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DETERMINANTS OF INORGANIC FERTILISER USE IN THE MIXED CROP-LIVESTOCK FARMING SYSTEMS OF CENTRAL HIGHLANDS OF ETHIOPIA

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ABSTRACT

Increased use of inorganic fertilisers is believed to be fundamental to addressing the low and declining soil fertility and improving food security in sub-Sahara Africa (SSA). Despite notable improvements in the supply of inorganic fertilisers and supporting services such as extension and credit, use of inorganic fertilisers among smallholder farmers remained disappointingly low. The objective of this study was to determine key factors responsible for use of inorganic fertilisers in the mixed crop-livestock farming systems in the central highlands of Ethiopia. Heckman's two-step procedure was used to analyse the variables. Education level of the head of the household, number of livestock owned, number of plots owned, land tenure, access to credit and extension, agro-ecology and manure use influenced both the likelihood of adoption and intensity of inorganic fertiliser use. Continued land redistribution in the already degraded and land scarce highlands further undermine sustainable farming and increase nutrient mining. On the other hand, shrinking plot size as a result of repeated plot subdivisions may induce current users of inorganic fertilisers to use more nutrients per unit of land in an attempt to raise productivity. This positive effect, however, may be more than offset by the negative effects exerted by plot distance, thus leading to nutrient mining.

Key Words: Adoption, Heckman two-stage, land tenure, manure

RÉSUMÉ

L'utilisation accrue des engrais inorganiques est reconnue être fondamentale pour addresser la baisse de la fertilité du sol et l'amélioration de la sécurité alimentaire en Afrique sub-Saharienne (SSA). Malgré des ameliorations notables dans l'approvisionnement des engrais et les services de soutien tels que la vulgarization et credit, l'utilisation des engrais inorganiques par les petits expolitants est de façon décevante restée basse. L'objectif de cette étude était de déterminer les faclteurs clés reponsables pour l'utilisation des engrais inorganiques dans les systèmes mixtes agro-elevages dans les hautes terres du Centre de l'Ethiopie. La procédure dite two-step de Heckman était utilisée pour analyser les variables. Le niveau d'étude du chef de ménage, le nombre de bétail possédé, le nombre de parcelle possédé, la possession de terre, l'accès au credit et les services de vulgarization, l'utilisation agro-écologique et fumure organique comme influencé par l'adoption et l'intensité de l'utilisation des engrais inorganiques. La redistribution des terres des hautes terres déjà dégradées et rares compromet toute tentative de leur exploitation durable et accélère l'appauvrissement du sol en élements minéraux. D'autre part, la réduction de la taille des parcelles comme résultat des subdivisions répétées des parcelles pourrait induire une utilisation plus accrue des engrais inorganiques par unité de terre dans la tentative d'accroître la productivité. Cet effet positif, par ailleur, pourrait être plus que contre-balancé par les effets négatifs tels qu' influencés par la distance, ainsi, conduisant à la perte d'élements minéraux du sol.

Mots Clés: Adoption, Heckman two-stage, possession de terre, fumure

INTRODUCTION

In Sub-Saharan Africa (SSA), low and declining soil fertility due to net nutrient extraction by crops is responsible for low agricultural productivity and food insecurity (Yirga and Hassan, 2010; Nakhumwa and Hassan, 2012). In Ethiopia, nutrient depletion is more severe in the highland areas higher than 1500 meters above sea level, constituting 44% of the total area supporting 88% of the human and 75% of the livestock population. Stoorvogel and Smaling (1990) estimated soil nutrient losses for the highlands of Ethiopia to be exceeding 80 kg N, P_2O_5 and K_2O per cultivated hectare. On the other hand, nutrient application from commercial sources amounts to only 12 percent (10 kg ha^{-1}) of the total nutrients applied. Equally disappointing is the low use of organic forms of fertiliser such as compost, dung and crop residues due to their increasing alternative uses such as source of energy for households (Yirga and Hassan, 2010). As a result, yields have stagnated at low levels contributing to the worsening food insecurity and poverty (Yirga *et al.*, 1996; Shiferaw and Holden, 1998; Yirga and Hassan, 2010).

Sanchez *et al.* (1997) indicated that among others, the breakdown of traditional soil nutrient management practices as a result of increasing pressures on agricultural land prompted by the need to feed increasing population in the face of shrinking land frontier is responsible for nutrient depletion in SSA. However, others argue that population pressure induces households to intensify agricultural production, invest in land improvements and develop land saving innovations eventually resulting in improved resource conditions and possibly improved welfare .

Increasing agricultural productivity, improving farm income and reversing soil nutrient mining have thus become a priority policy objective of the Ethiopian government. The government adopted a new development strategy popularly known as the Agricultural Development Led Industrialisation (ADLI) aimed at improving the productivity of smallholder agriculture. Consequently, inorganic fertiliser recommendations (type, rate and time of application) alone or associated with improved seeds and other agronomic practices were developed and promoted among smallholder farmers for widespread use through a combination of programmes and special projects.

Despite the intensified research-extension efforts and policy reforms, commercial fertiliser use showed modest improvement. Consumption increased from 190,000 metric tonnes in 1994 to 253, 000 t in 1996 and 286, 000 t in 1999 (Adunga and Demeke, 2000). For Ethiopia as a whole, the proportion of farmers using commercial fertilisers was estimated at 15 per cent in 1992 (Makken, 1993) and increased to 31 per cent in 1997 (Demeke *et al.*, 1997). Likewise, the intensity of use, measured as kilogramme of nutrients per hectare of cultivated land, grew from less than 7 kg in 1992 (Makken, 1993) to 17-20 kg in 1999 (Adunga and Demeke, 2000).

Several studies analysed the determinants of inorganic fertiliser use in Ethiopia (Yirga *et al.*, 1996; Dadi *et al.*, 2001). These studies noted that knowledge on the benefits of using fertiliser and other inputs is widespread, but limited supply and late delivery of fertilisers and improved seeds hindered increased fertiliser use. Other factors identified included lack of access to institutional credit, extension and markets. Recently, notable improvements in the supply of inorganic fertilisers and supporting services such as extension and credit were made. Despite the achievements in addressing these constraints, fertiliser use among smallholder farmers remained below expectations; thus necessitating further investigation into the emerging determinants of fertiliser use among smallholder farmers in the highlands of Ethiopia.

A fundamental problem characterising all previous fertiliser adoption studies is the absence of economic theory that could serve as a basis for selection of the determinants of technology adoption decision variables. Consequently, plot characteristics, perception of soil degradation problem and past use of alternative soil fertility management practices (crop rotations involving legumes, farm yard manure and seasonal fallowing) are believed to be important in explaining variations in inorganic fertiliser use among smallholder farmers, yet previous studies did not consider these factors in their analysis (Waktola, 1980; Kebede *et al.*, 1990; Yirga *et al.*, 1996; Dadi *et al*., 2001). Furthermore, most previous fertiliser adoption studies that modeled intensity of inorganic fertiliser use employed a Tobit regression model, which presupposes no sample selection problem. In the presence of self-selection, however, results of Tobit model are biased and inefficient (Winship and Mare, 1992; Vella, 1998). The Tobit model assumes that a variable that increases the probability of adoption will also increase the mean amount of inputs used (Lin and Schmidt, 1984; Green, 2000). The preposition that the same variables and the same parameter vector affect both the adoption decision and the intensity of use has been questioned (Green, 2000; Gebremedhin and Swinton, 2003; Katchova and Miranda, 2004). Among others Nakuma and Hassan (2004) 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 are 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.

The objective of this study was to analyse the determinants of inorganic fertiliser adoption behavior of smallholder subsistence farmers in the highlands of Ethiopia employing an econometric model that explicitly accounts sample selection. Moreover, taking into account that smallholder farmer soil fertility management decisions are made at a plot level due to heterogeneity of plots managed by a household, this study analysed the adoption decision at a plot level.

METHODOLOGY

This study was conducted in Dendi and Debre Birehan districts in the central Highlands of Ethiopia. The area is characterised by two dominant farming systems: the barley based crop-livestock farming systems of the upper highlands lying above 2600 meters and the tef (*Eragrostis tef*) and wheat (*Triticum aestivum*) based crop-livestock farming systems of the mid highlands lying between 2000 and 2600 meters. The upper highlands being cooler and frost prone are better suited to long cycle (season) crops mainly barley (*Hordeum vulgare* L.) (Yirga *et al*., 1998) while the mid-highlands being relatively warmer and less susceptible to frost are suited to tef and wheat.

The study was based on cross-sectional data collected from four peasant associations (PA). A multi-stage sampling procedure was used for purposive selection of regions, zones and districts followed by a simple random selection of PAs within districts; and finally sample households in the selected PAs. Within the central Highlands, North Shewa zone from the Amhara region and West Shewa zone from the Oromia region were purposively selected to capture diversity in terms of agro-ecological representation (having both high potential and low potential zones), degree of past soil conservation effort and socio-economic differences (settlement pattern, whether or not recent land redistribution has been implemented). Understanding the influence of agro-ecological variations and socio-economic differences on the adoption decision of farmers can provide insights into identifying target variables and areas that enhance the use of inorganic fertilisers.

Following the identification of zones, two districts; one from each of the two zones namely Dendi from West Shewa zone and Debre Birehan, also referred to as Basona Worena district from North Shewa zone were purposively selected. While Dendi district is characterised by a warmer mid highlands lying between 2000 to 2600 meters and a cooler upper highlands lying over 2600 meters; the Debre Berihan Zuria district on the other hand, is predominantly cool temperate like climate lying above 2800 meters.

The data were collected from a formal household survey involving 229 randomly selected households, managing 1411 cultivated plots during the 2003 cropping season. The data included plot characteristics (size, distance from residence, severity of soil degradation, fertility level, perceived plot productivity, and slope); soil fertility and soil conservation practices used and production. Major socio-economic variables included demographic structure of households, farm size, livestock owned, access to credit, extension and improved inputs.

Analytical model. Intensity of inorganic fertilisers use measured as the sum of diamonium phosphate (DAP) and urea fertilisers applied per unit of cropped unit area is continuously censored. This censoring arises due to the fact that not all sampled households used inorganic fertilisers. Even those who used inorganic fertiliser may not have done so on all plots cultivated. 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 the Tobit model (Winship and Mare, 1992; Long, 1997; Vella, 1998).

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

$$y_i^* = \beta' x_i + \varepsilon_i \quad \text{...} \quad (1)$$

Where X_i = 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 fertiliser or length; 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 fertiliser used is zero in the Tobit model could be specified as:

$$P(y_i = 0) = \phi(-\frac{\beta' x_i}{\sigma}) \quad \text{..........................} \quad (2)$$

and the density function for the positive values of Y_i is:

$$f(y_i / y_i > 0) = \frac{f(y_i)}{P(y_i > 0)} = \frac{\frac{1}{\sigma}\phi(\frac{y_1 - \beta' x_i}{\sigma})}{\phi(\frac{\beta' x_i}{\sigma})} \quad \text{........} \quad (3)$$

where ϕ (•) is the standard normal probability density function. Equation (2) is a probit model representing the adoption decision whereas equation (3) represents a truncated regression for the positive values of the continuous decision of how much inorganic fertiliser 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 estimated coefficients, β, do not represent the marginal effects of a unit change in the independent variable on E(Y) or E(Y^*). McDonald *et al*. (1997), Green (2000) showed the following decomposition of the marginal effects of the Tobit model:

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

$$E(Y / Y > 0)\frac{\partial \Pr(Y > 0)}{\partial X_j} \quad \text{......................} \quad (4)$$

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.

One 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). The Huber/White/sandwich estimator of variance could be used to correct for possible heteroscendasticity of unknown forms. Test for the non-normality of the disturbance terms in the Tobit model, however, is not straight forward. 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 is endogeneity. Besides, household, farm, plot and institutional variables hypothesized to condition inorganic fertiliser use and soil fertility management practices used the previous season (fallow, legume or farmyard manure) are believed to be important in explaining variations in inorganic fertiliser use among smallholder farmers. These variables could, thus be 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 using a two-stage model or using instrumental variable technique (Green, 2000). The problem for our data, however, is not expected to be serious as the decisions to use inorganic fertiliser 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 fertiliser and how much inorganic fertiliser to use on a plot given the farmer has made his/her mind to cultivate the plot in question is done 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. 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):

$$\lambda = -2[\ln L_T - (\log L_P + \log L_{TR}) \quad \text{........ (5)}$$

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.

The first step in Heckman's two-step procedure 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.

$$P_i(Z_i = 1) = \phi(\varpi_i^{'}\alpha) + e_i \quad \text{....................... (6)}$$

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).

$$E(Y_i \mid z = 1, X_i) = X_i^{'}\beta + E(\mu_i \mid Z_i) \quad \text{..... (7)}$$

The third procedure is to evaluate the conditional expectation of ì in equation (8) with respect to the variable, e, represented by:

$$E(\mu_i \mid e_i)\omega_i^{'}\alpha = \rho\sigma_e\sigma_\mu \frac{\phi(\omega_i^{'}\alpha)}{\Phi(\omega_i^{'}\alpha)} \quad \text{........ (8)}$$

Then, inserting Equation 9 into Equation 8 we get Equation 10 as follows:

$$E(Y_i \mid z = 1, X_i) = X_i^{'}\beta + \quad \text{........................ (9)}$$

$$\rho\sigma_e\sigma_\mu \frac{\varphi(\omega_i^{'}\alpha)}{\Phi(\omega_i^{'}\alpha)}$$

Finally, we use OLS to regress Y on X and given by:

$$E(Y_i \mid Z = 1, X_i) = X_i^{'}\hat{\beta} + \theta\hat{\lambda}_i \quad \text{.......... (10)}$$

Hypothesis and definition of variables. Previous research on farmers' adoption of new technologies including inorganic fertilisers considered perception of the problem or constraint (soil degradation), profitability of adoption 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 (Shiferaw and Holden, 1998; Bekele and Drake, 2003; Gebremedhin and Swinton, 2003). Therefore, based on 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 hypothesised to influence adoption of inorganic fertilisers by smallholder farmers in the highlands of Ethiopia (Table 1).

Recognition of soil degradation has been found to positively influence adoption behavior in a number of studies (Shiferaw and Holden, 1998;

TABLE 1. Definition of variables hypothesized to condition adoption of inorganic fertilisers 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)
Soil erosion	Farmer perception of the severity of soil loss on a plot	1=none, 2=light, 3=medium, 4=severe
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 fertiliser	Amount of money borrowed (Birr[1])
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 Berihane0=Dendi
Soil fertility management practices used the previous year		
Fallow	If plot were fallowed the last season	1=yes. 0=otherwise
Legume	If precursor crop was a legume	1=yes. 0=otherwise
Manure	If animal manure was applied on plot last season	1=yes. 0=otherwise

HH = household

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

Bekele and Drake, 2003). Hence, it is expected that households who managed marginal plots (plots with poor soil fertility), or face the most severe potential erosion problems are more likely to adopt soil fertility management practices.

Household attributes often considered having differential impacts on the adoption decision include age, education level of the household head, family size and wealth (livestock ownership and type of house). The effect of age of the farmer on adoption decision is considered as a composite effect of farming experience and planning horizon. Many equated short planning horizons with older but more experienced farmers who are well aware of the productivity consequences of low soil fertility; whereas younger farmers being more educated on the average and having longer planning horizons may be more likely to take up new opportunities (Dadi *et al.*, 2001; Yirga and Hassan, 2008). The effect of age of the household head, therefore, cannot be predicted in the empirical model a priori.

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 iron 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). Number of livestock and ownership of corrugated roofed house are expected to be positively associated with both the decision and intensity of use of inorganic fertilisers. Large family size is normally associated with a higher labor endowment that would enable a household to accomplish various agricultural tasks on timely bases thus raise productivity. Hence, we expect a household with large family size to be more likely to adopt inorganic fertilisers.

Farm and plot characteristics hypothesised to influence adoption of inorganic fertilisers in this study are plot size, number of plots (parcels) owned (a proxy for farm size) and distance of plots from the homestead. Land scarce households might have incentives to adopt labor intensive management practices compared to households with relatively large farm size. Hence, we expect plot size to be inversely related with the use of inorganic fertiliser.

Distance of a plot from a household's residence may influence a households investment decisions in two ways. First, unlike farmyard manure and compost, inorganic fertilizer requires less labour to transport to distant plots (lower transaction costs) thereby raise the likelihood of adoption. Second, 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 positively associated with the use of inorganic fertiliser that is assumed to have very little residual effects.

Institutional factors often considered to have differential impacts on technology adoption by smallholder farmers are access to information, institutional credit, off-farm employment and land tenure. Various studies in developing countries including Ethiopia reported a strong positive relationship between access to information and the adoption behaviour of farmers (Yirga *et al*., 1996; Dadi *et al.*, 2001). Hence, it is hypothesised that the greater the number of contacts a household has with extension workers, the more likely the adoption decision. Also, studies by several researchers (Yirga *et al*., 1996; Dadi *et al*., 2001) underscored the role of credit in enhancing adoption of crop technologies. It is, therefore, hypothesised that access to credit will have a positive impact on adoption of inorganic fertilisers. It is observed that farmers with off-farm income are less risk-averse than farmers without sources of off-farm income. Hence, off-farm income is expected to have a positive impact on the use of inorganic fertilisers.

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. We expect adoption of inorganic fertilisers to be more likely on rented or share cropped plots than on owned plots (plots allotted to a household directly by PA officials).

Agro-ecological variation is believed to have a profound effect on the likelihood of adopting improved technologies (Yirga and Hassan, 2008). Bread wheat and tef mainly grown in mid-highlands are reported to have a better response to inorganic fertilisers than barley, the dominant crop in the upper highlands making the use of inorganic fertilisers more profitable on wheat and tef than barley. Therefore, it is hypothesised that the probability of using inorganic fertilisers 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.

Empirical parameter estimation procedures. Prior to estimating the adoption models, the independent variables were scrutinised for possible strong correlations among them. Among the variables hypothesised 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 multi-collinearity, initial runs of the Tobit model 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. Similarly, district was found to be highly correlated with agroecology and stone/soil bunds and hence dropped. Also, for identification purposes and to explore whether investments in soil conservation have impact on fertiliser use intensity an interaction variable (stone/soil bund * district) was included as explanatory variables in the outcome equation.

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 (5) 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 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 fertilisers. 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 fertiliser use are presented and discussed.

RESULTS AND DISCUSSION

Adoption rate and use pattern of inorganic fertilisers. This study has revealed that fertiliser use is more spread in the tef/wheat based farming systems of the mid-highlands than its barley based crop-livestock based counterpart in the upper highlands (Table 2). The wide use of inorganic

TABLE 2. Intensity of inorganic fertiliser use by major crops, central highlands of Ethiopia, 2004

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 fertilised (%)	27.9	26.6	0.0	94.6	25.0	91.5
Average rate of use (kg/fertilised 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

fertilisers in the mid-highlands, with the bulk used on wheat and tef, supports the hypothesis that inorganic fertilisers are widely used in this region mainly for cash. However, the average use rate was below the recommended level of 100 kg ha^{-1} for both diammonium phosphate (DAP) and urea for the major cereals (Croppenstedt *et al*., 2003; Yirga and Hassan, 2010). Previous inorganic fertiliser adoption studies attributed the sub-optimal use rate to inadequate supplies, late availability and the risk aversion behaviour of farmers (Yirga *et al*., 1996; Demeke *et al*, 1997; Croppenstedt *et al*., 2003). The influence of these factors on the likelihood of adoption and intensity of inorganic fertiliser use are discussed in the following section.

Econometric results. Table 3 presents parameter estimates of Heckman's two-step model. The likelihood function of the two-step Heckman model was significant (Wald with P<0.0000), showing a strong explanatory power. Also, the coefficient of the mills lambda was significant (P<0.0000) providing evidence of the presence of self-selection and, hence justifying the use of Heckman's two-step procedure.

As evident in Table 3, all hypothesised variables, except land tenure and fallowing, significantly influenced the likelihood of using inorganic fertilisers. On the other hand, only a subset of the hypothesised variables had a significant influence on intensity of inorganic fertiliser use. Variables that significantly influenced intensity of inorganic fertiliser use included education, livestock, number of plots owned, land tenure, access to credit and extension, agro-ecology and manure use.

As expected, education of the household head positively and significantly influenced both the likelihood of adoption and intensity of inorganic fertiliser use. A unit increase in the number of years of formal schooling of the head of a household would have the impact of raising the probability of using inorganic fertiliser by 1.5%. Likewise, cattle heard size positively and significantly associated with both the probability and intensity of commercial fertiliser use. A unit increase in heard size would lead to an increase in the likelihood of commercial fertiliser use by 1.7%. The results, therefore, suggest that institutional interventions targeting expanded 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 fertilisers 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 fertiliser use. Other things being constant, the chance of using inorganic fertilisers 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 use intensity. 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. This is 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 (Table 3). Keeping other variables at the mean level, the chance of using inorganic fertilisers 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 fertilisers, respectively. Assuming other factors kept constant, the type of land ownership, although had no 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, had a high potential for raising both number of farmers using inorganic fertilisers and expected use rates among those currently using.

TABLE 3. Parameter estimates of Heckman's two-step model for the likelihood of adoption and intensity of inorganic fertiliser use (kg ha^{-1}), Central highlands of Ethiopia

Variable	Probability of adoption				Intensity of use	
	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

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 fertiliser 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 fertiliser, 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 fertilisers.

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 fertilisers. Other things being equal, the chances of using inorganic fertilisers on a typical 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 fertiliser suggesting that intensity of fertiliser 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 fertilisers on plots that benefited from stone/soil bund investments. Also, the intensity of use of inorganic fertilisers 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 fertilisers or increasing the intensity of use among household who are already using inorganic fertilisers. Information on the agro-ecology of an area, coupled with knowledge of plot characteristics, is important in predicting adoption rates, use intensities and could be valuable in fine-tuning inorganic fertiliser recommendations and marketing of inorganic fertilisers.

CONCLUSION

This study reveals a wider policy implication for the adoption of improved agricultural technologies in general and inorganic fertilisers, in particular in the highlands of Ethiopia. Continued land redistribution in the already degraded and land scarce highlands not only contributes 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. On the other hand, shrinking plot size as a result of repeated subdivision of plots to accommodate new land claimants may induce current users of inorganic fertilisers to use more nutrients per unit of land in an attempt to raise productivity. This positive effect, however, may be more than offset by the negative effects exerted by plot distance thus leading to nutrient mining. The Strategies to enhance both adoption and intensity of use of inorganic fertilisers in the central highlands of Ethiopia, in general and the highlands in particular thus 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 may have a great potential in raising the likelihood of adoption and intensity of use of inorganic fertilisers.

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