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RESEARCH ARTICLE

Determinants of smallholder farmers' decisions on fertilizer use for cereal crops in the Ethiopian highlands

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Abstract
This study identified decision variables influencing fertilizer adoption and optimal fertilizer rates among smallholder farmers in the Ethiopian highlands. The fertilizer adoption and fertilizer use were examined in four regional states using a questionnaire survey, which was administered to 2880 farm households. A double hurdle model was used to analyze factors influencing the two independent decisions of adoption of fertilizers and use of fertilizers. The model estimates of the first hurdle revealed that the probability of fertilizer adoption increased by 1.2% as household education status improved, by 1.4% for an increased number of active family members, by 5.6% with improved access to credit, by 3.4% with cooperative membership, by 3.3% with an increase in farm size, by 4.6% when soil and water conservation practices are employed, and by 3.4% when agroecology of the farm is located in the medium to highland zone. Conversely, the probability of fertilizer adoption reduced by 0.9% for an increase in family size, 0.6% with 1 km distance from all-weather road, 1.6% for a kilometer further to farm plots, and 0.9% for an increase in number of parcels. The intensity of use of fertilizers was influenced by education status of the household head, family size, access to credit, membership to cooperatives, use of crop rotation, annual income, number of farm plots owned, use of soil and water conservation, and agroecology. Therefore, a concerted effort is needed to encourage fertilizer adoption and optimum fertilizer use intensity by improving households' resource endowment, institutional capacity to deliver services, and infrastructure development.

Keywords: Adoption; Fertilizer use; Double hurdle model

Introduction

Soil nutrient deficiency is a major factor in determining current yield levels in Sub-Saharan Africa (SSA) (IIRR, 2002). Studies show that the majority of soils in smallholder fields in SSA are depleted and that nutrient depletion is ongoing (van Beek *et al.*, 2016). Contributing factors include unbalanced and low levels of fertilizer application, complete removal of crop residues and dung burning for household fuel (Elias, 2016; Elias *et al.*, 1998; Stoorvogel and Smaling, 1990). Fertilizer use intensity in SSA is estimated to be less than 1% of the world average (Kelly and Naseen, 2009; Yamano and Kijima, 2010). The average fertilizer use intensity from 2000 to 2003 in SSA was 9 kg ha^{-1}, compared to 86 kg ha^{-1} in Latin America, 104 kg ha^{-1} in South Asia, 142 kg ha^{-1} in Southeast Asia (Crawford *et al.*, 2006), and 288 kg ha^{-1} in Europe and USA (Hernandez and Torero, 2011). According to Mutegi *et al.* (2015), one of the major challenges for effective nutrient management in SSA is the lack of site-specific fertilizer recommendations that are appropriate for the socioeconomic conditions of the farmers. Fertilizer recommendations in SSA are mostly generalized for all soil types and ecological conditions, irrespective of the huge diversities in the biophysical, ecological, and socioeconomic conditions. This blanket fertilizer recommendation approach has resulted in low fertilizer use efficiency, low factor productivity, and development of multi-nutrient deficiency in soils, ultimately leading to declining crop productivity and low farmer profitability.

Like many places in SSA, the agriculture sector in Ethiopia is dominated by smallholder farmers and characterized by low productivity partly due to declining soil fertility (Belachew and Abera, 2010; Scoones and Toulmin, 1999). Improving the productivity, profitability, and commercialization of agriculture has been the major agricultural policy concern in recent years (Belay *et al.*, 2003; Gebremedhin *et al.*, 2006). Fertilizer application is one of the yield-enhancing strategies and constitutes a central focus of the Ethiopian agricultural extension policy (Abebayehu *et al.*, 2014). The extension system uses a package approach that consists of improved seed, blanket recommendation for fertilizer application, and cultural agricultural practices (tillage, row planting, seeding rate, pest control, etc.). However, the use of both improved seed and fertilizer is still quite limited despite government efforts to encourage their adoption (Yu and Nin-Pratt, 2014). In fact, a study by the World Bank indicates that much of the increase in production over the past decade can be explained by area expansion rather than by widespread productivity growth (World Bank, 2011). Another study, conducted under controlled conditions, showed that adoption of the complete package by smallholder farmers [use of certified wheat seed, lower seeding rates, row planting, and balanced use of urea and di-ammonium phosphate (DAP)] increased wheat (*Triticum aestivum*) yields by approximately 14% (Abate *et al.*, 2018). Combined use of fertilizer and improved seeds for strategic crops such as maize and wheat resulted in 12% production growth between 2003/2004 and 2007/2008 (IFPRI, 2010). However, the reported yield gain is not enough to match increasing demand for food by the ever-growing population of Ethiopia. Moreover, additional cultivable lands in the highlands have become scarce. Therefore, Ethiopia has strong incentives to improve future agricultural outputs through increased use of fertilizers along with other yield-enhancing interventions.

Until recently, fertilizer selection was limited to N and P resulting in unbalanced nutrient supply and mining of the soils for other nutrients. The agricultural extension system has issued a national blanket recommendation of 100 kg DAP (18–46% N-P_2O_5) and 100 kg urea (46% N) per ha for most cereals, except for barley (100-50 kg DAP-urea ha^{-1}). According to a previous diagnostic study, the average actual fertilizer use in cereal crops is 45 kg ha^{-1} (IFPRI, 2010), while the average nutrient consumption is 26 kg ha^{-1} (FAO, 2017), far below the recommendation. Low and sub-optimal fertilizer application is further reflected in the low fertilizer use efficiency (kg grain yield per kg nutrient) which ranges between 9 and 17 kg grain of maize per kg N in Ethiopia, compared to Tanzania where it is 18–36 kg maize grain per kg N (IFPRI, 2010). This limited fertilizer effectiveness needs to be addressed by generating site-specific information (Kihara *et al.*, 2016). To this effect, the first step is to understand the determinants of fertilizer and its use intensity by major crops. Understanding the determinants of fertilizer use among smallholder farmers is crucially important to guide the extension system components and messaging. Therefore, this study was conducted to explore the socioeconomic and biophysical determinants of fertilizer use in the 30 high potential highland districts of Ethiopia. The study sets out to identify drivers and pathways to promote more rapid and extensive use of fertilizer.

Material and Methods

Theoretical model and empirical specifications

According to the von Neumann–Morgenstern utility function, farmers, as decision-makers, are assumed to maximize expected utility (EU) function defined over alternatives (W). In this case, when confronted with a choice between two alternative practices, the ith farmer compares the EU with the modern intervention (MI) to the EU with the traditional intervention (TI). While direct measurement of farmers' perceptions and risk attitudes on farming technology are not available, inferences can be made for variables that influence the distribution and EU evaluation of the technology. These variables are used as a vector 'X' of attributes of the choices made by farmer 'i' and ϵ_i is a random disturbance that arises from unobserved variation in preferences, attributes of the alternatives, and errors in optimization. Given the usual discrete choice analysis and limiting the amount of non-linearity in the likelihood function, EU_{mi} (W) and EU_{ti} (W) may be written as:

$$EU_{mi}\ (W) = \alpha_m X_i\ +\ \varepsilon_{mi} \ldots \tag{1}$$

$$EU_{ti}\ (W) = \alpha_t X_i\ +\ \varepsilon_{ti} \ldots \tag{2}$$

The difference in EU may then be written as:

$$\begin{aligned} EU_{mi}\ (W) - EU_{ti}\ (W) &= (\alpha_m X_i + \varepsilon_{mi}) - (\alpha_t X_i + \varepsilon_{ti}) = (\alpha_m - \alpha_t)\ X_i + (\varepsilon_{mi} - \varepsilon_{ti}) \\ &= \alpha X_i + \varepsilon_i \ldots \end{aligned} \tag{3}$$

A preference for the MI will result if $EU_{mi}\ (W) - EU_{ti}\ (W) > 0$, whereas a preference for the TI will be revealed if $EU_{mi}\ (W) - EU_{ti}\ (W)\ <\ 0$. The observed adoption choice of an agricultural technology (e.g., the use of fertilizers) is hypothesized to be the end result of socioeconomic characteristics of farmers and a complex set of inter-technology preference comparisons made by farmers (Adesina and Forson, 1995). The empirical analysis permits investigation of the decision whether or not to adopt fertilizers and the conditional level of the technology (amount of fertilizer to be used) if the initial adoption decision was made. Several hypotheses can be derived on these two sets of decision – factors that affect adoption and factors that affect intensity of fertilizers use.

Study area, sampling procedure, and data source

This study involved extensive surveys administered among smallholder farmers in Ethiopia to collect data on fertilizer use and decision-making processes. The study was conducted in 30 high potential districts of the Ethiopian highlands during the 2013/2014 cropping season covering the 4 main administrative regions. The main rainy season in Ethiopia usually starts in early June and extends up to September. Figure 1 presents the locations of the study districts, which are a subsample of the high potential agricultural districts identified by the National Agricultural Growth Program. Sample districts were selected using consecutive sampling techniques. A structured questionnaire was prepared and pretested in all study districts. Then, 2880 households were systematically selected from strata of model and non-model farmers[1] using a simple random procedure to compare farmers' typology linkage with optimal fertilizer application.

The questionnaire captured data on type of cereal cultivated, amount of fertilizer applied and optimal rate, land allocation in 2013 crop season, household demography and household resource endowment, access to institutional services and infrastructure, location, and agroecology. Five major cereals that account for the bulk of food production and fertilizer consumption in the Ethiopian highlands were considered. These include tef (*Eragrostis tef Zucc*), maize (*Zea mays*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), and sorghum (*Sorghum bicolor*). Actual fertilizer use against the recommended application rate (as defined by the extension system) was computed for each cereal crop and land allocation. Household characteristics included demography (sex, age and educational of household head, family size, dependency ratio, and education status) and household resource endowment (e.g., farm size, livestock ownership, annual gross income, etc.). Spatial variables included proximity to all-weather road, distance to market and farmer training centers, and agroecological zone, and institutional factors such as membership to cooperatives and contact with extension agents were also collected and analyzed. Survey

[1]Model farmers are defined as those who have adopted at least 70% of the technology package delivered by the agricultural extension system and are recognized by Development Agents (grass root extension workers) for their influence in the agricultural community.

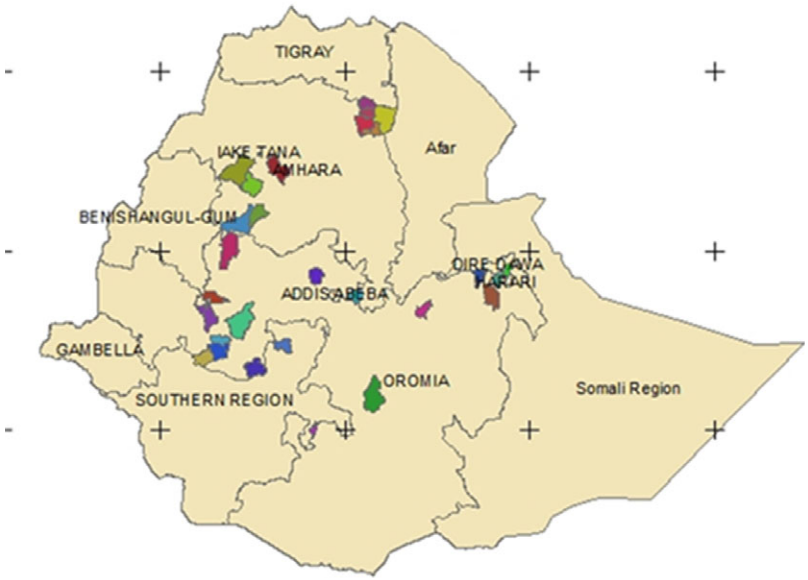

Figure 1. Location map of the 30 study districts in the Ethiopian highlands.

data were analyzed using regression and probit models to detect factors contributing to decisions on fertilizer use and rate of application.

Econometric specification: the double hurdle model

Double hurdle (DH) model, also known as two-tier model, is a corner solution model in which zero values associated with non-participation are assumed to be the outcome of rational choice (Wooldridge, 2002). It is an extension of the Tobit model, but relaxes the restriction imposed by the Tobit model by allowing different mechanisms to determine the discrete probability of participation and volume of fertilizer applied, conditional on participation. The DH model is more flexible and appropriate for this dataset and study than the Tobit model because it allows for consideration that household-related characteristics, location-specific factors, and access to institutional services may affect a farmer's decision to apply fertilizer. However, once the decision to apply has been made, different set of factors may affect the quantity applied. The DH model also allows the same factor to affect participation and amount applied in different ways. Therefore, the DH model proposed by Cragg (1971) was implemented in this study. This model has been widely applied to technology adoption and other utility maximization decisions (Adeyemo and Salman, 2016; Danso-Abbeam *et al.*, 2019; Holden and Quiggn, 2017). The Cragg's model assumes that farming household heads make two sequential decisions with regard to adoption and intensity of use of fertilizers. The first hurdle is the fertilizer adoption equation, estimated by using a probit model as described below:

$$d_i^* = X'_{1i}\beta_1 + \mu_i, \mu_i \sim N(0, 1)\ldots \tag{4}$$

$$d_i = \{1 \text{ if } d_i^* > 0 \text{ and is } 0 \text{ if } d_i^* \le 0\} \tag{5}$$

where d_i* is the latent discrete adoption choice variable that denotes binary censoring, X'_{1i} is vector of explanatory variables hypothesized to influence adoption choice, and β_i is vector of parameters. μ_i is the standard error term and is the observed quantity of fertilizer representing the respondent's participation decision (i.e., 1 = the respondent is reporting fertilizer intensity greater than 0 and 0 = otherwise).

The second hurdle involves an outcome equation, which uses a truncated model to determine the extent of fertilizer use. This stage uses observations only from farming household heads that reported positive, or greater than, optimum fertilizer use intensity. The truncated model, which closely resembles the Tobit model, was expressed as:

$$Y^{*}_{i} = X'_{2i}\beta_2 + v_i \, v_i \sim N(0, \delta^2)\ldots \tag{6}$$

Y_i is the observed fertilizer use intensity for the sample respondents. Y is the amount of fertilizer use intensity where individual sample households applied for crop production.

As shown by Katchova and Miranda (2004), the log-likelihood for the Tobit model consists of the probabilities for non-approval and a classical regression for the positive values of α:

$$InL = \sum\nolimits_{\alpha_i=0} In\phi\left(-\frac{x_i\beta'_\alpha}{\sigma}\right) + \sum_{\alpha_i > 0} In\left[\frac{1}{\sigma}\phi\left(\frac{\alpha_i - x_i\beta'_\alpha}{\sigma}\right)\right] \tag{7}$$

Cragg (1971) relaxed the assumption that the same covariates and the same parameter vector affect both the loan approval decision and the loan volume decision. Following Cragg, this study considers a hurdle model in which a lender makes a two-step decision. In the first step, a probit model represents a farm household's decision to apply fertilizer (C_i):

$$P(C_i = 0) = \varphi(-\Upsilon' Z_i) \tag{8}$$

If this hurdle is crossed and a fertilizer use intensity (volume) decision is made ($C_i = 1$), a truncated regression (equation 6) describes the choice of how much fertilizer to apply ($\alpha_i > 0$). The log-likelihood in Cragg's model is thus a sum of the log-likelihood of the probit model (the first two terms) and the log-likelihood of the truncated regression model (the second two terms) (Katchova and Miranda, 2004):

$$InL = \sum_{\alpha_i=0} In\phi(-\gamma' Z_i) \sum_{\alpha_i > 0} \left\{ In\phi(\gamma' Z_i) + In\left[\frac{1}{2}\phi\left(\frac{\alpha_i - \beta'_\alpha x_i}{\sigma}\right) - In\phi\left[\frac{\beta'_\alpha x_i}{\sigma}\right]\right]\right\} \tag{9}$$

Results

Descriptive statistics and definition of the variables used in econometric model

Table 1 summarizes the statistics of the dataset and shows significant differences between the regions, especially for distances to markets and roads and annual incomes. Table 2 summarizes the variables of the dataset and shows that 80% of surveyed households use fertilizer for cereal. The chi-square tests in Table 1 showed there was statistically significant variation among regions in, for instance, access to institutional services like extension, credit, and cooperative membership.

Fertilizer use

The majority of farmers (80%) in the study area used fertilizer in cereal crops (Table 2). There were significant ($p < 0.01$) regional differences, with the highest proportion of households applying fertilizer (96%) in Amhara, followed by Southern Nations, Nationalities, and Peoples' Region (SNNPR) (89%), Tigray (86%), and Oromia (69%), respectively. The average rate of DAP and urea applied was calculated with average for tef, maize, wheat, barley, and sorghum as 72, 102, 100, 72, and 46 kg ha^{-1}, respectively (Table 3). The application level of urea fertilizer for the same crops was 39 kg ha^{-1} for tef, 94 kg ha^{-1} for maize, 79 kg ha^{-1} for wheat, 34 kg ha^{-1} for barley, and 50 kg ha^{-1} for sorghum. Based on these findings, only maize and wheat crops received the average recommended amount of DAP fertilizer while none of the crops received recommended amount

Table 1. Mean descriptive statistics of continuous variables (%) per region

Variable	Whole sample ($n = 2880$)	Region: Tigray ($n = 480$)	Oromia ($n = 1440$)	SNNPR ($n = 480$)	Amhara ($n = 480$)	Kruskal–Wallis rank test
Amount of DAP and urea fertilizer used (kg ha^{-1})	38.22	39.06	28.69	27.03	77.17	674.2*
Age of a farmer (years)	43.19	43.83	41.52	46.94	43.81	78.6*
Active labor (family member aged between 15 and 64)	3.69	3.35	4.26	4.42	3.45	80.7*
Total family members (count)	6.61	5.90	6.80	7.26	6.16	90.3*
Close to nearest market (km)	4.62	7.65	4.10	3.81	4.02	161.8*
Distance from all-weather road (km)	1.796	2.54	1.51	1.49	2.24	85.3*
Average distance from home to farm (km)	1.472	1.47	0.38	0.15	0.24	639.8*
Total landholding size (ha)	1.44	1.08	1.48	1.32	1.78	216.5*
TLU	5.656	5.84	5.98	4.54	5.62	49.9*
Lagged annual income (Birr[a])	17978.1	17117.3	22331.3	9756.6	13745.2	251.6*
Number of parcels owned	3.843	3.56	3.74	2.41	5.87	641.2*

Note: Shapiro–Wilk and Shapiro–Francia tests for normality reject the null hypothesis at 0.05 for variables considered. [a]In 2013, the average conversion of USD to Ethiopian Birr was 1 USD = 18.627 ETB (Source: www.ceicdata.com/World Bank).
*Significant ($p < 0.001$).

Table 2. Descriptive statistics of variables (%)

Variable	Whole dataset (n = 2880)	Region: Tigray (n = 480)	Oromia (n = 1440)	SNNPR (n = 480)	Amhara (n = 480)	Chi-square test
Use of DAP and urea fertilizers (% to yes)	80	86	69	89	96	219.7*
Farmer type (% to model farmers)	66	66	66	67	67	0.13 ns
Education level (% to literate)	72	63	75	74	71	22.2*
Sex of respondents (% to male)	85	74	84	93	91	86.7*
Contact with extension agents (% to yes)	56	47	37	42	66	117.5*
Accredit access	52	85	28	57	86	748.8*
Cooperative membership (% to yes)	67	54	68	57	90	180.7*
Crop rotation (% to yes)	43	12	47	4	100	1100*
Use of conservation measure (% to yes)	53	40	55	20	93	548.1*
Lowland agroecology (% to yes)	23	40	13	0	0	443.1*
Midland agroecology (% to yes)	55	20	53	50	100	636.7*
Highland agroecology (% to yes)	32	40	33	50	0	314.3*

ns, not significant.
*Significant ($p < 0.001$)

of urea. According to Kefyalew (2011), the average application rate of DAP and urea combined per hectare of cultivated land was 57 kg ha^{-1} for wheat, 40 kg ha^{-1} for tef, 29 kg ha^{-1} for maize, and 22 kg ha^{-1} for barley.

Table 3. DAP and urea fertilizer applications by crop and combined for major cereals (kg ha^{-1}) per region

Fertilizer	Crop	RFR[a]	Region				Total	Kruskal–Wallis rank test
			Tigray	Oromia	Amhara	SNNPR		
DAP	Tef	100	49±49	57±65	117±52	85±28	72±64	443.4*
	Maize	100	76±45	71±89	202±101	70±31	102±98	819.9*
	Wheat	100	95±46	87±70	171±75	85±26	100±67	110.4*
	Barley	100	71±48	39±53	101±59	75±32	72±53	449.0*
	Sorghum	100	21±41	59±99	–	–	46±86	
	Cereal[b]		41±28	32±31	97±43	33±16	45±39	777.2*
Urea	Tef	100	40±45	39±57	29±42	69±31	39±51	19.1*
	Maize	200	75±44	73±91	173±94	60±35	94±92	690.4*
	Wheat	125	90±38	70±65	93±77	77±32	79±59	172.3*
	Barley	50	65±49	4±18	23±38	139±21	34±41	545.0*
	Sorghum	100	23±42	63±115	–	–	50±100	
	Cereal[b]		38±27	26±29	57±32	25±15	33±30	428.0*

[a]RFR is the recommended fertilizer rate promoted by the agricultural extension system (kg ha^{-1}).
[b]The cereal crops considered in this study are tef, maize, wheat, barley, and sorghum only.
*Significant ($p < 0.001$).

Table 4. Difference from recommended fertilizer rate per crop and per region (%)

Fertilizer type	RFR	Crop	Region				Total (%)	*F*-test
			Tigray	Oromia	Amhara	SNNPR		
DAP	100	Tef	25	78	89	83	72	117.2*
	100	Maize	78	62	88	70	51	64.6*
	100	Wheat	95	99	97	83	95	4.32*
	100	Barley	74	57	84	75	72	22.0*
	100	Sorghum	20	39	–	–	32	27.9*
	100	Tef	24	54	50	68	50	38.1*
Urea	200	Maize	50	48	75	31	52	122.7*
	125	Wheat	90	61	74	63	70	39.9*
	50	Barley	42	36	86	78	66	46.4*
	100	Sorghum	19	43	–	–	35	37.9*

Note: The use intensity percentage is computed based on the RFR for the respective crops and represented farmers who use optimal rate.
*Indicates significant difference ($p < 0.001$).

Fertilizer use for cereal crops

DAP was more extensively used than urea for all cereal crops, except for sorghum (see Table 4). The percentage of farmers who used optimal fertilizers rate is presented in Table 5. For tef, farmers applied 72% of the recommended rate of DAP but only 50% of the recommended urea. For maize, the highest level of DAP application in relation to the recommended was in Amhara region, followed by Tigray. Farmers growing wheat applied 95% of the recommended rate of DAP. Despite the low intensity of urea fertilizer applied compared to DAP for all crops, wheat received the highest rate while sorghum the lowest for both DAP and urea. The one-way analysis of variance showed that the fertilizer use intensity varied significantly across regions for all crops.

Estimation results

The maximum likelihood estimates of the independent DH model for fertilizer use intensity, the likelihood ratio, and the information criteria attest to the reliability of the model by region as shown in Table 5. The results show that factors influencing the two-stage decision relating to adoption and fertilizer use intensity can well be expressed using the independent DH model. Coefficients in the first hurdle indicate how a given decision variable affects the likelihood

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Table 5. Maximum likelihood estimates of double hurdle models for adoption and optimum fertilizer use intensity in selected regions of Ethiopia

	Whole sample		
Variables	1st hurdle (probit)	Marginal effect in probit model	2nd hurdle (truncated model)
fartype	0.017	0.004	−0.527
eduhhh	0.054**	0.012	−1.286**
hhhexpf	0.002	0.000	−0.105
famsize	−0.039**	−0.009	−1.996***
extencd	0.245***	0.056	−0.797
accredit	0.243***	0.056	11.64***
membcoop	0.150**	0.034	10.23***
distnrmktd	0.016	0.004	2.148
disallwr	−0.024*	−0.006	−0.561
avdisfarm	−0.070***	−0.016	0.001
totlandszha	0.144***	0.033	−0.662
croprot	0.205***	0.047	17.25***
TLU	0.002	0.003	0.278
Annual_inc	0.000***	0.0001	0.000***
conserv	0.199***	0.046	10.24***
numplot	−0.040**	−0.009	3.184***
kgroeco	0.148***	0.034	2.729**
Chi-square	49.76***		23.99***
LL	−1824.1		−1942.7
BIC	3888.8		4101.6
AIC	3726.3		3957.4

Fartype, farm type; Eduhhh, education level household head; hhhexpf, household expenditures on farm inputs; farmsize, farm size; extencd, access to extension services; accredit, access to credit; membcoop, membership to primary cooperative; distnrmktd, distance to nearest market; disallwr, distance to all-weather road; avdisfar, average distance between plots to the farm; totlanszha, total land size; croprot, crop rotation; TL, tropical livestock units; annual inc, annual income; conserve, application of conservation methods; numplot, number of plots, agroeco, agroecological zone.

*** significant at 1%, ** significant at 5%, * significant at 10%.

(probability) to adopt fertilizer. Those in the second hurdle indicate how decision variables influence the level of fertilizer usage. The result of the first hurdle (probit model) indicates that education status of the household head, family size, active labor force, access to extension service, access to credit, membership to cooperatives, distance to all-weather road, average distance to farm plots, farm size, use of crop rotation, number of farm plots owned, annual gross income, and agroecology[2] are all significant decision variables influencing the probability of adopting fertilizer technology. The marginal effects of the probit model show changes in the probability of fertilizer adoption to increase with, predominantly, increasing access to credit, cooperative membership, farm size, application of soil and water conservation, and medium and highland agroecology. On the other hand, probability of fertilizer adoption decreased, predominantly, with increasing distances to fields, roads, and markets. The fertilizer use intensity among the farm households was influenced by education status of household head, family size, access to credit, membership to cooperatives, use of crop rotation, annual income, number of farm plots owned, use of soil and water conservation, and agroecology. Differences between regions were mainly found in crop rotation and Tropical Livestock Units (TLUs) (Table 5).

[2]The traditional agroecological zonation more precisely as being 'Kolla' at altitudes below 1800 m a.s.l. 'Weyna Dega' for altitudes between 1800 and 2400 m, and 'Dega' for areas above 2400 m was used in this study following Dove (1890) as cited in Huri (1998).

Discussion

According to Ariga *et al.* (2008), fertilizer use intensity in Ethiopia is on average 17 kg ha^{-1}, which is comparable to application rates elsewhere SSA but low when compared to the smallholder highland farms in Kenya and the rest of the world. Several authors reported that this low fertilizer use is due to market and non-market-based constraints, for example, high cost of fertilizers and lack of varieties (Agbahey *et al.*, 2015; Dercon and Christiaensen, 2011; EEA, 2006; Matsumoto and Yamano, 2009). This study shows higher rates of fertilizer application for major crops (Table 4) and this can be explained by increasing supply and availability of fertilizers, as well as improvements in extension support over the last few years. Moreover, the present study targeted high agricultural potential areas, which may create a bias when compared to the national average.

This study showed that access to credit, cooperative membership, farm size, the application of soil and water conservation practices, and agroecological zones were main factors determining the fertilizer adoption and intensity of use (Table 5). Our results are in line with those of Gebremedhin *et al.* (2009).

Farmers living in a lowland agroecological zones applied significantly lower levels of fertilizer when compared to farmers in the midland and highland agroecological zones (Table 5). This difference is associated with drought risks in the lowlands. In agreement with Kassie *et al.* (2011) and Pender and Gebremedhin (2007), this study found that fertilizers provide a higher crop return per hectare in wetter areas than in the drought prone areas suggesting that agroecology influences the level of fertilizer application. The negative and significant influence of agroecology at less than 1% significance level was also reported by another study in southern Ethiopia (Endrias *et al.*, 2013). Model farmers are more likely to use fertilizer compared to non-model farmers although not statistically significant (Table 5).

Access to credit and cooperative memberships were the two institutional factors that were found to positively and significantly influencing the level of fertilizer use. A change in farmers' status from not accessing credit to accessing credit, and from non-membership to membership of cooperatives significantly enhanced fertilizer use intensity. Endale (2010) also reported the positive and significant influence of credit on fertilizer adoption. The major reason for the positive influence of access to finance is the agricultural production gap between land preparation and gathering of the final output. Small farmers have difficulties in financing the lag between application of fertilizer and the generation of return, and access to credit fills this gap and boosts the adoption of fertilizer and other agricultural inputs.

Two explanatory variables related to resource endowment turn out to influence fertilizer application on cereal crops. These are tropical livestock units and gross annual income. A unit increase in tropical livestock unit can increase fertilizer application by 0.32 kg. Similarly, gross annual income positively and significantly influences fertilizer application on cereal at 1% level of significance (Table 5). Livestock affects fertilizer adoption in many ways. The direct effect is that farmers can sell their livestock to finance fertilizer or that livestock can serve as collateral for fertilizer credit. These results agree with Endale (2010), who reported the significant and positive influence of livestock ownership on levels of fertilizer application. Plots located far from homestead were found to receive less fertilizer and as landholding size increased, fertilizer application declined (Table 5). Similar result was reported by another study done in the Tigray region (Gebreselassie and Sanders, 2006). Apparently, farm size can both indicate extensive (low fertilizer) systems in dry land areas as to well-endowed farms in high potential areas.

Conclusion

The study showed that farmers' decision to adopt fertilizer and the decision on the intensity of use of fertilizer are two independent decisions. In spite of some region-specific differences, the most important factors are household resource endowments (livestock ownership, farm size, etc.), institutional services (credit and membership to cooperatives), infrastructure (proximity to markets and roads), and communities' indigenous knowledge (crop rotation, use of soil and water conservation). Policies to increase fertilizer uptake could, for instance, include strengthening cooperatives, access to credits, and infrastructure development. This study highlights that, to increase fertilizer uptake, a concerted effort is needed which goes beyond the traditional supply push strategy.

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