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Cropping systems diversification, improved seed, manure and inorganic fertilizer adoption by maize producers of eastern Ethiopia

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Abstract

The gap between demand for and supply of food in Ethiopia can be reduced by improving farm productivity through the introduction of productivity-enhancing technologies. Conversely, in Ethiopia, the adoption rates of agricultural technologies remain below the expected levels. Hence, by using multivariate probit model, this study identifies factors that motivate the adoption of a combination of inorganic fertilizer, improved seed, manure and cropping system diversification in eastern Ethiopia using multiple plot-level observations. The analysis shows that the probabilities of adoption of agricultural technologies are influenced by household, socioeconomic, institutional and plot-level characteristics. Alongside this, the paper also shows that there is a significant correlation between the selected technologies, suggesting that adoptions of technologies are interrelated. Specifically, the result indicates that there is complementarity between inorganic fertilizer and improved seed; and substitutability between inorganic fertilizer and manure. The result also indicates there is complementarity between adoption of improved seed and manure; and adoption of improved seed and crop diversification.

Keywords: Adoption, Multiple technologies, MVP, Maize, Ethiopia

JEL Classification: Q01, Q12, Q16, Q18

1 Background

From development history of the world, one can recognize the role of sustained agricultural growth in the early stages of development (Hazell et al. 2007; Abate et al. 2016). This has been experienced in Europe (Lains and Pinella 2010), North America (Timmer 2014) and Asia (Rashid et al. 2007). Nevertheless, the agricultural sector's growth in Africa has dawdled behind population growth even in 2001–2010, which was a period globally believed to be a 'decade of growth' (Diao et al. 2012). It is undeniable fact that agricultural production has increased over the years in Africa. However, much of the yield growth comes from the expansion of cultivated land and productivity has not been increased as much as the size of cultivated land (Shiferaw et al. 2011). Besides,

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the continent has significant yield gaps in major cereals (Abate et al. 2016). Within the continent, the agricultural sector of most of the countries located in Sub-Saharan Africa (SSA) has not been able to ensure food security both at national and household level (Bezu et al. 2014). Soil fertility depletion and slow rates of innovation and adoption of productivity-enhancing technologies are considered as the main limiting factors for increasing farm productivity in SSA (Asfaw et al. 2012; Kassie et al. 2013; Pamuk et al. 2014).

Empirical studies pointed out that adoption of agricultural technologies can help to reduce poverty through its direct and indirect effects. The direct effects of agricultural technologies include productivity improvements and lower average production costs, which can improve the livelihood of rural households by increasing their income. The role of agricultural technologies in reducing poverty and food insecurity, improving wellbeing and increasing farm income has been widely researched by (Khonje et al. 2015; Shiferaw et al. 2014; Zeng et al. 2015; Asfaw et al. 2012; Kassie et al. 2011; Becerril and Abdulai; 2010; Alene et al. 2009; Minten and Barrett 2008). For instance, in 2010 alone, 1.6–2.7% of the rural poor escaped poverty in Ethiopia due to the diffusion of improved maize (Zeng et al. 2015).

The significance of agricultural technologies in increasing farm productivity is also discussed by (Conley and Udry 2001; Fang and Richards 2016). In line with this, Dercon et al. (2009) indicated that farmers can increase maize production by 60% via adopting improved seeds in combination with best practices on a quarter of the current crop area in Ethiopia. Zeng et al. (2015) also estimated the yield advantage of improved maize that is 48–63% over local maize types.

There are also indirect benefits associated with agricultural technologies. As argued by Minten and Barrett (2008), agricultural technologies have the potential to enhance food security for all sections of the poor including nonfarm households. It also improves nutrition security of net food buyers due to fall in real food prices as supply outpaced demand due to productivity improvement (Evenson and Gollin 2003; Karanja et al. 2003). Improvement in productivity due to agricultural technologies may also increase the demand for labor, which increases earnings for landless laborers (Kassie et al. 2011; Bezu et al. 2014). Agricultural technologies could also stimulate overall economic growth through inter-sectoral linkages (Sanchez et al. 2009). Hence, as argued by Streeten (1987), agricultural technologies can benefit both producers and non-producers of developing countries.

Despite all those benefits, Africa has lagged behind other developing regions in terms of each indicator of technology adoption (O'Gorman 2015). Particularly, the adoption of agricultural technologies in SSA remains very low (Duflo et al. 2011; Jayne and Rashid 2013). Likewise, in Ethiopia, the adoption of productivity-enhancing technologies is low (Feleke and Zegeye 2006; Jaleta et al. 2015). Hence, it is worthwhile to search for factors that are impeding farmers from adopting these technologies, which can improve their farm productivity and their wellbeing in general.

Agricultural technology adoption is a well-documented area of study in Ethiopia. However, the vast majorities of the studies (including Gebremedhin and Swinton 2003; Feleke and Zegeye 2006; Abebe et al. 2013; Tesfaye et al. 2014) have focused on technologies in isolation though farmers adopt multiple technologies as complements, substitutes, or supplements to tackle their multiple problems, such as weeds, pest and disease infestations, and low farm productivity (Khanna 2001; Moyo and Veeman 2004; Kassie et al. 2013). For instance, Ethiopian farmers face a wide set of problems including low farm productivity (Haji 2007; Ahmed et al. 2002), top soil erosion (Gessesse et al. 2015), soil acidity (Abdenna et al. 2007) and salinity (Tolessa and Beshir 2009). Given those sets of constraints, focusing on technologies separately does not work and it requires approaches, which can achieve food security and reduce poverty while simultaneously mitigating degradation of essential ecosystem services.

The purpose of this study is, therefore, to analyze factors that jointly facilitate and/or impede the probability of adoption of productivity-enhancing technologies by smallholder maize producing farmers of eastern Ethiopia by selecting improved seed, crop diversification, manure, and inorganic fertilizers. Alongside this, the study will also examine the relationship between the selected technologies.

2 Profile of maize in Ethiopia

Developing countries account for two-thirds of the global maize production (M'mboyi et al. 2010). Out of this figure, SSA covers 15.7% of maize produced globally (Pingali 2001) and it is a staple food for half of the population in the region and constitutes a significant part of their daily diet (Kassie et al. 2014; Abate et al. 2015). From counties in the region, Ethiopia is the third largest producer of maize, following South Africa and Nigeria (FAOSTAT 2015).

Maize arrived in Ethiopia in the late seventeenth century (Huffnagel 1961). Compared to other cereals, though it is a late comer to the country, currently it accounts for the largest share of production by volume and is produced by more farmers than any other crop (Chamberlin and Schmidt 2012). In the 2015/16 production season, 2.11 Million hectares of land was covered by maize in the country from which 71.51 Million qt of output were produced by 9.55 Million holders (CSA 2016). The productivity of maize has reached to 34.29 qt/ha in 2014/15 production season by achieving a tremendous growth compared with a 21.87 qt/ha in 2005/06 production season (CSA 2015a).

Concerning inputs utilizations, maize has the largest area covered with improved seeds compared with other cereals. The improved maize seed utilization grew from five percent of total area under maize cultivation in 1997 to 46.38% in 2015 (Byerlee et al. 2007; CSA 2015b). In 2015, about 75% of the maize farmers used fertilizer, compared to the national average of 57.06% for all cereal farmers. About 46% of the maize plots were covered by improved seed, which is three times more than the national average for all cereals. The size of land allocated for maize production is also expanding in the country. Data from FAOSTAT confirms that between 1993 and 2014; maize production has expanded almost by fivefold; and the area under maize increased by 2.5-fold in the same period (FAOSTAT 2015).

Maize is also an important food security crop, and it is a cheaper source of calorie and protein in the country (Rashid and Negassa 2011). In 2013, the dietary calorie and protein contribution of maize had reached 398 kcal/day and 9.2 g/day, respectively (FAO 2013). Per capital calorie consumption of maize in rural areas is over four times that of urban areas (Demeke et al. 2012).

3 Methodology

3.1 Description of the study area

This study is undertaken in the eastern part of Ethiopia specifically in the East Hararge zone of Oromia regional state. The zone is geographically located between 7°32′–9°44′ North latitude and 41°10′–43°16′ East longitudes with the total area of 24,247.66 km^2. The zone is classified into three major climatic categories namely: temperate tropical highlands, semi-temperate and semi-arid constituting 11.4, 26.4 and 62.2% of the administrative zone. This wide range of agro-climatic zone allowed the area to produce different types of products including cereals, pulses, oilseed, vegetables, fruits and cash crops such as coffee and *chat or Khat (Catha edulis)*. From East Hararghe zone, two districts namely *Haramaya* and *Girawa* were selected for this study based on their extent of maize production.

3.2 Sample size and sampling techniques

For this study, a multi-stage sampling technique was implemented. In the first stage, *Haramaya* and *Girawa* districts were purposively selected on the basis of their extent of maize production. Next, four rural *kebeles*[1] were randomly picked from each district. Finally, 355 households were selected, proportional to the size of maize producing farmers using simple random sampling technique with replacement.[2] Data were collected on plot level—leading to 480 observations, the number of plots cultivated with maize in the 2014/15 production period.

3.3 Sources of data and methods of data collection

Both primary and secondary data were collected for this study. The primary data were collected using structured questionnaires that were administered by trained enumerators from February to March 2016.[3] The survey mainly focused on household characteristics, types of technologies adopted, asset holding, production and consumption of crops, income sources, access to infrastructure and institutions etc. Plot-level characteristics such as fertility status, slope, distance from the homestead, tenure structure etc. were also included. Although this study principally employed a primary data, secondary data were also collected from relevant sources such as the bureau of agriculture of the districts to verify the cross-sectional data.

3.4 Methods of data analysis

Numerous empirical studies related to agricultural technology adoption (e.g. Khanna 2001; Moyo and Veeman 2004; Kassie et al. 2013; Rodríguez-Entrena and Arriaza 2013; Kassie et al. 2015; Wainaina et al. 2016) indicated that agricultural technologies are interdependent and adoption of a particular technology may influence the likelihood of adoption of another technology. Therefore, this study adopted multivariate probit (MVP) model as it simultaneously models the influence of the set of explanatory variables on each of the dependent variables, while allowing the unobserved characteristics

[1] *Kebele* is the smallest administrative hierarchy in Ethiopia.

[2] Every *kebele* administration has a full list of households living in the area. We used this list as a sample frame. When the randomly selected farmer does not produce maize s/he will be replaced by farmer next to him/her in the list.

[3] The first and the third authors were directly involved in the data collection process.

to be freely correlated (Belderbos et al. 2004). Relying on univariate modeling for such analysis leaves out useful information regarding the interdependency of technologies (Dorfman 1996; Kassie et al. 2010) and failure to capture this interdependence may lead to bias and inefficient coefficient estimates (Wu and Babcock 1998).

The observed outcome of farmers' adoption decision can be modeled using random utility formulation. Consider the jth household is facing a decision on whether or not to adopt the available technologies on plot p ($p = 1, \ldots, p$). The farmer chooses to adopt the Kth technology if $Y^*_{jpK} = U^*_K - U_i > 0$ where U_i denotes the benefit to the farmer from the traditional production system and U_K represents the benefit from adopting the Kth technology. The net benefit Y^*_{jpK} that the farmer gains from Kth technology is a latent variable determined by observed and unobserved characteristics given in Eq. 1:

$$Y^*_{jpK} = X_{jp}\beta_K + \overline{X}_j\alpha_K + \varepsilon_{jp} \quad (K = F, V, M, R) \tag{1}$$

where X_{jp} represents observed plot invariant characteristics; ($\bar{X}_j$) represents the mean value of plot varying covariates; (ε_{jp}) represents a multivariate normally distributed stochastic terms; K denotes the type of technology available [representing choice of inorganic fertilizer (F), improved seed (V), manure (M) and crop diversification (R)] and β_K denotes the vector of parameter to be estimated.

The unobserved preferences in Eq. (1) translate into the observed binary outcome equation for each choice as follow:

$$Y_K = \begin{cases} 1 & \text{if } Y^*_{jpk} > 0 \\ 0 & \text{otherwise} \end{cases} \quad (K = F, V, M, R) \tag{2}$$

In the MVP model, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity where $(u_F, u_V, u_M, u_R) \sim \text{MVN}(0, \Omega)$ and the symmetric covariance matrix Ω is given by:

$$\Omega = \begin{pmatrix} 1 & \rho_{FV} & \rho_{FM} & \rho_{FR} \\ \rho_{VF} & 1 & \rho_{VM} & \rho_{VR} \\ \rho_{MF} & \rho_{MV} & 1 & \rho_{MR} \\ \rho_{RF} & \rho_{RV} & \rho_{RM} & 1 \end{pmatrix} \tag{3}$$

where (ρ_{ij}) denotes the pair wise correlation coefficient of the error terms corresponding to any two adoption equations to be estimated in the model and the off-diagonal elements in the covariance matrix represent the unobserved correlation between the stochastic components of the different types of technologies.

Following the works of Teklewold et al. (2013) and Koppmair et al. (2016), we implemented the Mundlak's (1978) approach to control the influence of non-observable household characteristics on adoption decisions.

The regression coefficients of the MVP regression model cannot be interpreted like traditional regression coefficients. Therefore, we have computed the marginal effects of each variable that give the magnitude of the marginal effects of change in the explanatory variables on the expected value of the dependent based on Greene (2002).

4 Results and discussion

Before embarking into the empirical results of the econometrics model, it is praiseworthy to provide the characteristics of both the dependent and independent variables used in the estimation process.

4.1 List and definition of variables

4.1.1 Dependent variables

The dependent variables used in our MVP model are the adoption of improved maize seed, manure, inorganic fertilize and crop diversification. Following Byerlee et al. (1994), both hybrids and open pollinated varieties whose traits have been enhanced for selected characteristics including drought tolerance, disease resistance, early maturing, increased productivity and quality protein are considered for this study as improved seeds. In Ethiopia, more than 40 improved varieties of maize have been developed and released over the last four decades (Zeng et al. 2015). Despite this fact, adoption of improves maize verities by smallholder farmers is very low (Jaleta et al. 2015). Out of the total 480 plots considered for this study, 51.46% of them were covered by improved seeds.

Organic fertilizer, a biological nitrogen fixation process through application of manure and crop residuals, is probably the cheapest and most effective means for maintaining sustainable yields in African (Dakora and Keya 1997). However, application of organic fertilizer as a single technology is less effective as the quantities produced at farm level are more often inadequate to meet the nutritional requirements of various crops (Makokha et al. 2001). This calls for the use of a combination of both organic and inorganic fertilizers since it has the potential to resolve this practical limitation of input availability (Gentile et al. 2009). About 38% of maize plots considered for this study adopted manure.

Since poor soil fertility due to lack of plant nutrients is one of the major causes of low farm productivity and food insecurity in Africa (Sanchez 2002), providing those nutrients via inorganic fertilizer is essential to improve soil productivity in the region. However, the continent accounts for less than one percent of global fertilizer consumption (Denning et al. 2009). Though Ethiopia is the biggest chemical fertilizer importer in SSA, fertilizer use per unit of land is still low and only one-fourth of the recommended rate is applied (Minten et al. 2013). Inorganic fertilizer was adopted by 58.75% of maize plots considered for this study.

Cropping system diversification can help farmers increase crop productivity through Nitrogen fixation since legumes such as cowpea and soybean can produce a lot of biomass (Mpepereki et al. 2000). As observed by Sanginga et al. (2004), crop diversification could double the yield of maize compared to those of maize grown after the new varieties. Crop diversification was practiced on 39.38% of the plots during the cropping season used for this analysis.

Table 1 presents the conditional and unconditional probabilities of the four technologies selected for this study. The unconditional probability of a plot with inorganic fertilizer is 59%. However, it increases to 79% conditional on adoption of improved seed and it decreases to 47% conditional on the adoption of manure. This gives a hint for the existence of complementarity between inorganic fertilizer and improved seed, and the presence of substitutability between inorganic fertilizer and manure application.

Table 1 Unconditional and conditional adoption probabilities

	Improved seed	Inorganic fertilizer	Crop diversification	Manure
$P(Y_K = 1)$	0.52	0.59	0.39	0.38
$P(Y_K = 1 \vert Y_R = 1)$	0.57	0.59	1.00	0.43
$P(Y_K = 1 \vert Y_V = 1)$	1.00	0.79	0.43	0.26
$P(Y_K = 1 \vert Y_F = 1)$	0.69	1.00	0.39	0.30
$P(Y_K = 1 \vert Y_M = 1)$	0.36	0.47	0.45	1.00
$P(Y_K = 1 \vert Y_R = 1, Y_V = 1)$	1.00	0.29	1.00	0.19
$P(Y_K = 1 \vert Y_R = 1, Y_F = 1)$	0.33	1.00	1.00	0.23
$P(Y_K = 1 \vert Y_R = 1, Y_M = 1)$	0.14	0.15	1.00	1.00
$P(Y_K = 1 \vert Y_V = 1, Y_F = 1)$	1.00	1.00	0.43	0.29
$P(Y_K = 1 \vert Y_V = 1, Y_M = 1)$	1.00	0.19	0.19	1.00
$P(Y_K = 1 \vert Y_F = 1, Y_M = 1)$	0.22	1.00	0.22	1.00
$P(Y_K = 1 \vert Y_R = 1, Y_V = 1, Y_F = 1)$	1.00	1.00	1.00	0.15
$P(Y_K = 1 \vert Y_R = 1, Y_V = 1, Y_M = 1)$	1.00	0.10	1.00	1.00
$P(Y_K = 1 \vert Y_R = 1, Y_F = 1, Y_M = 1)$	0.11	1.00	1.00	1.00
$P(Y_K = 1 \vert Y_V = 1, Y_F = 1, Y_M = 1)$	1.00	1.00	0.15	1.00

Y_K is a binary variable representing the adoption status with respect to practice K ($K =$ improved seed (V), inorganic fertilizer (F), crop diversification (R), manure (M))

Similarly, the unconditional probability of a plot with improved seed is 52% and this figure increases to 69% conditional on adoption of inorganic fertilizer and the likelihood of improved seed use is reduced to 12% when households applied manure to a plot, suggesting substitutability between the technologies.

4.1.2 Independent variables

We have included a range of household, socioeconomic, institutional and plot characteristics as independent variables in the MVP model based on empirical works (including Abate et al. 2016; Alene et al. 2009; Asfaw et al. 2012; Bezu et al. 2014; Jaleta et al. 2015; Kassie et al. 2013, 2014, 2015; Shiferaw et al. 2014; Teklewold et al. 2013 and Wainaina et al. 2016). The description and summary statistics of the variables is given in Table 2.

Among the household level variables, 87.5% of the households were male headed. The sample household heads were aging between 18 and 70 with the mean value of 38.67 and they cultivated maize for about 17 years. Around 64% of the respondents were at least capable of reading and writing. However, only the quarter of the spouses of the household heads were literate. We have also incorporated important socio-demographic characteristics, such as family size, asset holding and source of income. Accordingly, the mean family size of the respondents expressed in adult equivalent was 5.42. On average the respondents have 2.82 *quxi*[4] of land and 3.09 units of livestock measured in tropical livestock units. Nearly quarter of the respondents were also participating in off/nonfarm activities.

Concerning the institutional variables, about 23% of the respondents were the member of agricultural cooperatives and 58.5% of them obtained training specific to maize production. On average each respondent travels 36.18 and 20.07 min to reach the closest market and farmers training centers (FTC), respectively. Respondents also indicated that on average, they are receiving extension services about 51 days in a year. Fifty percent of

[4] One quxi is equivalent with 1/8 ha.

Table 2 Summary statistics of the variables used in the analysis. *Source*: Own estimation result (2016)

Variable	Mean	SD	Min	Max
Age of the household head (HH)	38.67	9.52	18	70
Sex of HH (1 = if HH is male)	0.88	0.33	0	1
Literacy of HH (1 = if HH is literate)	0.64	0.48	0	1
Literacy of spouse (1 = if the spouse is literate)	0.26	0.44	0	1
Family size in adult equivalent	5.42	1.82	1	10.55
Maize production experience	16.71	9.64	1	55
Size of land owned	2.82	2.02	0.25	25
Size of livestock in TLU	3.09	1.87	0	9.49
Cooperative membership	0.23	0.42	0	1
Frequency of extension contact	50.71	40.30	0	244
Training regarding maize production	0.59	0.49	0	1
Access to market information	0.50	0.50	0	1
Credit constraint (1 = if the farmer is facing)	0.40	0.49	0	1
Participation in off/nonfarm activities	0.25	0.43	0	1
Distance to the nearest market	36.18	21.53	5	120
Distance to FTC	20.07	11.88	1	60
Distance from plot to home	14.32	13.33	0.5	90
Plot ownership (1 = if owned by HH)	0.93	0.26	0	1
The plot is good in fertility[a]	0.34	0.47	0	1
The plot is Medium in fertility	0.50	0.50	0	1
The plot is poor in fertility	0.17	0.38	0	1
The plot is steeper in slope[b]	0.11	0.31	0	1
The plot is medium in slope	0.57	0.50	0	1
The plot is flatter in slope	0.32	0.47	0	1
The plot is in *Kola* ecology[c]	0.05	0.22	0	1
The plot is in *Weynadega* ecology	0.57	0.50	0	1
The plot is in *dega* ecology	0.38	0.49	0	1

[a] The farmer ranked each plot as "poor", "medium" or "good"

[b] The farmer ranked each plot as "steeper", "medium slope" or "flatter"

[c] *Dega* ecological zone lies between 2300 and 3200 m altitude, 900–1200 mm/year of rainfall and average annual temperature of 11.5 °C. *Weynadega* lies in the altitude of 1500–2300/2400 m, rainfall of 800–1200 mm/year and average annual temperature of 20.0–17.5/16.0 °C, Kola's altitude is from 500 to 1500/1800 m with rainfall of 200–800 mm/year and annual temperature of 27.5–20 °C (MoA 2000)

the respondents revealed that they have access to market information and about 40% of the respondents indicated that they are facing credit constraints (those who need credit but are unable to find it).

We also included several plot-specific attributes, including soil fertility, ownership, slope and distance of the plot from the farmer's home. Accordingly, 92.9% of plots were owned and operated by the sample respondents and about 33% plots are good in their fertility based on the perception of the farmers.

4.2 Empirical result

4.2.1 Relationship between the adopted technologies

The MVP model is estimated using the maximum likelihood method on plot-level observations. Our MVP model fits the data reasonably well [Wald $\chi^2(100) = 531.17$, $p = 0.000$)]. Accordingly, the hypothesis that all regression coefficients in each equation are jointly equal to zero is rejected. Likewise, the likelihood ratio test of the null hypothesis that the covariance of the error terms across equations are not correlated is also rejected [$\chi^2(6) = 77.1778, p = 0.000$] confirming the presence of interdependency among technologies. Out of six possible pairs of the error terms of the adoption equations, four of them are statistically significant, where three of them are inversely related and the remaining one has a positive sign. Among the significant correlation, the correlation between improved seed and inorganic fertilizer is the highest (54.6%) (Table 3). A different but related approach is to estimate a probit model for the adoption of each technology, where adoption dummies for all the other technologies are used as right-hand-side variables. The result is presented in Table 5.

The positive sign indicates complementarity and the negative sign shows substitutability between technologies. Hence, the result indicates that there is complementarity between inorganic fertilizer and improved seed and substitutability between inorganic fertilizer and manure. The result is in line with the finding of Teklewold et al. (2013). Kassie et al. (2015) also found the same result in Ethiopia and Malawi. However, it contradicts the finding of Marenya and Barrett (2007). The result also indicates there is complementarity between adoption of improved seed and manure; and adoption of improved seed and crop diversification. Information regarding the relationship between technologies has important policy implications as policy changes which affect adoption of one technology can affect adoption of another technology positively or inversely.

4.2.2 Factors affecting the adoption of technologies

Though farmers adopt a combination of technologies as complements and substitutes, our MVP model indicated that there are also important factors that could affect their decision to choose a particular technology. As it is presented in Table 4, the coefficients of the independent variables vary noticeably across the technologies, representing the appropriateness of differentiating between the technologies. We have also statistically tested this by estimating a constrained specification by which all slope coefficients are forced to be equal. Accordingly, the likelihood ratio test rejected the null hypothesis, which states equal slope coefficient for all technologies. For sake of completeness, we have also presented the result of MVP model without Mundlak's approach under Table 6.

The MVP model results reveal that age of the household head and the square of age of the household head significantly determine adoption of manure and inorganic fertilizer.

Table 3 Correlation matrix of the technologies from the multivariate probit model. *Source*: own calculations

	Manure	Improved seed	Inorganic fertilizer	Crop diversification
Rho2	− 0.282 (0.074)***			
Rho3	− 0.337 (0.076)***	0.546 (0.063)***		
Rho4	0.115 (0.084)	− 0.134 (0.074) *	− 0.065 (0.076)	
Predicted probability	0.376	0.515	0.58	0.396
Joint probability (success)		0.051		
Joint probability (failure)		0.094		
Log likelihood		77.178		

***, ** and * significant at 1, 5 and 10% probability level, respectively, and the figures in parenthesis are the standard errors

Table 4 Multivariate probit simulation results for households' technology adoption decisions with Mundlak's approach

Variables	Manure		Improved seed		Inorganic fertilizer		Crop diversification	
	Coef.	Mfx	Coef.	Mfx	Coef.	Mfx	Coef.	Mfx
Age of HH	0.127 (0.072)*	0.0285	0.043 (0.043)	0.0070	0.099 (0.041)**	0.0397	− 0.036 (0.039)	0.0108
age2	− 0.002 (0.001)**	− 0.0005	− 0.001 (0.000)	− 0.0002	− 0.001 (0.000)**	− 0.0006	0.000 (0.000)	− 0.0002
Sex of HH	− 0.161 (0.235)	− 0.1338	0.318 (0.226)	− 0.1273	0.403 (0.212)*	− 0.0397	− 0.481 (0.223)**	− 0.0717
Literacy of HH	0.280 (0.173)	0.1422	0.119 (0.158)	0.1550	0.252 (0.150)*	0.2483	0.350 (0.152)**	0.1078
Literacy of the spouse	− 0.079 (0.162)	0.0596	0.219 (0.167)	0.1608	− 0.134 (0.155)	0.0979	0.287 (0.157)*	0.0693
Maize production experience	0.020 (0.011)*	0.0131	0.002 (0.009)	0.0157	− 0.013 (0.009)	0.0122	0.034 (0.009)***	0.0085
Size land owned	− 0.017 (0.039)	− 0.0196	0.027 (0.034)	− 0.0254	0.181 (0.073)**	0.0389	− 0.020 (0.033)	− 0.0023
Size of livestock (TLU)	0.305 (0.046)***	0.0971	− 0.115 (0.045)**	0.0429	− 0.111 (0.042)***	0.0271	0.069 (0.040)*	0.0302
Cooperative membership	0.204 (0.159)	0.0514	0.413 (0.164)**	0.0658	0.290 (0.156)*	0.1306	− 0.147 (0.156)	0.0361
Frequency of extension contact	− 0.003 (0.002)*	− 0.0009	0.004 (0.002)**	− 0.0001	0.008 (0.002)***	0.0023	0.001 (0.002)	0.0003
Training	− 0.078 (0.151)	0.0712	0.229 (0.153)	0.1876	− 0.020 (0.142)	0.1746	0.423 (0.143)***	0.0940
Access to market information	− 0.121 (0.143)	0.0815	0.857 (0.147)***	0.2905	0.386 (0.137)***	0.3602	0.364 (0.136)***	0.1439
Credit constraint	0.212 (0.154)	− 0.0190	− 0.605 (0.159)***	− 0.1851	− 0.418 (0.152)***	− 0.2914	− 0.323 (0.157)**	− 0.1009
Distance from FTC	0.003 (0.006)	− 0.0004	− 0.029 (0.006)***	− 0.0056	− 0.015 (0.006)**	− 0.0078	0.001 (0.006)	− 0.0024
Plot to home distance	− 0.018 (0.016)	− 0.0039	− 0.007 (0.006)	− 0.0004	− 0.003 (0.006)	− 0.0009	0.013 (0.005)**	− 0.0003
Plot ownership	1.207 (0.483)**	0.3944	0.053 (0.328)	0.2188	− 0.061 (0.320)	0.2285	0.076 (0.341)	0.1422
Medium fertile	− 0.335 (0.184)*	− 0.1786	0.031 (0.178)	− 0.1808	0.293 (0.177)*	− 0.1007	− 0.363 (0.170)**	− 0.0944
Poorly fertile	− 0.126 (0.243)	− 0.1299	0.260 (0.258)	− 0.1326	0.103 (0.234)	− 0.1361	− 0.604 (0.242)**	− 0.0939
The plot is in *weynadega*	1.013 (0.522)	0.1824	− 1.281 (0.361)***	− 0.2230	0.042 (0.377)	− 0.0439	0.079 (0.363)	− 0.0204
The plot is in *dega*	0.866 (0.519)	0.2664	− 0.742 (0.360)**	0.0513	− 0.336 (0.365)	0.0215	0.328 (0.357)	0.0675
Joint significance of plot variables:	23.09		20.06		12.01		14.9	
Prob. > χ^2 (7)	0.003		0.010		0.151		0.061	

*, ** and *** indicate statistical difference at 10, 5 and 1%, respectively. Non-significant control variables include: distance to the nearest market, participation in off/nonfarm activity, family size, steeper slope and medium slope. The figures in parenthesis are the standard errors

This implies that age has a nonlinear effect on adoption of manure and inorganic fertilizer. The result discloses young farmers adopt manure and inorganic fertilizer than their old and very young counterparts. This is plausible as older farmers are experienced much with their conventional farming system; they are less interested to change the production techniques that they are using.

The result indicates that female-headed households are less likely to adopt inorganic fertilizer than their male counterpart. This result is in line with the work of Doss and Morris (2000). The result also indicates that literacy level of the household head is positively and significantly related to the adoption of inorganic fertilizer and crop diversification. Besides, the education level of spouse's also has a positive contribution to the adoption of crop diversification. Maize farming experience is significant in determining adoption of crop diversification. This is plausible, as farmers with higher experience appear to have a wide knowledge and experiences on the operation and methods of agricultural production; they can easily evaluate the advantage of crop diversification.

The size of cultivated land is found to have a positive relationship with the adoption of inorganic fertilizer. This is because; land is a proxy for wealth in the rural area. Therefore, it may also indicate the capacity to purchase external inputs such as inorganic fertilizer. Livestock ownership measured in TLU is found to have a positive relationship with manure and crop diversification; and negative relationship with the adoption of inorganic fertilizer and improved seed. The positive relationship is understandable because livestock waste is the single most important source of manure in most parts of Ethiopia. The result is consistent with Kassie et al. (2015) which indicated a positive influence of livestock ownership on the adoption of manure in Kenya, Malawi, and Tanzania. Their work has also indicated a similar effect of livestock ownership on crop diversification in Malawi and Tanzania. The opposite relationship between livestock holding and; inorganic fertilizer and improved seed indicates the presence of tradeoff between crop production and animal husbandry.

The result also indicates the frequency of extension contact significantly determines adoption of manure, improved seed, and inorganic fertilizer. The result conveys that farmers who have frequent contact with agricultural experts are more likely to adopt new technologies. This is again plausible because agricultural extension services are the major sources of agricultural information for smallholder farmers in Ethiopia. This is consistent with Feleke and Zegeye (2006) who find that the number of extension contacts has a positive relationship with the adoption of improved maize varieties in the southern part of Ethiopia. Credit constraints negatively influence adoption of improved seed, inorganic fertilizers, and crop diversification, suggesting that liquidity-constrained households are less likely to adopt agricultural technologies that require cash outlays. This is plausible as timely availability of production loan is essential for acquiring required inputs. This is also consistent with Feleke and Zegeye (2006).

The result also indicates that training regarding maize production affects adoption of crop diversification positively. Access to market information affects adoption of improved seed, inorganic fertilizers, and crop diversification positively. This is again conceivable because the availability of market information will reduce transaction costs to farmers in the search to find markets for farm produce and inputs. A similar result is found in the work of Khonje et al. (2015). As expected, being a member of agricultural cooperative positively influences the adoption of improved seed and inorganic fertilizers. Abebaw and Haile (2013) indicated the important role of agricultural cooperatives in accelerating the adoption of agricultural technologies by smallholder farmers in Ethiopia. Being close to farmers training center also positively influences the adoption of improved seed and inorganic fertilizers.

As far as plot-level characteristics, plots located in *weynadega* and *dega* adopts manure and improved seed more likely compared with plots in *kola* agroecology. The distance between the plot and the home of the household is positively related with the adoption of Crop diversification. The result also indicates that compared with fertile plots, farmers are less likely to adopt manure and Crop diversification and they are more likely to adopt inorganic fertilizer on plots with medium fertility. Consistent with the work of Teklewold et al. (2013) and Kassie et al. (2010), land tenure influences the adoption of manure, which is more common on owned plots, suggesting that secure land tenure will encourage adoption decisions.

5 Conclusion and recommendations

Ethiopia is known for food security, hunger, and poverty. Improving agricultural productivity through investment in productivity-enhancing agricultural resources is important to overcome those problems. In this study, by implementing MVP model, we analyzed the probability of adoption of multiple agricultural using plot-level observations collected from eastern Ethiopia. The results reveal that there are strong complementarities and substitutabilities between agricultural technologies.

The result show that the probability of adoption of productivity-enhancing agricultural technologies is influenced by household head characteristics (age, maize production experience, gender, literacy), socioeconomics characteristics (family size, size of land and livestock owned), institutional characteristics (frequency of extension contact, cooperative membership, distance to FTC, credit constraint, training and access to market information) and plot characteristics including land tenure, plot proximity to home and fertility status of the plots. The following are the major recommendations drawn based on the findings of this study:

The result suggests the need for establishing and strengthening local institutions and service providers including, agricultural cooperatives, credit, extension and market information. Accordingly, the credit delivery systems should have to be improved and bureaucracies and administrative credit constraints should have to be solved. Appropriate and adequate extension services should also be provided by designing appropriate capacity building program to train additional development agents to reduce the existing higher ratio of farmers to development agents as well as by providing refreshment training for development agents.

Education, training and farming experience are also found to be crucial factors. Thus, government and other stakeholders have to give due attention to training farmers through strengthening and establishing both formal and informal type of framers' education, farmers' training centers, technical and vocational schools. Besides this, development agents, local leaders and other participants should create the room for experience sharing among farmers regarding the importance of improved technologies.

Authors' contributions

MHA conceptualized the study. AT designed the household surveys, coordinated implementation and collected field data. HMM provided guidelines for MVP model, and she performed the data analysis. KMG was responsible for interpretation and preparation of the manuscript. EAT contributed to descriptive analysis, writing the manuscript and made editorial comments of the manuscript draft. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The data that support the findings of this study can be obtained from the authors based on the request.

Ethical approval and consent to participate

Ethical approval and consent to participate is not applicable for our study.

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Appendix

See Tables 5 and 6.

Table 5 Simple probit models showing relationships between technologies

	Inorganic fertilizer	Manure	Improved seed	Crop diversification
Inorganic fertilizer		− 0.331 (0.130) **	1.008 (0.125)***	− 0.008 (0.127)
Manure	− 0.337 (0.131) **		− 0.510 (0.130)***	0.403 (0.122) ***
Improved seed	1.015 (0.126)***	− 0.514 (0.129)***		0.051 (0.126)
Diversification	− 0.007 (0.131)	0.414 (0.124) ***	0.056 (0.130)	

Coefficient are shown with standard errors in parentheses; ***, **, * significant at 1, 5, and 10% level, respectively

Table 6 Multivariate probit simulation results for households' technology adoption decisions without Mundlak's approach

	Manure		Improved seed		Inorganic fertilizer		Crop diversification	
	Coef	se	Coef	se	Coef	se	Coef	se
Age of house hold head	0.123*	0.073	0.042	0.042	0.095**	0.041	− 0.038	0.040
Square of age of the household head	− 0.002*	0.001	− 0.001	0.000	− 0.001**	0.000	0.000	0.000
Sex of house hold head	− 0.275	0.266	0.352	0.228	0.413*	0.212	− 0.490**	0.221
Education (HH)	0.415**	0.185	0.120	0.156	0.259*	0.150	0.344**	0.152
Education of spouse	0.029	0.169	0.182	0.167	− 0.144	0.157	0.298*	0.156
Maize cultivation experience	0.018	0.011	0.002	0.009	− 0.011	0.009	0.033***	0.009
Size of land owned in qoxi	− 0.045	0.038	0.029	0.034	0.179**	0.072	− 0.017	0.033
Livestock in TLU	0.353***	0.052	− 0.119***	0.045	− 0.107**	0.042	0.065	0.040
Cooperative membership	0.132	0.169	0.407**	0.164	0.304*	0.156	− 0.159	0.158
Number of extension contact	− 0.003	0.002	0.004**	0.002	0.008***	0.002	0.001	0.002
Training regarding maize	− 0.175	0.156	0.228	0.152	− 0.011	0.143	0.417***	0.142
Access to market information	− 0.139	0.157	0.852***	0.145	0.399***	0.136	0.370***	0.135
Credit constraint	0.207	0.163	− 0.599***	0.158	− 0.398***	0.152	− 0.355**	0.156
Distance to FTc	0.007	0.006	− 0.029***	0.006	− 0.015**	0.006	0.001	0.006
Distance b/n plot and home	− 0.090***	0.013	− 0.002	0.005	0.003	0.005	0.007	0.005
The plot tenure	0.925**	0.415	− 0.031	0.256	− 0.094	0.261	0.179	0.278
The plot is good in fertility	− 0.114	0.245	− 0.106	0.212	− 0.088	0.204	0.481**	0.199
The plot is in kola ecology	− 0.886	0.654	1.096***	0.314	− 0.019	0.385	− 0.344	0.371
The plot is in dega ecology	− 0.358	0.223	0.567***	0.193	− 0.370**	0.188	0.205	0.183
_cons	− 3.668**	1.573	− 1.098	0.951	− 1.904**	0.966	− 1.040	0.922

*, ** and *** indicate statistical difference at 10, 5 and 1%, respectively. Non-significant control variables include: distance to the nearest market, participation in off/nonfarm activity, family size, steeper slope and medium slope

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