub agro-ecologies or farming systems have been identified based on variations in altitudes, rainfall, soil type, topographic conditions and type of associated vegetative cover. Earlier studies indicated that while the sub agro-ecologies are similar in some features they exhibit marked differences in terms of soil types, cropping pattern and soil management practices used by farmers that have a strong bearing on the adoption of soil conservation and soil fertility management practices. The upper highlands being cooler and frost prone are better suited to long cycle (season) crops and crop varieties such as oats and six rowed barley varieties. The mid highlands on the other hand are relatively warmer and less susceptible to frost and hence are favorable for growing tef and wheat, the two most important cash sources to smallholder farmers in the highlands. Besides, wheat and tef are reported to have a better response to inorganic fertilizers than barley making the use of inorganic fertilizers more profitable on wheat and tef than barley. Therefore, it is hypothesized that the probability and intensity of inorganic fertilizer use would be higher in the mid highlands where wheat and tef dominate the cropping system than the barley based farming systems of the upper highlands. On the other hand, in the upper highlands where intensive and continuous crop cultivation is less attractive compared to the warmer mid highlands, smallholder farmers tend to keep relatively larger livestock than their counterparts in the mid highlands. Hence, it is hypothesized that the probability of using manure alone or in combination with other soil fertility management practices is likely to be higher in the upper highlands.

Table 7.1. Definition of variables hypothesized to condition adoption of soil fertility management and soil conservation practices by smallholder farmers in the Central highlands of Ethiopian, 2003

Variable	Description	Values
HH characteristics		
Age	Age of the head of the farm HH	Years
Education	Level of formal schooling attained by the head of the HH	Highest grade attend
Livestock	Number of livestock owned by a HH	Number in TLU
House type	Whether a HH owned corrugated iron roofed house or not	1= yes, 0=no
Family size	Number of family members of a HH	Number
Farm and plot characteristics		
Farm size	Total area (crop, fallow, grazing) managed by a HH	Area in hectares
Plot area	The physical size of a plot	Area in hectares
No. of plots	Plots owned and managed by a HH	Number
Plot distance	The distance of a plot from homestead	Minutes walked
Slope	Slop of a plot	1=flat, 2=medium, 3=high
Soil fertility	Farmer perception of the level of soil fertility of a plot	1=poor, 2=medium, 3=fertile, 4=manured (kossi)
Degradation	Farmer perception of the severity of soil loss on a plot	1=none, 2=light, 3=sever, 4=very sever
Institutional factors		
Extension	If HH has access to extension services	1= yes, 0=no
Assistance	If HH had received assistance from government/NGO for constructing conservation structures	1= yes, 0=no
Credit	If a HH had access to institutional credit for inorganic fertilizer	Amount of money borrowed (Birr[29])
Off-farm	Income from off-farm activities during the survey year	Estimated average income (Birr/year)
Tenure	If plot is owned (allotted to HH by PA) or rented/share cropped	1=owned, 0=otherwise
Agro-ecology	Upper highlands or mid highlands	1=upper highlands, 0=mid highlands
District	Dendi and Debre Berihan	1=Debre Berihane 0=Dendi

HH=household

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[29] Local currency, 1USD=8.6 Ethiopian Birr

CHAPTER VIII: FACTORS INFLUENCING ADOPTION OF SOIL FERTILITY MANAGEMENT AND SOIL CONSERVATION PRACTICES

This chapter applied the econometric adoption models specified in chapter 7 to analyze factors determining adoption of soil fertility management and soil conservation practices by smallholder farmers in the Central highlands of Ethiopia. Section one presents the econometric procedures followed to estimate model parameters discussed in subsequent sections. Sections two and three discuss empirical results of the econometric analyses of the factors determining adoption of soil fertility management and soil conservation practices, respectively. The last section summarizes the findings and implications of the empirical results.

8.1 Empirical parameter estimation procedures

This section discusses econometric procedures used to estimate model parameters based on the frameworks developed in the previous chapter. Two multinomial logit (MNL) models for the discrete dependent variables of soil fertility and soil conservation practices and two Tobit models for the intensity of inorganic fertilizer and stone/soil bunds are estimated. All analysis is based on pooled data from the Debere Birehan and Dendi districts.

In empirical adoption studies involving cross-section data multicollinearity often poses a major econometric challenge. Hence, as a first step, prior to estimating any of the adoption models, the independent variables were scrutinized for possible strong correlations among them. Among the variables hypothesized to influence adoption behaviour, age of the head of the farm household was found to be correlated with education level of the household head (ρ=0.29), farm size (ρ=0.26) and number of livestock owned (ρ=0.22). Farm size was also found to be correlated with plot area (ρ=0.39), number of plots (ρ=0.17) and number of livestock owned (ρ=0.31). Although these correlation coefficients do not suggest incidence of strong multicollinearity, initial runs of the models revealed that parameter estimates of age and farm size were consistently insignificant and hence dropped from further consideration. Farmer perception of the severity of soil degradation showed a high degree of correlation with various plot attributes: soil depth, level of soil fertility and potential productivity and hence the later were excluded from the final regression equations. Similary, district was found to be highly correlated with agroecology (ρ=0.64) and hence either district or agroecology were included as regressors in the estimated models.

In all models (both MNL and Tobit specifications) robust standard errors of the Huber/White/sandwich estimators of variance are used to correct for possible heteroscendasticity of unknown form (White, 1980; Vella, 1998). Furthermore, the variance covariance matrix is modified to account for the non-independence of observations from different plots under the management of the same household through clustering. All models were estimated by Stata version 8.0. Model specific specification tests (the IIA assumption for the MNL models and sensitivity of parameter estimates to alternative distributional assumptions of the error term for the Tobit models) are discussed in the respective sections along with empirical model results.

8.2 Results of the empirical analyses of determinants of the use of soil fertility management practices

8.2.1 Adoption rate and pattern of soil fertility management

The study revealed that smallholder farmers in the central highlands used four types of soil fertility management (SFM) practices namely seasonal fallowing (fallow rotations, SF), legume rotations (LG), animal manure (AM) and inorganic fertilizers (IGF) and their combinations at various intensities. As shown in Table 8.1, while SF and LR are dominant in the upper highlands, IGF alone or combined with traditional practices appears to be the most important practice in the mid highlands. Animal manure singly or in association with other practices is equally important in both the upper and mid highlands. The data further showed that wheat and tef were the priority crops receiving inorganic fertilizer. About 95% and 92% of the wheat and tef plots, respectively, were fertilized in the mid-highlands (Table 8.2).

Table 8.1. Soil fertility management practices used by smallholder farmers for crop production in the Central highlands of Ethiopia (% of plots receiving treatment), 2003

Soil fertility management practice	Agro-ecology		Whole sample (N=1411)
	Upper highlands (N=1099)	Mid highlands (N=312)	
Continuous cropping without soil fertility amendment practice	23.1	25.6	23.7
Single management practice			
Fallow rotation (SF)	19.5	0.0	15.2
Legume rotations (LR)	17.6	2.9	14.3
Animal manure (AM)	15.9	18.9	16.6
Inorganic fertilizer (IGF)	3.2	28.8	8.9
Multiple practices	6.8	2.2	5.8
AM+SF	1.5	0.3	1.3
AM+LR	5.3	1.9	4.5
Integrated SFM practices	13.9	21.5	15.6
IGF+SF	8.1	1.0	6.5
IGF+LR	3.7	17.6	6.8
IGF+AM	1.4	1.9	1.5
IGF+AM+SF	0.5	0.0	0.4
IGF+AM+LR	0.2	1.0	0.4

Source: Farmer survey

Furthermore, the data revealed that intensity of inorganic fertilizer use is highest in the mid highlands, with the bulk used on wheat and tef. These findings support the hypothesis that inorganic fertilizers are widely used in the more favorable areas of the mid highlands where wheat and tef are grown mainly for cash. However, average rate of use, particularly for the mid-highlands, was below the recommended[30] level. Previous inorganic fertilizer adoption studies attributed the sub-optimal rate of use to inadequate supplies, late availability and the risk aversion behaviour of farmers (Yirga et al., 1996; Demeke et al, 1997; Croppenstedt et al., 2003). Determinants of alternative soil fertility management practices and intensity of inorganic fertilizer use are explored more formally in the next section.

Table 8.2. Intensity of inorganic fertilizer use by major crops, Central highlands of Ethiopia, 2003.

Indicator of use	Agro-ecology					
	Upper highlands (N=1099)			Mid highlands (N=312)		
	Wheat	Barley	Tef	Wheat	Barley	Tef
Plots cultivated (No.)	244	323	1	37	4	117
Plots cultivated (%)	22.2	29.4	-	11.9	1.3	37.5
Mean plot size (ha)	0.28	0.38	-	0.39	0.24	0.65
Plots fertilized (%)	27.9	26.6	0.0	94.6	25.0	91.5
Average rate of use (kg/fertilized ha)	126.7	99.7	50	136.8	69.4	109.6
Average rate of use (kg/cropped ha)	35.3	27.2	-	129.4	17.4	100.3

Source: Farmers' survey

8.2.2 Empirical results of the multinomial soil fertility adoption model

This section presents the empirical results of the MNL soil fertility adoption model. The MNL model as specified in chapter seven with eight SFM options were used to test the

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[30] Inorganic fertilizer recommendations for the major crops evolved from a blanket recommendation of 100 kg/ha of DAP for the major cereals to area specific recommendations. Currently, the nation-wide extension package program recommends the use of 100 kg/ha of DAP and 100 kg/ha of Urea for the major cereals.

validity of the independence of irrelevant alternatives (IIA) assumption. Parameter estimates from the initial run, although, had the expected sign failed to meet the IIA assumption. The model was thus restructured (redefined) following the suggestions of Heinrich and Wenger (2002) by collapsing closely related options into the same category. A close examination of the data revealed that within the choice set available to households, fallow and legume rotations were closely related. It has been noted in the previous chapter that smallholder farmers consider fallow and legume rotations as investments in soil fertility improvements with two years of maturity. A household's decision to use either a fallow or legume rotation on a given plot in the current year involves weighing foregone output against anticipated productivity gains in the second year from implementing the practices this year. Hence it was found appropriate to aggregate fallow and legume rotations into one category and animal manure use after fallow and legume rotations into another category reducing considered options from eight to six. Accordingly, the choice set in the restructured MNL model included the following soil fertility management options:

i. Fallow/legume rotations (SF/LR)
ii. Animal manure (AM) alone
iii. Animal manure in association with either SF or LR
iv. Inorganic fertilizer (IGF) alone
v. Inorganic fertilizer in association with SF, LR or AM (hence forth referred to as integrated soil fertility management)
vi. Continuous cropping without any soil fertility practice (no adoption)

The MNL model with these restructuring were then run and tested for the IIA assumption using a seemingly unrelated post-estimation procedure (SUEST)[31]. The test failed to reject the null hypothesis of independence of the included soil fertility management options suggesting there is no evidence against the correct specification of the MNL model for the soil fertility management practices (χ^2 value ranged from 8.6 to 16.9 with a

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[31] SUEST is a generalization of the classical Hausman specification test useful for intra-model and cross-model hypotheses tests (StataCorp, 2003).

P value of 0.19 to 0.84). Therefore, the application of the MNL specification to the data set for modeling soil fertility adoption behavior of smallholder farmers is justified.

Table 8.3 presents the marginal effects along with the level of significance while the estimated coefficients are provided in Appendix VII. The likelihood ratio statistics as indicated by the χ^2 statistics is highly significant ($P<0.00001$) suggesting strong explanatory power of the model. The marginal effects measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable (Long, 1997; Green, 2000). In the MNL model, the marginal probabilities resulting from a unit change in an independent variable sum to zero since expected increases in marginal probabilities for a certain option induces a concomitant decrease for the other option(s) within the choice set. Noteworthy is that the interpretation of the marginal effects are dependent on the units of measurement of the independent variables. For instance a unit increase in the number of years of schooling of an average farmer would result in a 0.6% and 1.4% increase in the probability of using animal manure and integrated[32] soil fertility management (ISFM) practices. In all cases the estimated coefficients should be compared with the base category of not adopting any of the SFM practices (continuous cropping without soil fertility amendment practices).

Of household characteristics considered, education level of the head of a household is found to have a positive impact on the likelihood of using animal manure and ISFM practices. These results suggest that farmers with some level of formal education are well aware of the soil degradation problem and the synergetic effects of using multiple sources of plant nutrients. Hence, public interventions aimed at improving farmers' access to formal education are likely to improve the likelihood of using ISFM practices among smallholder farmers in the study area.

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[32] Integrated soil fertility management refers to the combined use of inorganic and organic nutrient sources on the same plot of land.

Number of livestock owned, measured in TLU showed a positive and significant influence on the use of inorganic fertilizers alone or in association with traditional practices. Livestock is a source of traction, manure, cash and cushion against crop failures and other misfortunes. Households who own livestock are thus more likely to adopt ISFM practices and/or use multiple sources of nutrients as these households could get manure from their livestock and as the same time finance purchases of inorganic fertilizers from income generated from livestock products. The greater likelihood of using ISFM practices, therefore, could be due to the fact that respondents owning livestock are relatively better off, have got the resources and management skills, and are able to take the production and marketing risks associated with using inorganic fertilizers.

The institutional variables considered in the study were access to extension services, institutional credit for the purchase of inorganic fertilizers and off-farm income earning activities as well as land ownership (all measured as binary variables). As expected, access to extension services was positively and significantly associated with the use of animal manure, inorganic fertilizer alone or in association with traditional practices. Other things being equal, the chance of using ISFM on a typical plot would be higher by 12.5% for a households having access to extension services. However, the likelihood of using fallow/legume rotations reduces by 10.1% for a household having access to extension. These results suggest that households who have links with extension personnel are likely to switch to more intensive forms of production. It appears that extension messages emphasizing the complementary role of inorganic fertilizers with traditional practices (ISFM and multiple sources of nutrients) supported by practical demonstrations may stand a higher chance of success. These results, therefore, suggest an important role of increased institutional support to promote diffusion of knowledge regarding integrated soil fertility management.

Access to credit for the purchase of inorganic fertilizers found to have a significant positive impact on the likelihood of using inorganic fertilizers with and without traditional practices. On the other hand, the likelihood of using animal manure in association with fallow/legume rotations on a typical plot drops by 2.7% for a household having access to credit. This negative impact might be attributed to the fact that access to credit and hence access to inorganic fertilizers allows farmers to switch to more productive cereals. The positive marginal impact of credit access on adoption of ISFM practices could be explained by the marginal productivity of inorganic fertilizers when used after fallow/legume rotations or combined with animal manure. The results, therefore, suggest improving smallholder farmers access to institutional credit coupled with extension services would play an important role in raising the likelihood of inorganic fertilizer adoption as singly or in combination with other soil fertility management practices.

The dummy variable representing land ownership (PA[33] allotted plots as opposed to land leased in through informal land markets) showed a significant positive impact on the likelihood of using animal manure and ISFM practice. On the other hand the chances of using inorganic fertilizers alone on less secure (leased in plots through the informal land markets) would be higher by 5.0% compared to PA allotted plots that carry relatively better security. A possible explanation, other things being equal, farmers lacking legally defensible use rights prefer to use inorganic fertilizers on leased in land in an attempt to maximize short term benefits and save available manure to be used on relatively secure PA allotted plots. Therefore, the results support the contention that households engage in SFM practices that have a long-term nature such as animal manure on owned plots but use short term SFM practice (inorganic fertilizers) on leased in plots obtained through informal mechanisms. In a study of the impact of land tenure contracts on production efficiency in the highlands of Ethiopia, Gavian and Ehui (1999) found smallholder farmers use relatively higher amounts of chemical inputs (mainly commercial fertilizers) on less secure, non-PA allocated lands compared on relatively secure PA allotted plots. This result, therefore, support the hypothesis that the effect of land ownership on the adoption decision depends on the type of soil fertility management technology considered.

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[33] PA allotted plots refers to those parcels of land allocated by PA officials directly to households for own cultivation.

Another factor hypothesized to influence the adoption decision was access to off-farm activity. Although access to off-farm activity was positively associated with all types of SFM practices but animal manure its impact was not statistically significant. This weak relationship might be attributed to the limited off-farm job opportunities available in the study area. Only 24.9% of the sample households were gainfully employed in various types of off-farm activities during the study year. A major criterion used for assessing a household's credit worthiness for the purchase of inputs such as commercial fertilizers, improved seeds and herbicides in the study area was ability to pay 10% of the cost of the input as a down payment. Therefore, expanding smallholder farmers access to off-farm cash earning activities is likely to raise inorganic fertilizer use by improving its credit worthiness.

It is widely believed that individual perceptions of plot characteristics and knowledge of site specific conditions influence the adoption decision of smallholder farmers in the study area. As expected, plot size positively and significantly influenced the likelihood of adopting all types of soil fertility management practices with the exception of the use of animal manure. Large plots are more convenient to work with and provide better returns to investments, as transaction costs per unit area are lower for larger plots than small plots. On the other hand, given the scarcity of manure due to limited herd size and its alternative use as a source of domestic fuel and cash sources, available manure resource would be efficiently used on smaller plots.

Number of plots owned by a household would have the effect of raising the likelihood of using fallow/legume rotations and ISFM practice. More plots mean larger farm size and hence making fallow/legume rotations more attractive than manure or inorganic fertilizers. Similarly, plot distance is negatively and significantly related with the use of animal manure alone or in combination with fallow/legume rotations. The use of manure involves extra costs for hauling and distributing manure to distant plots. Plots located near residences (backyard or a short distance from residences) are easy to manage, monitor and guard harvests as transaction costs are inversely related with distance. The negative association of plot distance with the likelihood of using animal manure thus confirms the empirical observations that transaction costs incurred for transporting and distributing manure are higher, the further the location of a field from a homestead. Most importantly, being attached to farmers' residences or a short distance thereof, such plots are low risk investments as the chance of loosing them is minimal in the event of land redistribution. The above results, therefore, suggest that land consolidation (fewer but larger plots located within a reasonable distance from households residence), might have a positive impact on adoption of manure that have a long term impact on soil fertility and crop productivity. Any land consolidation attempt, however, need to weigh the trade offs between increased benefits arising from reduced transaction costs with the potential losses that would be incurred from not having spatially scattered heterogeneous plots of land of various soil quality.

A household's perception of soil degradation measured as dichotomous variables indicating severity of degradation (sever, medium, light and none) and intensity of animal manure use in the recent past (whether a plot is rich in organic residues locally referred as "kossi" or "areda") significantly influenced the differential use of most of the SFM options. The likelihood of using manure by a household on a plot that received fortuitous manure in previous years (last five years) would be higher by 28.8% compared to a plot that did not receive manure in the recent past. Likewise, the chance of using inorganic fertilizers alone or combined with a traditional practice is higher on plots perceived to have some degree of physical degradation compared to the base category of no physical degradation. Given that distance of a plot is negatively related with the likelihood of using animal manure and that current use of animal manure is significantly associated with past use suggests that adoption of animal manure is mainly a function of transaction costs. Hence, measures that reduce transaction costs involved with hauling and distributing manure to distant fields would help improve the efficiency of resource use. The use of animal manure singly or in combination with other practices, however, appears not to be influenced by the degree of soil degradation of a plot.

As expected, agro-ecology turned out to be an important factor conditioning the differential use of SFM practices in the study area. The likelihood of using multiple sources of nutrients for an average farmer in the upper highlands appears to be higher compared to a similar farmer in the mid highlands. On the other hand, the chances of using inorganic fertilizer alone on a plot of average soil quality in the upper highlands is lower by 24.2% compared to a similar plot in the mid highlands. These findings confirm the hypothesis that inorganic fertilizers use is higher in the mid highlands where higher value crops, tef and wheat are well adapted and where crop responses to inorganic fertilizers are generally better due to the favourable climate. The finding that household in the upper highlands are more likely to adopt traditional SFM practices further confirm the hypothesis that traditional soil fertility management practices are better suited in the upper highlands where intensive and continuous crop cultivation is less attractive compared to the warmer mid highlands, and where smallholder farmers keep relatively larger number of livestock and own larger farm sizes than their counterparts in the mid highlands. This result suggests that future soil fertility management research and promotion programmes in the highlands need to clearly take into account agro-ecological variations.

Table 8.3. Marginal effects from the multinomial logit soil fertility adoption model, Central highlands of Ethiopia, 2003

Explanatory Variable	Seasonal fallowing (SF) or Crop rotations (LG)		Animal manure (AM) alone		Animal manure associated with either SF or LR		Inorganic fertilizers (IGF) alone		Inorganic fertilizer associated with either SF, LR or MR (ISFM)		No soil fertility management	
	Marginal effects	Sig. level	Marginal effects	Sig. level	Marginal effects	Sig. level	Marginal effects	Sig. level	Marginal effects	Sig. level	Marginal effects	Sig. level
Education[1]	-0.0050	0.421	0.0062*	0.089	0.0014	0.404	-0.0010	0.760	0.0142**	0.013	-0.0158*	0.054
Off-farm[2] income	0.0023	0.951	-0.0252	0.204	-0.0092	0.412	0.0275	0.314	0.0482	0.204	-0.0437	0.304
Livestock[3]	-0.0103**	0.022	0.0010	0.616	-0.0002	0.892	0.0035	0.144	0.0121***	0.001	-0.0061	0.231
Plot size[4]	0.2852***	0.000	-0.1293**	0.011	0.0033	0.895	0.0975***	0.000	0.2264***	0.000	-0.4832***	0.000
No. of plots	0.0219***	0.004	-0.0085**	0.024	-0.0022	0.288	0.0016	0.742	-0.0234***	0.000	0.0106	0.180
Plot distant[5]	0.0041***	0.000	-0.0091***	0.000	-0.0033***	0.000	0.0007	0.118	0.0029***	0.000	0.0047***	0.000
Severity of soil degradation[6]												
Light	-0.0957***	0.009	0.0457**	0.048	0.0580**	0.032	0.0422*	0.061	0.0185	0.622	-0.0687*	0.058
Medium	-0.0865**	0.026	-0.0013	0.947	0.0355	0.192	0.0429	0.102	0.0671*	0.077	-0.0576	0.186
Sever	-0.0172	0.727	-0.0334	0.178	0.0200	0.402	0.0596	0.165	0.0750*	0.081	-0.1040**	0.021
Tenure[7]	-0.0378	0.305	0.0735***	0.002	0.0163	0.158	-0.0495*	0.077	0.0599**	0.037	-0.0625	0.119
Credit[8]	-0.0432	0.278	-0.0198	0.308	-0.0265**	0.049	0.0461**	0.025	0.2465***	0.000	-0.2031***	0.000
Extension[9]	-0.1012**	0.009	-0.0118	0.724	0.0267	0.381	0.0679	0.173	0.1246*	0.056	-0.1061	0.159
Agro-ecology[10]	0.4212***	0.000	0.0172	0.305	0.0219*	0.068	-0.2422***	0.000	0.0379	0.136	-0.2560***	0.000
Kossi[11]	-0.2261***	0.000	0.2878***	0.002	0.0034	0.881	-0.0350*	0.073	-0.0675*	0.060	0.0374	0.707

***, **, *= Significant at 1%, 5% and 10% probability level, respectively;

[1] Number of years; [2] Dummy variable, 1 denoting participation in off-activities; [3] Tropical Livestock Unit (TLU); [4] hectares; [5] Minutes walked from residence; [6] comparison category is plots perceived not having shown any form of soil degradation; [7] dummy variable, 1 denoting PA allotted plots, 0 otherwise; [8] dummy variable, 1 denoting access to institutional credit; [9] dummy variable, 1 representing access to government extension; [10] dummy variable, 1 referring to upper highlands; [11] dummy variable with 1 indicating plot is reach in organic matter due to repeated manure application.

8.2.3 Results of the two-step Heckman model of adoption of inorganic fertilizers

This section presents empirical results of Heckman's two-step model determining the likelihood as well as intensity of inorganic fertilizer use among smallholder farmers in the Ethiopian highlands. While the dependent variable for the selection equation is binary indicating whether or not inorganic fertilizer was used on the plot in question, the dependent variable for the outcome equation is amount of inorganic fertilizer measured as the sum of DAP and Urea fertilizers in kilogram per hectare (kg/ha). The explanatory variables, besides those discussed in the previous section, include dummy variables representing soil fertility management practices used on the same plot the previous season (fallow rotation, legume rotation or farmyard manure) and an iteraction variable of district by use of stone/soil bunds.

As noted in chapter 7, one concern with the application of the Tobit specification is whether or not it adequately fits the data. The appropriateness of the Tobit model was tested using equation (7.12) by first estimating a probit, Tobit and truncated regression models with the same explanatory variables separately and then comparing the log-likelihood statistics of the Tobit model to the sum of the probit and truncated regression models. The loge-likelihood ratio (LR) test is highly significant (LR $\chi^2 = 259.20$ with P<0.0000) suggesting not only the presence of sample selection problem but also different set of variables are likely to influence the adoption decision and intensity of use of inorganic fertilizer use. The sample selection problem for the data set, however, does not require truncated regression for data exists for non-adopters. Hence, in what follows, results form the two-step Heckman model, which corrects for self-selection and assumes different set of variables influence the adoption decision and intensity of inorganic fertilizer use are presented and discussed. Noenethelless, given that most empirical studies use Tobit to estimate intensity of adoption and that the Tobit model allows estimation and decomposition of marginal effects, results from the Tobit model are presented in Appendix IX, for comparison purposes.

Table 8.4 presents Heckman's two-step model coefficient estimates (for the selection and outcome equations) and marginal probabilities for the selection equation. The likelihood function of the two-step Heckman model was significant (Wald $\chi^2 = 335.99$ with P<0.0000) showing a strong explanatory power. Also, the coffiecint of the mills lambda was significant (P<0.0000) providing evidence the presence of self-selection and hence justifaying the use of Heckman's two-step procedure.

As shown in Table 8.4, all hypothesized variables but land tenure and fallowing significantly influenced the likelihood of using inorganic fertilizers. On the other hand only a sub set of the hypothesized variables had a significant influence on intensity of inorganic fertilizer use. Variables significantly influenced intensity of inorganic fertilizer use includes education, livestock, number of plots owned, land tenure, access to credit and extension, agro-ecology and manure use.

As expected, education of the head of the household positively and significantly influenced both the likelihood of adoption and intensity of inorganic fertilizer use. A unit increase in the number of years of formal schooling of the head of a household will have the impact of raising the probability of using inorganic fertilizer by 1.5%. Likewise, heard size positively and significantly associated with both the probability and intensity of commercial fertilizer use. A unit increase in heard size would lead to an increase in the likelihood of commercial fertilizer use by 1.7%. The results, therefore, suggest that institutional interventions targeted at expanding access to education as well as improving herd size (e.g. improving access to veterinary services and credit) will have a positive impact on raising adoption and expected use of inorganic fertilizers in the study area.

Of the considered plot and farm characteristics, plot size, plot distance and perception of land degradation had a significant positive impact whereas number of plots owned negatively and significantly influenced adoption of inorganic fertilizer use. Other things being constant, the chances of using inorganic fertilizers on plots showing severe, medium and light degradation would be higher by 9.6%, 10.1% and 6.4%, respectively, compared to a plot perceived to be free from soil degradation. On the other hand, only number of plots owned had a significant influence on intensity of inorganic fertilizer. The negative marginal impact of number of plots might be explained by the high transaction costs and management inconveniences associated with managing a number of micro-plots scattered in a highly difficult terrain in the highlands. These results, therefore, call for land consolidation that allows households to have access to fewer but larger plots within the context of exploiting the diverse microclimates and heterogeneous land quality, a highly valued management strategy that allows households to exploit unique microenvironments and reduce climatic uncertainties.

Access to credit and extension showed positive and significant impact on both the adoption decision and use intensities. All else constant, the chances of using inorganic fertilizers on an average plot would be higher by 22.2% and 18.9% for households having access to extension and institutional credit for the purchase of inorganic fertilizers, respectively. Controlling for other factors, the type of land ownership, although, did not have significant association with the adoption decision; it positively and significantly influenced expected use. The results, therefore, suggest that making agricultural credit available coupled with technical support form extension have a high potential for raising both number of farmers using inorganic fertilizers and expected use rates among those currently using. Furthermore, reorienting extension efforts from the current method of prescribing blanket recommendation to providing information that empowers smallholder farmers to correctly diagnose soil degradation problems appears to have a high dividend.

The likelihood of using inorganic fertilizer increased for plots, which were put to fallow the previous year (chiflik plot) but reduced for plots that had either manure or were under legume rotations. Intensity of inorganic fertilizer, however, was only affected by manure use. Hence, it appears that smallholder farmers consider seasonal fallowing as a complementary soil fertility management practice whereas animal manure and legume rotations as a substitute input to inorganic fertilizers.

Another important result is that the dummy variable district (proxy for unobservable factors such as climatic variations, traditional values, attitudes and aspirations of the community) had a significant negative impact on the likelihood of using fertilizers. Other things being equal, the chances of using inorganic fertilizers on a typeical plot in Debre Birehan district would be lower by 23.9% compared to a similar plot in Dendi woreda. The differential impact of district on the likelihood of adoption could be explained by the relative agricultural potential of the two districts. While Dendi district is considered to be a high potential area with assured rainfall, the

Debre Birehan districted is a low potential area often experiencing crop failures arising from rainfall variability. On the other hand, the interaction variable, district by stone/soil bund use positively and significantly related to intensity of inorganic fertilizer suggesting that intenisity of fertilzer use is higher in Debre Birehan district on plots that had stone/soil bunds compared to plots that did not have stone/soil bunds. The positive impact of this interaction variable might be explained by the higher productivity and lower risk of using higher rates of inorganic fertilizers on plots that benefited from stone/soil bund investments. Also, intensity of use of inorganic fertilizers on a typical plot would be lower in the upper highlands compared to a similar plot in the mid-highlands. These results, therefore, suggest that different policy options could be pursued depending on whether the objective is to raise the number of farmers adopting inorganic fertilizers or increasing the intensity of use among household who are already using inorganic fertilizers. Information on the agro-ecology of an area coupled with knowledge of plot characteristics are important in predicting adoption rates, use intensities and could be valuable in fine-tuning inorganic fertilizer recommendations and marketing of inorganic fertilizers.

Table 8.4. Parameter estimates of Heckman's two-step model for the likelihood of adoption and intensity of inorganic fertilizer use (kg/ha), Central highlands of Ethiopia

	Probability of Adoption				Intensity of Use	
Variable	Coefficient	P-level	Marginal impact	P-level	Coefficient	P-level
Constant	-1.2343***	0.000			31.4010	0.358
Education[1]	0.0586***	0.004	0.0148***	0.0050	8.5763***	0.000
Off-farm income[2]	0.2970**	0.015	0.0860**	0.0150	-0.3603	0.971
Livestock[3]	0.0631***	0.000	0.0165***	0.0000	2.4061**	0.026
Plot size[4]	1.0600***	0.000	0.2669***	0.0000	-9.0019	0.535
No. of plots	-0.0415*	0.090	-0.0116*	0.0650	-5.8926***	0.006
Plot distant[5]	0.0051*	0.053	0.0013**	0.0470	0.0233	0.907
Severity of soil degradation[6]						
Light	0.2430**	0.046	0.0637*	0.0620	-1.5810	0.866
Medium	0.3683***	0.003	0.1017***	0.0080	8.0128	0.427
Sever	0.3468**	0.025	0.0963*	0.0490	17.2799	0.139
Tenure[7]	0.0325	0.799	0.0055	0.8660	20.9019**	0.019
Credit[8]	0.6636***	0.000	0.1885***	0.0000	35.3667**	0.010
Extension[9]	0.6955***	0.000	0.2217***	0.0000	29.8606**	0.038
Agro-ecology[10]	N.A	N.A	N.A	N.A	-27.8721***	0.004
District[11]	-0.8816***	0.000	-0.2385***	0.0000	N.A	N.A
SWC*District[12]	N.A	N.A	N.A	N.A	24.5376**	0.015
SFM used previous year[13]						
Legume rotations	-0.2388**	0.039	-0.0624**	0.0360	-3.2842	0.723
Manure	-1.0732***	0.000	-0.2160***	0.0000	-90.2482***	0.000
Fallow	0.1604	0.262	0.0481	0.2390	17.7982	0.108
Diagnostics						
Total observations	1293					
Censored	345					
Uncensored	948					
Mills lambda	68.3903***					
Wald Chi Square	335.3900***					

***, **, *= Significant at 1%, 5% and 10% probability levels, respectively; N.A=not applicable;
[1]Number of years; [2]Dummy variable, 1 denoting participation in off-activities; [3]Tropical Livestock Unit (TLU); [4]hectares; [5]Minutes walked from residence; [6]comparison category is plots perceived not having shown any form of soil degradation; [7]dummy variable, 1 denoting PA allotted plots, 0 otherwise; [8]dummy variable, 1 denoting access to institutional credit; [9]dummy variable, 1 representing access to government extension; [10]dummy variable, 1 referring to upper highlands; [11]dummy variables with 1 indicating Debre Birehan district; [12] interaction dummy variable (stone/soil bund use by district) with 1 indicating plots with stone/soil bunds in Debre Berihan district; [13]dummy variables with 1 indicating use of the respective SFM practices.

8.3 Results of the econometric analyses of factors determining use of soil and water conservation practices

This section discusses the empirical results of factors determining soil conservation practices among smallholder farmers in the study area. As is done in the previous section, two regression equations, a MNL model for the discrete choice variable of soil conservation adoption and a Tobit for the continuous variable of intensity of stone/soil bunds is estimated. The Tobit model is aimed at examining the factors associated with the intensity of the widely used soil conservation practice (stone/soil bunds popularly known as terraces measured in meters per ha).

Soil conservation practices traditionally practiced and promoted by the various projects on cultivated lands in the highlands include traditional ditches (*boyi*), cut-off drains (*golenta*), stone and soil bunds, grass-strips and Fanya juu[34]. While the first three practices are traditional, grass-strips and Fanya juu represent soil conservation practices introduced by various SWC projects. The importance and intensity of use of these physical soil conservation structures, however, varied widely between districts. Traditional ditches (*boyi*), simple drainage furrows constructed manually or by the traditional oxen drawn plow for removing excess water from a plot, are used widely in both districts, agro-ecologies and landforms except in extreme sloping plots. The traditional ditches are largely considered as a production practice mainly designed to minimize water logging rather than a soil conservation practice. Unlike the traditional ditches, which are believed to be a production practice, cut-off drains and stone/soil bunds are well-recognized soil conservation practices in both districts. Cut-off drains are semi-permanent drainage ditches constructed around a plot or parcel to protect draining water from upslope fields to inundate a parcel. While cut-off drains are used in both districts the use of stone/soil bunds is restricted to Debre Birehan district, constructed on 42% (2.5% in reasonable condition and 39.4% in excellent shape) of the cultivated plots compared to 1.4% (0.24% in reasonable condition and 1.2 in good shape) in Dendi district (Table 8.5). Debre Birehan district, identified as one of the heavily degraded areas in the central highlands and one with a tradition of using soil conservation practices, received government assistance for constructing stone and soil bunds on individual and

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[34] Fanya juu are stone/soil embankments with drainage ditch on the lower side.

communal holdings in the 1980's and 1990's. Interestingly, despite the widely held view that smallholder farmers remove much of the soil conservation practices constructed by public assistance only 7.7% and 16.3% of the plots, which had some type of soil conservation structures (3.9% and 3.7% of the total plots) in Debre Birehan and Dendi, respectively, were removed. Adoptions of grass strips were dismal due to its incompatibility with the land tenure system where stubble fields after harvest are considered as communal (open to all community members for grazing livestock). Fanya juu were also rejected for its alleged problem of aggravating water logging.

Table 8.5. Use of soil conservation practices by smallholder farmers on cultivated lands (% of plots treated), Central highlands of Ethiopia, 2003

Soil and water conservation practices	Debre Birehan (N=724)	Dendi (417)	Both districts combined (1141)
Not ever constructed	50.00	79.38	60.74
Cut off drains (golenta) only			
Removed	1.66	2.88	2.10
Reasonable condition	0.14	1.68	0.70
Excellent condition	4.14	14.15	7.80
Stone and soil bunds			
Removed	2.21	0.48	1.58
Reasonable condition	2.49	0.24	1.67
Excellent condition	39.36	1.20	25.42

Source: Farmer's survey

8.3.1 Empirical results of the multinomial soil conservation adoption model

The choice set considered in the MNL model includes: cut off drains (golenta) only, stone/soil bunds with or without cut-off drains and no adoption of soil and water conservation practices. Marginal probabilities from the MNL soil conservation model are presented in Tables 8.6

whereas the model coefficients are given in Appendix VIII. The likelihood ratio statistics was highly significant (P<0.001) suggesting strong explanatory power of the included regressors. The IIA test, shown in Equation (5) of chapter 7, was implemented restricting (omitting) the cut-off drains option. The corresponding test statistics was ($P > \chi^2 = 0.6324$) suggesting that there was not enough evidence to reject the null hypothesis of independence of irrelevant alternatives. Therefore, the application of the MNL specification to the data set for modeling soil conservation adoption behavior of smallholder farmers appears to be justified.

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Interestingly, none of the household, farm and plot characteristics were found to be associated with the likelihood of using cut-off drains among smallholder farmers. This could be due to the very nature of the technology itself. Cut-off drains constitute simple and inexpensive drainage ditches constructed around a boundary of a plot or crop field in order to protect the field from inundation by runoff from up-slope fields. Once, cut-off drains are in place, maintenance costs are negligible and cooperation among smallholder farmers is a norm than the exception. Therefore, location rather than socio-economic differences among smallholder farmers might explain observed differential adoption of cut-off drains in the study area.

Education, off farm income, plot slope, perception of severity of soil degradation and government assistance significantly associated with the likelihood and intensity of using stone/soil bunds in the MNL model. The effect of considered factors will be discussed in more detail in the next section.

8.3.2 Empirical results of the Tobit soil conservation adoption model

As is done in the previous section, the presence of sample selection problem and whether or not the same set of covariates influence the adoption decision and intensity of use is tested using equation (7.17) of chapter 7. The Wald test of independence of the selection and outcome equations (ρ=0, Wald $\chi^2 = 0.54$ and P<0.4641) was not significant. Hence, based on the Wald test, the proposition that the same explanatory variables influence both the adoption decision and intensity of use as well as the hypothesis that there is no sample selection problem are not rejected. Hence, in what follows, results form the classical Tobit model, which assumes the same set of covariates influence the adoption decision and intensity of use are presented and discussed.

As expected, education is positively and significantly correlated with the adoption and intensity of stone/soil bund use. Household heads with relatively better formal education are likely to foresee the productivity consequences of soil degradation and soil conservation. Providing access to formal education would therefore play a crucial role in the fight against soil degradation and its consequences on food insecurity and poverty in the highlands of Ethiopia.

Among the farm and plot characteristics, plot size and plot slope positively and significantly affect both the likelihood of adoption and intensity of use. Similarly, other things being equal the chances of constructing soil conservation structures would be higher by 12% for plots having a medium slope compared to plots on bottom lands. In their soil conservation adoption studies, Shiferaw and Holden (1998) in the central highlands and Bekele and Drake (2003) eastern highlands of Ethiopia reported a positive correlation between slope and likelihood of using soil conservation structures.

The results also indicated that type of land ownership (PA allotted land as opposed to plots acquired through informal transactions) significantly influence both the adoption decision and intensity of use of stone/soil bunds by smallholder farmers. Stone/soil bunds are long term investments the benefits of which are realized after several years of initial investment. It is therefore rational for a household to restrict soil conservation investments on own land (land allotted directly by a PA to a household) as opposed to land acquired through informal land markets. While a household has legally defensible rights on land allotted to a household by PA officials, thus enjoy the benefits of soil conservation investments at such a time when land redistribution is to be done in the area, plots acquired through informal mechanisms have to be surrendered to the legal owner at the end of each cropping season.

Number of livestock owned, a proxy for the wealth position of a household, positively and significantly conditioned the likelihood and intensity of stone/soil bunds. As argued in the previous section, livestock are sources of cash and security against climatic uncertainties.

Households with livestock, therefore, are in a better position to invest on soil conservation for they have the financial resources to pay for the extra labour required for initial investments as well as afford the short term yield declines likely from reduced plot size (due to area taken by stone/soil bunds).

Access to extension measured by the number of contacts a household head had with extension personnel was positively and significantly (10.3%) related with the likelihood of using stone/soil bunds. In Ethiopia, agricultural extension services provided by the MOA is the major source of information on agriculture and natural resource conservation. The results therefore confirm the hypothesized positive role extension would play in natural resource conservation in general and soil conservation in particular.

Surprisingly, access to institutional credit for the purchase of inorganic fertilizers had a negative and significant influence both on the likelihood of adoption and intensity of use. The results suggest that the chances of investing in permanent soil conservation structures drops by 11.5% for a new household having access to short-term institutional credit. Similarly, among those who are currently using soil conservation structures intensity of use would be lower by 12.7 meters/ha for an average farmer having access to institutional credit compared to a household who did not have access. A possible explanation is that households who have access to short term credit for the purchase of inorganic fertilizers are likely to use inorganic fertilizers to compensate for lost soil nutrients and hence postpone adoption of soil conservation practices. This and other studies have shown the importance of improving smallholder farmers' access to credit in enhancing the adoption of inorganic fertilizers. The current short-term credit schemes targeted at raising the number of households using inorganic fertilizers and intensity of inorganic fertilizer use per unit of cropped area would only help solve the short term treats of soil degradation (soil nutrient mining) but could have a detrimental effect on the sustainable use of soil resources as inorganic fertilizer use do not compensate soil lost due to water erosion.

As expected perception of the severity of soil degradation and government assistance for initial construction of soil conservation practices positively and significantly influence the use of stone/soil bunds. The chances of investing in soil conservation structures would be higher by

23.1% for a household receiving assistance compared to a household who did not receive such assistance. This result contradicts the widely held view that assistance programs for construction of soil conservation structures in Ethiopia were largely unsuccessful and that soil conservation structures constructed under assistance programs were partially or wholly removed (Shiferaw and Holden, 1998). The result however, is consistent with the findings of Bekele and Drake (2003) who focused on the soil conservation research project (SCRP) site whereas our study areas are located outside the SCRP sites, and hence are broadly representative. Similarly, the chances of investing in soil conservation structures on plots displayed some degree of degradation would be higher by at least 14% compared to plots perceived to be free from any symptom of physical degradation.

Another important result noteworthy is that district (proxy for unobservable factors such as traditional values, attitudes and aspirations of the community) positively and significantly influenced the likelihood and intensity of investment in soil conservation structures. The chances of investing in soil conservation structures would be higher by 14.7% for a household in the Debre Birehan district compared to a similar household in Dendi. This could be explained by the relative extension efforts exerted in the two districts and local tradition. Smallholder farmers in Debre Birehan are well informed of the soil degradation problem and have a tradition of using stone and soil conservation structures. A number of soil conservation projects were also implemented by government and NGOs, which helped improve awareness and contributed to actual construction of soil conservation structures. In the Dendi district, however, extension efforts concentrated on extending improved crop packages consisting of improved crop varieties, agronomic practices and recommended type and rate of inorganic fertilizers. Group discussions with farmers in both districts revealed that for households in Dendi district soil degradation is tantamount to soil fertility decline while households in Debre Birehan stressed both dimensions of soil degradation, low soil fertility and soil physical degradation due to water erosion. This finding, therefore, suggest that use of soil conservation serves a different long –term purpose of reducing the long-term effects of soil degradation (irreversible aspect of soil degradation) whereas the use of inorganic fertilizer and integrated nutrient management only helps manage nutrient mining.

Table 8.6. Marginal effects of multinomial soil conservation adoption models, Central highlands of Ethiopia, 2003.

Variable	Cut-off drainage (golenta)		Stone, soil and raised boundary bunds			Non soil conservation (No adoption)
	Marginal effect	P-level	Marginal effect	P-level	Marginal effect	P-level
Education[1]	0.0035	0.465	0.0092**	0.039	-0.0127*	0.055
Off-farm income[2]	-0.0018	0.958	-0.0485***	0.010	0.0503	0.197
Livestock[3]	0.0055	0.164	-0.0014	0.555	-0.0041	0.394
Plot area[4]	-0.0284	0.214	0.0451	0.214	-0.0167	0.704
No. of plots	-0.0010	0.880	-0.0057	0.215	0.0067	0.394
Plot distance[5]	0.0007	0.251	-0.0003	0.553	-0.0004	0.564
Soil degradation[6]						
Sever	0.0714	0.248	0.4065***	0.000	-0.4779***	0.000
Medium	0.1356**	0.031	0.3671***	0.000	-0.5026***	0.000
Light	0.1333**	0.012	0.3254***	0.000	-0.4587***	0.000
Tenure[7]	0.0332	0.146	0.0229	0.271	-0.0562*	0.056
Credit[8]	-0.0479	0.178	-0.0300	0.257	0.0779*	0.095
Extension[9]	-0.0178	0.772	0.0310	0.587	-0.0133	0.881
Plot slope[10]	0.0061	0.750	0.1421***	0.000	-0.1483***	0.000
Assistance[11]	0.1393	0.343	0.3863**	0.012	-0.5257***	0.001
District[12]	-0.1450**	0.039	0.3172***	0.000	-0.1722**	0.035

***, **, *= Significant at 1%, 5% and 10% probability levels, respectively;

[1]Number of years; [2]Dummy variable, 1 denoting participation in off-farm activities; [3]Tropical Livestock Unit (TLU); [4]hectares; [5]Minutes walked from residence; [6]comparison category is plots perceived not having shown any form of soil degradation; [7]dummy variable, 1 denoting PA allotted plots; [8]dummy variable, 1 denoting access to institutional credit; [9]dummy variable, 1 representing access to government extension; [10]dummy variable, 1 representing plots on a higher slope (upland); [11]dummy variables, 1 denoting access to project assistance; [12]dummy variable, 1 referring to Debre Birehan district.

Table 8.7. Parameter estimates of the Tobit adoption model for the intensity of stone/soil bund use, Central highlands of Ethiopia, 2003

Variable	Coefficient	P-level	Adoption (index)		Expected use	
			Elasticity	Marginal effects	Elasticity	Marginal effects (m/ha)
Constant	-320.4803***	0.000				
Education[1]	6.0547*	0.068	0.0637*	0.0133**	0.0200**	1.4458**
Off-farm income[2]	-26.7276*	0.083	-0.0652*	-0.0567*	-0.0205*	-6.2248*
Livestock[3]	3.1450*	0.077	0.1650*	0.0069*	0.0518*	0.7510*
Plot area[4]	82.1367**	0.010	0.3153***	0.1798***	0.0989***	19.6137***
No. of plots	-3.5717	0.169	-0.1931	-0.0078	-0.0606	-0.8529
Plot distance[5]	0.0148	0.966	0.0022	0.0000	0.0007	0.0035
Soil degradation[6]						
Sever	127.4936***	0.000	0.1415***	0.3237***	0.0444***	37.7390***
Medium	158.7275***	0.000	0.2886***	0.3962***	0.0905***	47.1408***
Light	159.2407***	0.000	0.4400***	0.3802***	0.1380***	44.1137***
Tenure[7]	37.1450**	0.012	0.2769**	0.0763***	0.0869**	8.4359**
Credit[8]	-54.8909*	0.061	-0.1767*	-0.1153*	-0.0554*	-12.7187*
Extension[9]	43.1145	0.250	0.0231	0.1023	0.0072	11.1684
Plot slope[10]	54.7832***	0.000	0.2406***	0.1199***	0.0755***	13.1464***
Assistance[11]	91.7587***	0.001	0.0607***	0.2307***	0.0190***	26.0110***
District[12]	70.7553**	0.029	0.4032**	0.1470**	0.1265**	16.3012**
Diagnostics						
No. Observations	1141					
Wald Chi-Square	80.29***					

***, **, *= Significant at 1%, 5% and 10% probability levels, respectively;
[1]Number of years; [2]Dummy variable, 1 denoting participation in off-farm activities; [3]Tropical Livestock Unit (TLU); [4]hectares; [5]Minutes walked from residence; [6]comparison category is plots perceived not having shown any form of soil degradation; [7]dummy variable, 1 denoting PA allotted plots; [8]dummy variable, 1 denoting access to institutional credit; [9]dummy variable, 1 representing access to government extension; [10]dummy variable, 1 representing plots on a higher slope (upland); [11]dummy variable, 1 denoting access to project assistance; [12]dummy variable, 1 referring to Debre Birehan district.

8.4 Concluding summary

This chapter using plot level cross-sectional household survey data examined soil fertility management and soil conservation adoption behaviour of smallholder farmers in the Central Highlands of Ethiopia. Three sets of adoption models, a multinomial logit for the discrete dependent variables of soil fertility management and soil conservation practices involving multiple choices, Heckman's two-step and Tobit regression models for the continuous variables of inorganic fertilizers and stone/soil bund, respectively, were estimated. A number of important results of high policy significance were revealed.

First, the study showed the importance of farmer education in raising the likelihood of using most of the SFM practices as well as intensity of use of inorganic fertilizers and stone/soil bunds suggesting investment in education are indispensable to reducing soil degradation and improve farm income. Second, livestock a proxy for the wealth position of households, positively and significantly related with the likelihood of using inorganic fertilizers and ISFM practices. Livestock also has a positive and significant effect on the intensity of use of inorganic fertilizers and stone/soil bunds. Household with livestock (particularly oxen) not only use their land more productively but also leas in additional land from fellow farmers, take the production and marketing risks associated with using inorganic fertilizers and stone/soil bunds. Improving smallholder farmers' access to better livestock husbandry techniques particularly veterinary services coupled with measures that increases oxen ownership (individually or collaborative) would be vital to enhance adoption of soil fertility and conservation practices.

Third, project assistance in sharing the initial investment costs of SWC structures and access to extension are found to be important determinants of the intensity of SWC and inorganic fertilizers as well as the likelihood of using ISFM technologies suggesting government assistance is vital in improving adoption and hence contribute to more sustainable use of soil resources. Fourth, the likelihood of using manure, ISFM and stone/soil bunds is found to be significantly higher on owned lands than rented in or sharecropped plots suggesting improved tenure security is a precondition for households to engage in soil fertility management and soil conservation practices that have a long gestation period. Fifth, plot size and number of plots, a proxy for farm size, are positively and significantly related with the likelihood of using all types of SFM practices but animal manure suggesting land redistribution in the already degraded and land scarce highlands not only contribute to land fragmentation but also by raising the fixed costs of operating micro (very small) and dispersed plots further undermine sustainable farming and increase nutrient mining. Sixth, while access to institutional credit for the purchase of inorganic fertilizers enhanced both incidence and intensity of use of inorganic fertilizers it has a detrimental effect on the use of stone/soil bunds. This is an important tradeoff that should be considered seriously in policy formulation.

In view of the above findings the strategies to enhance both adoption and intensity of use of soil fertility and conservation practices in the highlands in general and the study area in particular need to focus on factors that showed higher marginal effects. Expanding formal education, improving smallholders' access to credit, extension services and off-farm income earning opportunities coupled with improving tenure security are vital policy requisites for raising adoption of soil fertility and conservation practices among smallholder farmers. Furthermore, government assistance in sharing the initial investment costs of soil conservation structures is likely to enhance adoption of soil conservation practices by smallholder farmers in the study area.

CHAPTER IX: SUMMARY, CONCLUSION AND IMPLICATIONS OF THE STUDY TO POLICY AND RESEARCH

Over the last three decades, agricultural production and income growth in Ethiopia lagged behind population growth. Consequently, per capita food production, income and savings have been falling. Disturbingly, in the highlands, soil, the basic natural resource on which the livelihood of the majority of the population is based has been progressively degraded. Excessive soil loss rates reaching over 100 tons/ha on croplands are not uncommon. Much worse, the amount of nutrients extracted from the soil through cropping is estimated to be several folds the nutrient inputs added to the soil in the form of organic and inorganic nutrients. Soil degradation due to water induced soil erosion and net nutrient extraction have thus become the major natural resource problem contributing to declining land productivity and food insecurity at household and national level.

In Ethiopia, past efforts to increase agricultural productivity, improve farm income, contain soil erosion and reverse soil nutrient mining are largely unsuccessful. Among others, biased development policies against smallholder farming, the institutional set up, population pressure, the biophysical environment, smallholder farmers' objectives and poor governance are thought to have contributed to declining land productivity, food insecurity and degradation of natural resource base.

First, development plans of the 1960's and 1970's focusing on industrialization and large-scale farming that could produce commodities for export or substitute imports denied the necessary supportive services required for improving the productivity of smallholder farming. Subsequent development plans recognized the vital role smallholder farming could play in reducing or closing the widening gap between food production and demand. However, assuming the country's food problem could be addressed through a quick fix of technological solutions, government and donor agencies adopted a technology transfer approach targeting few but high potential areas. Consequently, the vast majority of smallholder farmers producing for subsistence using traditional technologies on less favored areas with visible symptoms of soil degradation were neglected.

Second, the institutional set-up that perpetuated and accentuated land tenure insecurity hampered private investments in soil conservation and soil fertility enhancement. Third, the high population pressure characterizing the highlands of Ethiopia coupled with lack of alternative employment opportunities led to land fragmentation as the available land have been redistributed to the increasing population over generations. Land fragmentation exasperated by lack of suitable technologies to intensify farming forced farmers to either expand farming into marginal areas and/or mine the soil using traditional technologies that once were sustainable under low population pressure.

Fourth, soil degradation in the highlands of Ethiopia further worsened as smallholder farmers prompted by the need for securing adequate food for their family immediate needs continued to employ low-external input and erosive farming techniques which do not only mine the soil but also jeopardize the nations long-term food production ability. Last, but not least, lack of peace and security coupled with successive governments use of military power to deal with civil dissent and cross boundary conflicts not only undermined development efforts but also diverted scarce resources to support government war effort that would have been used otherwise.

Nevertheless, the notion that soil is a natural resource capital that could provide sustained flows of productive and environmental supporting services over time if managed properly appears to have received some recognition among the various stakeholders of agricultural development. Furthermore, the potential threat that soil degradation has posed on the income and welfare of smallholder farmers as well as on national food security is not disputed. However, the magnitude of the threat that soil degradation poses on current as well as future income to individual farmers and the national economy and how best to address the problem is not well known. Studies that estimate and model the economic costs of soil degradation are rare in Ethiopia. The few available studies employed static models, which do not account for the inter-temporal effects of changes in the soil capital (ignore the dynamic nature of the soil degradation and soil conservation investments). Furthermore, despite the fact that a large number of adoption studies had been carried out in Ethiopia to date, the attention provided to the analysis of soil conservation and soil nutrient management adoption behavior of smallholder farmers is minimal. Despite the fact that soil fertility management and conservation practices involve choices among several technological options the few available studies lumping the technological choices into two applied bi-variant models which did not consider information contained in interdependence and simultaneous adoption decision. This study, therefore, adopted a dynamic optimization framework in order to assess the inter-temporal trade-offs (the true social costs of soil loss relative to the value of output expected) that farmers face in their production decisions. It also analyzed the socio-economic factors that constrain adoption of soil fertility and soil conservation practices employing econometric models that account for simultaneity of choices.

The study was conducted in the highlands of Dendi and Debre Birehan Zuria in the Central Highlands of Ethiopia. The central highlands were chosen, as the area of focus for two reasons. First, the central highlands characterized by divers ecological aspects and settlement patterns represent the wider highlands of Ethiopia. Second, the central highlands provide a good contrast as soil fertility and soil conservation technologies were extensively promoted in some districts but not in others. The study, therefore, employed a multi-stage sampling procedure involving a purposive selection of regions, zones and districts followed by a random selection of peasant associations (PAs) within districts, and finally households from selected PAs. A total of 229 households managing some 1599 plots and sub plots were included in the study.

Necessary data were collected from various sources including secondary sources, participatory rural appraisal (PRA) and focused formal household surveys. Needed data at various scales (plot, farm and household) were collected. The collected data include plot characteristics (size, distance from residence, severity of soil degradation, fertility level, perceived plot productivity, slope), soil fertility and soil conservation practices used and production. Major socio-economic variables measured include demographic structure of households, farm size, livestock owned. Moreover, data on access to credit, extension and improved inputs were collected from the household survey.

Both positive (econometric) and normative (optimization) analytical approaches were employed to achieve the stated objectives. First, recognizing that smallholder farmers manage several small plots of land scattered across micro-environments and that the nature of soil degradation facing farmers in low lying (bottom lands) is different from the soil degradation problem on sloping lands, the study developed two versions of an analytical dynamic control model for the respective soil degradation scenarios. The analytical optimal control model was then applied to the two soil degradation scenarios facing smallholder farmers in the Central highlands of Ethiopia to solve and compare optimal steady state solutions with profit maximizing static solutions and current farmer practices. Second, using plot level cross-sectional farm household survey, the study analysed the soil fertility and soil conservation adoption behaviour of smallholder farmers in the Central Highlands of Ethiopia. For the latter purpose, three sets of adoption models, multinomial logit for discrete dependent variables involving multiple choices, Heckman's two-step and Tobit regression models for the censored continuous dependent variables of intensity of inorganic fertilizers and stone/soil bund use, respectively, were estimated.

A comparison of the dynamic solutions at a socially desirable steady state with solutions of the static decision rule and current average practices revealed the following insights. First, the study showed that output under the dynamic decision rule for both soil degradation scenarios is much higher than the optimal output level under the static decision rule and current farmer practices suggesting there is a lot of room for improving the productivity of smallholder agriculture in the Central highlands of Ethiopia. Second, the optimal nutrient input required to attain and sustain steady state output under the dynamic decision rule is significantly higher than the requirements of the static decision rule and current farmer practices. Third, the optimal conservation effort required to attain and sustain steady state stock levels is much higher than current conservation efforts on both plot categories (bottom and upland plots). Fourth, current farmer practices involve a net nutrient (N) extraction of 16.2 kg/ha from bottomlands and 56.7 kg/ha from slopping lands entailing a total soil user cost of Birr 255 per ha and Birr 928 per ha, respectively, suggesting smallholder farmers discount the future heavily (display a high rate of time preference) and hence over exploit the resource stock. The above results lend themselves to the following conclusions:

- The static decision rule and current farmer practices are sub optimal compared to the socially desirable steady state dynamic solutions.

- Current soil fertility management and conservation practices are insufficient to curb the soil nutrient mining and physical degradation hazards and its ensuing problems of food insecurity and poverty facing smallholder farmers in the highlands of Ethiopia.

The reasons for the sub optimal use and extraction of the soil capital by smallholder farmers in the highlands of Ethiopia are believed to be associated with poverty, risk aversion behavior and land tenure insecurity, which force smallholder farmers to discount the future heavily. Therefore, measures that reduce smallholder farmers' rate of time preference such as improved land tenure security, access to credit and actions targeted at reducing poverty would raise the future worth of soil resources thus provide incentives for the adoption of SWC measures which in turn contribute to a more sustainable use of soil resources.

- The social gains from better utilization of soil resources (moving from current practice to the socially desirable steady state input and output levels) are tremendous.
- Despite the fact that current smallholder teff production practices are sub optimal compared to the desirable steady state dynamic solutions, the fact that current levels of inorganic N application and conservation efforts are higher than the static solutions suggest smallholder farmers consider some of the externalities of nutrient mining and soil physical degradation. Government assistance that unlocks the private incentives and help smallholder farmers adjust input levels towards the socially desirable steady state levels would be desirable not only to improve profitability of smallholder agriculture but also attain sustainable use of the soil capital.

A comparison of the dynamic solutions of scenario II with the nutrient mining scenario at a socially desirable steady state further revealed the following insights.

- Optimal steady state output under scenario II is significantly lower than the optimal output level under scenario I.
- Optimal levels of the control variables (labor, capital and inorganic N inputs) required to attain and sustain steady state output under scenario II are much lower than the respective input levels under the nutrient mining scenario suggesting the on-site effect of soil erosion (decline in SD) is to shift the production possibility frontier inwards.

- The net private and social gains under scenario II are considerably lower than the corresponding gains under scenario I suggesting failure to consider soil depth depletion under estimates costs or over estimates benefits.
- The optimal nutrient stock level for scenario II is lower than for scenario I suggesting soil quality and hence future productivity of the soil capital on uplands would be lower than on bottomlands.
- The optimal conservation effort required to achieve and sustain steady state stock levels (N and SD) under scenario II are higher by four folds over the requirements of the nutrient mining scenario highlighting the costs of soil erosion control on upland plots is significantly higher than on bottom plots.

The above results further confirm the main hypothesis that the socially optimal path of soil use not only diverged from the private optimal path but also depends on the nature of soil degradation smallholder farmers face on their plots. In Ethiopia where smallholder farmers manage multiple plots of heterogeneous soil quality and where perception of soil degradation is a function of plot characteristics, soil conservation projects and programs need to consider plot heterogeneity in program design and implementation. For instance on low lying plots where the overriding problem is net extraction of nutrients, the optimal mix of soil management practice is to raise current nutrient application rates to the steady state optimal level associated with modest levels of conservation effort. On slopping plots where both net nutrient extraction and soil erosion impinge on soil quality, sustainable utilization of the soil capital requires not only use of substantial levels of external nutrient inputs but also considerable investments in soil conservation effort. Nonetheless, given the high rate of time preference that smallholder farmers display, the lower average yields and that soil conservation investments are costly on slopping lands than on low laying plots it is unlikely that smallholder subsistence farmers take private initiatives to curb the alarming soil degradation prevalent on slopping lands. Government assistance such as input subsidies, credit provision, cost sharing arrangements for initial construction of conservation structures and well-taught and properly coordinated food-for-work programs would be indispensable to induce farmers invest in soil fertility and conservation practices that would have a long term desirable effect on the soil capital.

The sensitivity analysis showed that a rise in the discount rate lowered steady state optimal input levels, output and the resource stock whereas a lower discount rate have the opposite effect suggesting measures that raise the future worth of soil resources would be crucial to induce smallholder farmers to adopt soil conserving farming techniques. Similarly a rise in output price and a fall in the price of N fertilizer would have the impact of raising steady state optimal input and output levels whereas a fall in output price and a rise in the price of inorganic N would have the opposite effect. Policies aimed at improving market access (improvement in road networks), improving the efficiency of existing input and output markets (reduce transaction costs) that ensure the delivery of inorganic fertilizers at the right time, product mix and reasonable price is likely to raise the use of inorganic fertilizers which ultimately contribute to a more sustainable use of soil resources.

The econometric analysis of soil fertility and soil conservation adoption behaviour of smallholder farmers revealed strong evidence that the likelihood and intensity of using alternative SFM and conservation technologies by smallholder farmers on croplands are conditioned by different factors and at different levels of significance by the same factor. A number of findings of policy relevance have emerged from the analysis.

In both study districts, smallholder farmers have recognized soil degradation as a major problem responsible for the low and declining crop productivity and food insecurity prevalent in the study area. Nonetheless, households in Dendi district largely identified soil degradation with poor or declining soil fertility while households in Debre Birehan acknowledged both declining soil fertility (soil nutrient mining) and soil erosion to be equally important. Consequently, about three-quarters of the cultivated plots in both districts had received some type of soil fertility enhancement practice. Adoption of stone/soil bunds, however, was mainly restricted to the Debre Birehan district. This differential perception of soil degradation and adoption of soil degradation control practices among smallholder farmers have partly been reinforced and nurtured by the relative emphasis agricultural extension had placed and interventions implemented in the study areas. Despite the fact that soil degradation were apparent in both districts (more so in Debre Birehan), agricultural extension programs in Dendi districts, until recently, emphasized on increasing crop productivity through the promotion of extension packages consisting of improved crop varieties, recommended types and rates of inorganic fertilizers, optimum weed and pest control practices. On the other hand, in Debre Birehan district, besides the promotion of improved crop technologies, soil conservation had received considerable attention. Given that the probability and intensity of using most of the soil fertility management practices is positively related with access to extension and that government assistance is positively associated with the likelihood of using stone/soil bunds, continued extension assistance and government support is vital in the fight against soil degradation and its consequences of food insecurity and poverty.

The study revealed that ago-ecological variations have a differential impact on the adoption of soil fertility management practices among smallholder farmers. The use of multiple sources of nutrients on a single plot is wide spread in the upper highlands while inorganic fertilizers seem to be the major soil fertility management practice in the mid highlands where a high value crop, teff, is predominantly grown. Hence, future soil fertility management research and promotion programmes in the highlands need to clearly take into account agro-ecological variations. In the upper highlands where manure use and fallow rotations are common the possibility of improving the efficiency of available manure through composting and introducing improved fallowing practices need to be looked at.

Across all specifications, access to education was found to be associated with the likelihood of adoption of most of the soil fertility management and soil conservation practices as well as the intensity of use of inorganic fertilisers and stone/soil bunds. In a country where 60% of the adult population (over 15 years of age) is illiterate, improving smallholder farmers' access to formal education and improving skills through extension education in diagnosing soil degradation and other soil related problems would be effective in improving both the likelihood of adoption and intensity of use of inorganic fertilizers and soil/stone bunds (conservation).

Poverty in asset endowments was found to be an important determinant of adoption of inorganic fertilizers and stone/soil bunds suggesting the less endowed (the poorest of the poor) will be less likely to use commercial fertilizers and engage in soil conservation activities. Policies geared towards reducing poverty are thus likely to improve adoption of soil fertility management and soil conservation practices in the study areas. Furthermore, project assistance in sharing initial costs for constructing soil conservation structures form an important incentive for adoption of stone/soil bunds suggesting government assistance will be pivotal in improving rural income as well as contribute to reversing soil degradation. Well thought and properly coordinated external assistance by government and NGO's (e.g. food for work) is thus likely to play a positive role in containing soil degradation, improving productivity thereby reduce poverty.

On the other hand, access to short term credit is found to have contradictory effects on adoption. While access to short term credit for the purchase of inorganic fertilizer has a positive impact on both the likelihood of adoption and intensity of use of inorganic fertilizer, it had a negative and significant impact on the probability and intensity of use of stone/soil bunds suggesting that farmers having access to institutional credit do not see the need for soil conservation or postpone adoption of soil conservation. This result is consistent with the findings of Holden and Shiferaw (2004) in the Andit Tid area of North Shewa. Improving smallholder farmers' access to short-term credit for the purchase of inorganic fertilizers, therefore, needs to be designed cautiously taking into consideration its long-term effect on soil conservation adoption. Providing information on the likely danger of relying heavily on short term yield enhancing soil fertility management practices to deal with the soil degradation problem would be useful to improve awareness and help households make informed decisions.

Plot size is found to have a positive impact (except in case of manure use) both on adoption of soil fertility and conservation practices as well as intensity of stone/soil bund use. Further land redistribution in the already degraded and land scarce highlands, therefore, not only contribute to land fragmentation but also by raising the fixed costs of operating micro (very small) and dispersed plots further undermine sustainable farming and increase nutrient mining. Land consolidation that allows households to have access to fewer but larger plots within the context of exploiting the diverse microclimates and heterogeneous land quality is likely to improve adoption of soil fertility and conservation practices.

The likelihood of using manure, ISFM and stone/soil bunds is found to be significantly higher on owned lands than leased in plots suggesting that improved tenure security is a precondition for households to engage in soil fertility management and soil conservation practices that have a long gestation period. Improving tenure security is thus likely to enhance adoption of soil fertility and soil conservation practices that have a long-term nature.

This thesis provided analysis of the socio-economic aspects of soil degradation as it applies to smallholder farmers based on data collected from two districts in the Central highlands of Ethiopia. Results of the study therefore need to be viewed and interpreted with the following caveats in mind. First, although all effort had been made to select representative locations so that results have relevance to the wider highlands, care need be exercised when extrapolating results to other parts of the highlands where natural and socio-economic features are much different from the Central Highlands. Second, the study employed econometric (positve) models for analysing the determinants of adoption of soil mangement technologies among smallholder farmers and normative (optimization) analytical techniques for estimating the intertemporal effects of soil nutrient depletion and erosion. Although the analytical approaches adopted for the considered research problems as such were appropriate, the discrete nature of the approaches did not allow exploring the linkage between socio-economic variables determining soil management adoption and biophysical processes governing erosion and soil nutrient depletion. The challagne for future research, therefore, would be to search for an alalytical tool that would enable exploring more fully the linakages between socio-economic variables influcning technology choice and biophysical variables governing soil erosion and soil nutrient depeletion. Third, due to data limitations the study assumed only one crop, teff, is grown on the same piece of land and modelled the inter-temporal allocation of resources. In reality, however, in the highlands, crop rotation is a norm than the exception and hence future modelling exercises need to consider, besides the conventional production and conservation inputs, crop mix as a choice variable. Fourth, despite the fact that soil degradation has both on-site and off-site impacts imposing far-reaching consequences on the welfare of individual households and society at large, this study concentrating on on-site impacts did not attempt to capture the off-site impacts of soil degradation. It is therefore important that future studies explore off-site impacts of soil degradation on the welfare of individual households as well as society at large. Fifth, another important aspect that has not been dealt with and need consideration in future research concerning soil fertility management and conservation is the impact of risk on the adoption and resource allocation decisions of smallholder farmers. Sixth, the study relied heavily upon broadly representative secondary data (e.g. erosion rates) to empirically specify some components of the optimal control model and subsequently solve for the optimal values. Model results should, therefore, be interpreted in this light.