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Adoption of multiple agricultural technologies in maize production of the Central Rift Valley of Ethiopia

The improvement of agricultural productivity using technology is an important avenue for increasing output, reducing poverty and tackling land degradation. However, there is disagreement about which type of technology is most appropriate for smallholders. While some promote the need for natural resource management practices and low external input, others advocate the need for input intensification. This study has examined the nature of the relationship that exists between the two broad categories by using fertiliser and certified seed as input-intensive technologies and manure and soil conservation as natural resource management practices. Alongside this, the paper has also identified the factors that facilitate and impede the probability of those technologies being adopted.

Keywords: maize, technologies, technology mix, adoption, multivariate probit

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Introduction

About ninety per cent of the world's poor live in rural areas and almost all of them rely on agriculture for their food, income and employment (Collier, 2007). Thus, growth of farm productivity is widely understood to be a prerequisite for broad economic development in those areas (Tiffen, 2003; Sanchez *et al.,* 2009). In Africa, however, the sector is mainly in the hands of small-scale farmers who use traditional methods and tools of production. The growth of the agricultural sector in the continent has lagged behind both economic and population growth even during the years 2001-2010, which was a period globally perceived as a 'decade of growth' (Diao *et al*., 2012). Particularly in Sub-Saharan Africa (SSA), productivity has not increased considerably (Shisanya *et al.*, 2009; Pretty *et al.*, 2011). The region has the lowest land and labour productivity rates in the world (Henk and Kofi, 2003). It is the only developing region not to have experienced significant declines in undernourishment and about one third of the people in the region are food insecure (Graaff *et al.,* 2011). SSA is the only region in which the share of people living in extreme poverty is still as high as it was 30 years ago (WB, 2013).

Ethiopia remains one of the poorest countries in the world. According to World Bank data, in 2010, food aid was equivalent to 13 per cent of its national output and in 2014 nearly 30 per cent of households in the country were in extreme poverty. The country receives more food aid than any other country in the world (Kirwan and Margaret, 2007), and the depth and intensity of food insecurity are high (Bogale and Shimelis, 2009; Zegeye and Hussien, 2011).

In the country, agriculture contributes about 41 per cent of GDP, employs 83 per cent of total labour force and contributes 90 per cent of exports (EEA, 2012). Yet the use of low capital-intensive technologies results in low productivity and income that constrain farmers' capacity (Dinar *et al*., 2008). As indicated by Taffesse *et al.,* (2012), 96 per cent of the cultivated land in the country is managed by smallholder farmers, the majority of whom own less than one hectare. Thirty-six per cent of Ethiopian farming households are engaged in subsistence farming, living on less than USD 2 per day. This means they can only afford low mechanisation implements that are small and use human power (MoA, 2014). In addition to human muscle, oxen-draft is the main source of power for land preparation and planting, and this has created complementarities between crop and livestock production for centuries. Yet achieving higher and sustained agricultural productivity growth remains one of the greatest challenges facing the nation (Spielman *et al.,* 2010; Ahmed *et al,* 2014).

One way to increase agricultural productivity is through wider adoption of farming technologies, and such measures have been shown to have positive impacts on income, food security and poverty reduction (Alene *et al*., 2009; Asfaw *et al*., 2011; Kassie *et al*., 2011). Technology adoption can also improve nutritional status (Kumar and Quisumbing, 2010); lower food prices (Karanja *et al.*, 2003) and reduce the risk of crop failure (Hagos *et al.,* 2012). However, especially in Africa, adoption rates of agricultural technologies remain quite low (Spielman *et al.,* 2010). There is also disagreement about which type of technology is most appropriate to the small farm sector (Priscilla *et al.*, 2014). While some believe low external input approaches are most fitting for African smallholders (IAASTD, 2009), others such as Pingali (2007) advocate the need for input intensification.

Low external input strategies involve different agronomic practices, such as soil and water management practices and use of organic manure (Priscilla *et al.*, 2014). Such agricultural production systems are expected to enhance sustainability while maintaining productivity that protects natural resources and the provision of public goods. Input intensification strategies, on the other hand, place higher emphasis on the use of certified seeds, mineral fertiliser, irrigation and other productivity-enhancing inputs. They argue that owing to negative soil nutrient balances caused by continuous cultivation with little or no addition of nutrients, enhanced food crop production in SSA is critically dependent on external nutrient inputs (Cobo *et al.,* 2010; Sanchez, 2002).

There is also a strategy that calls for integrated soil fertility management since agricultural intensification cannot occur unless certified seed, organic inputs and mineral fertiliser are combined and used with good agricultural practices adapted to local conditions (Place *et al.,* 2003; Vanlauwe *et al.,* 2010). In fact, these two strategies are not incompatible and they might be combined to increase production and productivity. For instance, Teklewold *et al.* (2013) indicated that the adoption of cropping system diversification, conservation tillage and modern varieties increases income from maize production. Kassie *et al.* (2015) also indicated that combining conservation agriculture with certified seeds and other external inputs could lead to positive synergistic effects. Furthermore, Mucheru-Muna *et al.* (2007) showed that significant yield benefits can be achieved through the combined application of organic matter and fertilisers compared to either resource applied alone. In general, there is no single approach that will work in every situation and the suitability of these technologies varies under different conditions (Priscilla *et al.*, 2014). Therefore, more research is required to show comparative evidence of what really works under which conditions.

Although numerous studies (e.g. Feleke and Zegeye, 2006; Beshir *et al.,* 2012; Wolka, 2014) have been conducted in Ethiopia to examine the adoption of agricultural technologies, most of them have looked at the adoption of technologies in isolation, while farmers typically adopt multiple technologies as complements, substitutes or supplements. By focusing on single technologies, such studies ignore the possibility that the choice of technologies to be adopted may be partly dependent on earlier technology choices (Teklewold *et al.,* 2013). The purpose of this study was therefore to identify the nature of the relationship that exists between the input-intensive technologies and natural resource management practices that have been adopted by smallholder maize-producing farms in the Central Rift Valley of Ethiopia. For this study, certified seed and fertiliser were considered as input-intensive technologies and manure and soil conservation practices were considered as natural resource management. Alongside this, the paper also analysed the factors that jointly facilitate and impede the probability of adopting productivity enhancing technologies.

Methodology

Description of study areas

In Ethiopia, maize accounts for the largest share of production by volume and is produced by more farms than any other crop (Chamberlin and Schmidt, 2012). CSA (2012a) indicated that about nine million smallholders were involved in maize production in the 2011/12 production season. It is primarily produced and consumed by the small-scale farmers predominantly in the mid-and low-altitude, sub-humid agro-ecologies (Dawit *et al.,* 2008). Maize is also one of the most important food sources in the country. From 1960 to 2009, the dietary calorie and protein contributions of maize have increased by around 20 and 16 per cent, respectively (Shiferaw *et al.,* 2013). According to FAO data, in 2013 the dietary calorie and protein contribution of maize had reached 398 KCal/day and 9.2 g/day, respectively.

During the 2011/12 production season, maize covered about 2.05 million ha of land at the national level, equivalent to 21.4 per cent of the total area covered by all cereals (CSA, 2012a). Of this area, 30.6 per cent was sown with certified seed varieties, and 23.3 and 27.7 per cent had utilised organic and inorganic fertiliser, respectively. The total output of maize in the same year at national level was 60.7 tonnes, i.e. 32.3 per cent of the total cereal production in that year. The productivity of maize in the same year was the highest among cereals with 2.95 t/ha which was an improvement of 32.5 per cent over 2006/07. Within this period, maize seed use has increased by 135 per cent, and application of inorganic and organic fertiliser to the maize crop increased by 82.3 per cent and 19 per cent respectively.

This study was undertaken in Arsi-Negele district, which is one of the major maize producing areas in the Central Rift Valley of Ethiopia. Geographically, it is situated at 7^{o}09'-7^{o}41' N and 38^{o}25'-38^{o}54' E. The study area covers three agro-ecological zones (low, mid and high land) based on annual mean temperature, rainfall, altitude and vegetation (ICRA, 2002). The temperature of the area ranges from 16^{o}C to 25^{o}C and annual rainfall ranges between 500-1150 mm. The topography of the area is a gentle slope or flatter. Some parts of the highlands in the study area are covered by natural forest, bush and shrub. The main crops grown in the area include wheat, maize, *teff*, barley, sorghum, onion and potato. Annual crops accounted for 95 per cent of all croplands in the district. *Andosol* soil type covers about 52.2 per cent of the district, while *nitosols* cover the remaining 47.8 per cent. The rainfall of the area is bimodal, with a short rainy season occurring from February to April and the main rainy season from June to October. The short rainy season allows farmers to grow potato early and later plant cereals, specifically wheat. Livestock are an important component of the farming system and a source of intermediate products in the district.

The area is intensively cultivated and private grazing land is unavailable. Communal pasture and straw from crops are the main source of feed for livestock production. According to CSA (2012b), the district has 303,223 inhabitants of which 150,245 are male and 152,978 are female.

Data sources and collection methods

A combination of purposive and random sampling techniques was employed to obtain a sample of respondents for this study. A two-stage random sampling technique was then applied to select sample households. In the first stage, three *Kebeles*[1] were randomly selected from Arsi Negelle district. In the second stage, 130 household heads were selected randomly using probability proportional to size. The analysis was conducted at plot-level since farmers may adopt certain technologies on some of their plots but not on others. Accordingly, plot-level data were collected from 148 plots managed by 130 randomly selected maize producers. The data were collected by means of a semi-structured questionnaire. The schedule was first pre-tested and, based on the result of the pre-test, some modifications were made to the questionnaire before the execution of the formal survey. Enumerators who are familiar with the study area, who can understand the local language and who have prior experience in data collection were recruited.

[1] *Kebele* is an administrative hierarchy in Ethiopia. The country is a federal state of regions where every region is structured into zones and zones are divided into districts. Every district is again divided into *kebeles*.

Econometric model

Since the adoption decision is inherently multivariate, attempting univariate modelling excludes useful economic information contained in interdependent and simultaneous adoption decisions (Dorfman, 1996). Therefore, this paper employs a multivariate probit model (MVP). The MVP technique simultaneously models the influence of the set of explanatory variables on each of the different practices while allowing for the potential correlation between unobserved disturbances, as well as the relationship between the adoptions of different practices (Belderbos *et al.*, 2004; Yu *et al.*, 2008; Kassie *et al.*, 2009). One source of correlation may be complementarity (positive correlation) or substitutability (negative correlation) between different practices (Belderbos *et al.*, 2004). Positive correlation also occurs if there are unobservable farmer-specific characteristics that affect several decisions but that are not easily captured by measurable proxies. Failure to capture unobserved factors and interrelationships among adoption decisions regarding different practices will lead to bias and inefficient estimates (Greene, 2008).

The observed outcome of technology adoption can be modelled following random utility formulation. Consider the j^{th} household ($j=1,...,N$) which is confronting a decision on whether or not to adopt the available productivity enhancing technologies on plot $p\,(p=1,...,P)$ over a specified time horizon. Let U_{i} represent the benefits to the farmer from the traditional production system, and let U_k represent the benefit of adopting the k^{th} productivity enhancing technology: ($k=F, S, C, M$) representing choice of fertiliser (F), certified crop variety (S), soil conservation (C) and manure application (M). The farmer chooses to adopt the k^{th} technology on plot p if $Y^*_{jpk} = U^*_k - U_i > 0$.

The net benefit Y^*_{jpk} that the farmer gains from k^{th} technology on plot p is a latent variable determined by observed and unobserved characteristics:

$$Y^*_{jpk} = X'_{jpk}\beta_k + u_{ip} \qquad (k=F,\ S,\ C,\ M) \tag{1}$$

where X_{jp} represents observed household, socioeconomic, institutional and plot characteristics; u_{jp} represents unobserved characteristics; K denotes the type of technology available and β_k denotes the vector of parameter to be estimated. Using the indicator function, the unobserved preferences in equation (1) translate into the observed binary outcome equation for each choice as follows:

$$Y_k = \begin{cases} 1 \text{ if } Y^*_{jpk} > 0 \\ 0 \text{ otherwise} \end{cases} \qquad (k=F,\ S,\ C,\ M) \tag{2}$$

In the MVP model, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalised to unity where (u_F, u_S, u_C, u_M)~MVN(0, Ω) and the symmetric covariance matrix Ω is given by:

$$\Omega = \begin{pmatrix} 1 & \rho_{FS} & \rho_{FC} & \rho_{FM} \\ \rho_{SF} & 1 & \rho_{SC} & \rho_{SM} \\ \rho_{CF} & \rho_{CS} & 1 & \rho_{CM} \\ \rho_{MF} & \rho_{MS} & \rho_{MC} & 1 \end{pmatrix} \tag{3}$$

The off-diagonal elements in the covariance matrix represent the unobserved correlation between the stochastic components of the different types of technologies (Teklewold *et al.,* 2013). This formulation with non-zero off-diagonal elements permits for correlation across the error terms of several latent equations, which represent unobserved characteristics that affect the choice of alternative technologies.

Results

Dependent variables

The dependent variable for this study was the type of technology adopted from the set of: fertiliser, certified seed, manure and soil conservation practices. Improved maize seed was adopted on about 70 per cent of the plots and mineral fertiliser was applied on 78.4 per cent of the plots. Meanwhile, the adoption of manure and soil conservation technologies was below 50 per cent. Out of the total plots, 48.7 per cent applied manure and 35 per cent soil conservation practices.

Independent variables

The mean age of the sample respondents was 42.3 with the range from 22 to 70 (Table 1). On average, the sample respondents have cultivated maize for more than 20 years. The mean educational level of the sample households was grade 4.3 and about 35 per cent of the respondents were capable of reading and writing though they did not attain formal education. Regarding socioeconomic variables, the family size of the sampled households varies from 1 to 13 with a mean of 5.7. The mean livestock holding of the sampled households in terms of tropical livestock unit (TLU)[2] was 8.7 and the area of cultivated land ranges from 0.5 to 7.0 hectares with an average size of about 2 hectares.

As regards institutional variables, 29 per cent of the total sample households surveyed reported that they have received credit. The mean distance from the nearest market to the homestead was 3.7 kilometres. Sixty-three per cent of respondents indicated that they have social responsibilities such as religious, administrative and/or community leadership roles. The frequency of extension contact ranges from 12 to 52 times with an average contact of 22.9 times per year. Currently, extension service is mostly provided by the public sector, operating in a decentralised manner where extension is implemented at the district level (Davis *et al*., 2009).

Concerning the plot characteristics, the mean plot size was 0.54 ha and, on average, the plots are 1.03 km away from the homestead. Around 37 per cent of the plots were fertile and, in the perception of the farmers who managed them, 32.7 per cent of them were sloppy. About 12 per cent of plots were either rented or shared. In Ethiopia, all rural land is owned by the state and part of this land is allocated to farmers on a use-right basis. The rural land reform policy strictly prohibits the transfer of land by sale. Therefore, farmers in the area get additional land mainly through two informal arrangements: sharecropping and hiring.

[2] To see how TLU is calculated, please refer to Annex 1.

Table 1: Characteristics of the sample households.

Variable	Mean	Std. error	Min	Max
Household characteristics				
Age of the head of household (HH, years)	42.3	11.1	22	70
Educational level (grade)	4.3	3.3	0	12
Maize production experience (years)	20.6	10.3	2	50
Socioeconomic characteristics				
Off/nonfarm activity = 1 if HH is engaged in off/non-farm activity; 0 otherwise	0.22	0.41	0	1
Family size (persons)	5.7	2.2	1	13
Livestock owned (TLU)	8.7	6.0	0	81
Area of cultivated land (ha)	1.9	1.4	0.5	7.0
Annual farm income (ETB)	11,543	23,295	1,200	214,460
Institutional characteristics				
Extension contact (number of times per year)	22.9	14.4	12	52
Distance from home to market (km)	3.7	1.9	0.1	9.0
Cooperatives membership = 1 if the HH is member; 0 otherwise	0.11	0.31	0	1
Social responsibility = 1 if HH has social responsibility; 0 otherwise	0.63	0.49	0	1
Credit utilisation = 1 if HH used credit; 0 otherwise	0.29	0.46	0	1
Plot characteristics				
Plot size (ha)	0.54	0.27	0.13	1.00
Soil fertility = 1 if HH perceives the plot is fertile; 0 otherwise	0.37	0.49	1	2
The slope of the plot = 1 if HH perceives the plot is flatter; 0 otherwise	0.33	0.47	2	3
Plot ownership = 1 if HH owns the plot; 0 otherwise	0.88	0.41	0	4
Distance from the plot to home (km)	1.03	0.89	0.01	5.00

Source: own data

Nature of the relationship between the technologies

The results of the correlation coefficients of the error terms from the MVP are significant for any pairs of equations ($p<0.000$) and they are statistically different from zero in four of the six cases (Table 2), confirming the appropriateness of the MVP specification. The result shows that the likelihoods of households to adopt fertiliser, manure, certified seed and soil conservation practices were 78.1, 47.6, 70.4 and 35.0 per cent respectively. It also shows that the joint probability of using all technologies was 11.6 per cent and the joint probability of failure to adopt all technologies was 3.8 per cent. The results of correlation coefficients[3] of the error terms indicate that there is positive (complementarity) and negative correlation (substitutability) between different technologies.

The simulated maximum likelihood estimation results indicated that there were positive and significant relationships between household decision to adopt fertiliser and manure, fertiliser and certified seed; and certified seed and soil conservation. The results also show that there were negative and significant relationships between adoption of manure and fertiliser and certified seed. The relationship between fertiliser and manure is plausible because both technologies deliver nutrients to the soil and the complementarily of certified seed and fertiliser is expected, especially in commercialised farms.

The result shows that there is no clear demarcation between technologies and farmers might combine input intensification and natural resource management or they might substitute each other as in the case of fertiliser and manure. This might be due to the nature of plurality of the role of extension workers in the country. In Ethiopia, extension workers are the main source of information for smallholder farmers regarding most of farming activities. They advise and consult farmers about the importance of certified seed, chemical fertilisers, compost, crop rotation, row planting and soil and water conservation simultaneously.

Table 2: Correlation matrix of the technologies from the multivariate probit model.

	Fertiliser	Manure	Improved seed	Soil conservation
R_{Manure}	-0.626***			
$R_{Improved\ seed}$	0.662***	-0.248*		
$R_{Soil\ conservation}$	0.188	-0.185	0.497***	
Predicted probability	0.781	0.476	0.704	0.350
Joint probability (success)	0.116			
Joint probability (failure)	0.038			
Log likelihood	-254.44			
Likelihood ratio test of Rhoij = 0, $P > \chi^2(6)$	0.000			

***, ** and * significant at 1%, 5% and 10% probability level, respectively
Source: own calculations

Determinants of farmers' choice of adaptation strategies

Although farmers adopt a combination of technologies, there are a number of factors that can influence their decision to choose a particular technology. This section has identified the variables which determine the adoption of various technologies using MVP (Table 3). Eighteen explanatory variables, of which nine were dummy and nine continuous, were included in the model. The selection of those explanatory variables for the model was done through literature review.

Among plot-level variables, plot ownership was positively related to soil conservation and negatively with certified seed. The positive relationship indicates soil conservation is more likely to be implemented on owned plots. As soil conservation is usually a long-term investment, the farmer (i.e. the person who rented-in the land) may not derive benefit from his/her investment in the short term. The negative relationship between plot ownership and fertiliser use may be because the farmers who own land tend to be more commercialised and thus also use more purchased inputs. Plot size was found to have a positive relationship with application of fertiliser. Area of farmland is considered as a measure of wealth in rural parts of Ethiopia, thus households with more land can afford the use of commercialised inputs such as fertiliser.

Distance from plot to the homestead was also negatively related to the application of fertiliser and certified seed. This is plausible because if the plot is far from the homestead it will receive less attention from the farmer. The perception of

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 Annex 2.

Table 3: Multivariate probit simulation results for households' technology adoption decisions.

Variables	Fertiliser		Manure		Improved seed		Soil conservation	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Household characteristics								
Age of the head of household	-0.090	0.114	0.003	0.090	-0.102	0.091	0.117	0.089
Age^2	0.001	0.001	-0.000	0.001	0.001	0.001	-0.001	0.001
Educational level	0.250*	0.129	0.028	0.117	0.062	0.109	0.196*	0.114
Experience	-0.026	0.029	-0.003	0.028	0.005	0.025	0.015	0.030
Socioeconomic characteristics								
Off/non-farm activity	0.349	0.390	-0.414	0.399	-0.129	0.295	-1.806***	0.445
Family size	-0.150*	0.087	0.087	0.076	-0.070	0.072	-0.148**	0.071
Livestock owned (TLU)	-0.023	0.019	0.081**	0.030	0.007	0.020	0.016	0.018
Area of cultivated land	-0.021	0.163	-0.115	0.192	-0.109	0.148	-0.086	0.154
Institutional characteristics								
Extension contact	0.203	0.240	0.826***	0.226	-0.141	0.194	-0.308	0.226
Distance from home to market	0.056	0.092	-0.035	0.083	-0.126*	0.071	-0.051	0.071
Membership of cooperatives	1.511**	0.744	-0.740	0.452	0.671	0.491	0.523	0.389
Social responsibility	-0.369	0.291	-0.332	0.293	-0.238	0.263	-0.327	0.269
Credit utilisation	0.080	0.319	0.055	0.323	0.299	0.285	-0.301	0.296
Plot characteristics								
Plot size	1.390*	0.740	0.938	0.696	0.548	0.608	0.217	0.628
Soil fertility	0.121	0.375	0.107	0.382	0.631	0.303**	-0.323	0.346
Slop of the plot	0.228	0.398	-1.080***	0.401	0.165	0.325	-0.445	0.390
Plot ownership	0.249	0.362	0.176	0.326	-0.538	0.294*	1.393**	0.628
Plot-home distance	-0.332**	0.158	-0.111	0.185	-0.356	0.148**	-0.205	0.176
_cons	1.667	3.002	4.392**	2.658	1.906	2.328	-0.028	2.363

Wald chi square (72) = 125.00; Log likelihood = -254.44248; Prob > chi square = 0.0001
***, ** and * significant at 1%, 5% and 10% probability level, respectively
Source: own calculations

farmers regarding the fertility status of the plot was significantly related to certified seed. Meanwhile, perception about the slop of the plot was negatively related to manure. This can be justified as if the plot becomes sloppy farmers do not apply manure due to the fear that it will be washed out and affect the neighbours' plots and the environment.

Education was found to have positive relationships with application of fertiliser and adoption of soil conservation practices. This result showed that higher educational status increases the awareness of farmer about the benefits of applying fertiliser and conserving the natural resource. Family size was related to fertiliser application negatively while it was related to soil conservation positively. The positive sign is plausible since conservation practices are often more labour intensive. The negative relationship might be due to the fact that larger family size would increase expenditure for home consumption, creating financial constraints to buying other commercial inputs such as fertiliser.

Livestock ownership was found to have a positive relationship with manure application. Owing to the fact that animal manure is bulky and less transportable it is more supply driven than demand driven. As such, households with more animals will also have more manure and will in turn be more likely to use animal manure in their farms (Priscilla *et al.,* 2014). Off/non-farm activities have a negative relationship with manure application. This can be justified as application of manure is labour intensive and if farmers are engaged in off/non-farm activities they will not have labour for this activity.

Among the institutional characteristics, cooperative membership was found to have a positive relationship with application of fertiliser, and extension contact has a positive relationship with manure application. Distance from home to market was found to have a negative relationship with improved seed. This is reasonable, because market distance contributes to higher transport and transaction costs, so that the use of purchased inputs is less likely in remote areas. Better access to markets enables farmers to obtain market information and other important inputs they may need. When farmers are far from the market, the transaction cost for acquiring inputs will be high and this will, in turn, reduce the relative advantage of adopting new technologies.

Conclusion and recommendations

The need for applying modern agricultural inputs in Ethiopian agriculture is not debatable as the possibility of expanding cultivable land is almost exhausted. Nevertheless, the agricultural sector in the county is well known for its being traditional and use of backward technologies. Therefore, research and adoption of technologies are crucial in increasing agricultural productivity and lowering the poverty levels as the fate of the sector, in terms of increasing its contribution to the overall growth of the economy and securing food self-sufficiency, depends on the development and application of appropriate technologies. Hence, there is a need to minimise constraints that hinder farmers from adopting modern inputs.

This study has analysed the adoption of different technologies among maize farmers using plot-, household-, institutional- and infrastructural-level data collected from the Central Rift Valley of Ethiopia. Owing to the fact that farmers are more likely to adopt a mix of technologies than a single strategy, the study used the MVP model. The technologies considered for this study were improved seed and fertiliser from input-intensive technologies, and manure and soil conservation practices from natural resource management technologies. The results of the multivariate correlation coefficient indicated that there are positive relationships between improved seed and fertiliser and between improved seed and soil conservation. There were also negative relationships between adoption of manure and fertiliser and between manure and improved seed. The estimation results indicated that the variables affecting farmers' decisions to adopt a technology differ between technologies. Educational level of the household, family size, off/non activities, livestock ownership, and distance to the market, plot ownership, slop of the plot and other variables also play significant roles, partly with differing signs across technologies.

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Annex 1: Conversion factors used to estimate tropical livestock unit (TLU) equivalents.

Type of animal	TLU
Calf	0.25
Donkey (young)	0.35
Weaned calf	0.34
Camel	1.25
Heifer	0.75
Sheep and goat (adult)	0.13
Cow and ox	1.00
Sheep and goat (young)	0.06
Horse	1.10
Chicken	0.013
Donkey (adult)	0.70

Source: Storck *et al.* (1991)

Annex 2: Simple probit models showing relationships between technologies.

	Fertiliser	Manure	Improved seed	Soil conservation
Fertiliser		-0.462*** (0.087)	0.561*** (0.095)	-0.016 (0.118)
Manure	-0.277*** (0.065)		0.162** (0.086)	0.020 (0.084)
Improved seed	0.424*** (0.087)	0.204* (0.107)		0.223*** (0.086)
Soil conservation	-0.003* (0.068)	0.016 (0.092)	0.194** (0.075)	

Marginal effects are shown with standard errors in parentheses.
N=148; ***, **, * significant at 1%, 5%, and 10% level, respectively.