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Adoption of Major Agricultural Technologies in Coffee Based Farming Systems of Ethiopia

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Abstract

This study used cross-sectional household survey data and assessed adoption of major agricultural technologies and its determinants in coffee based farming system of Ethiopia. Descriptive statistics and multivariate probit regression model were used to analyze the data. The study unveiled that 91% of the farmers in coffee-growing areas of the country at least adopted either one or a combination of the four major agricultural technologies (minimum tillage, soil and water conservation practices, improved livestock and improved varieties of major crops). In most of the cases, the farmers' adoption pattern was observed to have a combination of technologies. Seven percent of the farmers adopted all of the four combinations of technologies at a time while 30% adopted a combination of three technologies and 35% a combination of two technologies. Out of the major agricultural technologies considered in this study, improved crop varieties were most commonly adopted technologies by 75% of the farmers either alone or in combination with the other three. This was followed by 58% of the soil and water conservation technologies who were adopted either alone or in combination with others. Minimum tillage and livestock technologies adopters accounted for 48% and 26% respectively who adopted either alone or in combination with the other three. The study identified determinant factors of adoption of agricultural technologies. Principally improving awareness of farmers through trainings and field days is found crucial to enhance adoption of agricultural technologies. The study also revealed existence of adoption complementarity between the considered agricultural technologies. This can be exploited as an opportunity to set up intervention options which can enhance adoption of combinations of the technologies.

Keywords: Adoption, Coffee, Minimum-tillage, Multivariate probit, Soil and water conservation

Introduction

Ethiopia is dominated by rain fed agriculture, where the performance of the sector is highly dependent on the timely onset, duration, amount and distribution of rainfall that makes the sector highly vulnerable to drought and other natural troubles (CSA, 2019). It has been long that research working towards improvement of production and productivity in the agricultural sector generating and promoting improved agricultural technologies like improved seed of crops, improved animal breeds, improved agronomic managements and soil and water management practices. On the other side, there is also a growing interest among policymakers and development practitioners to get as many farmers as possible to hold sustainable farming practices using improved agricultural technologies that will fortify agricultural and food systems (Victor *et al*., 2019).

The coffee-based farming system of the country is situated in the south, southwestern, and western parts of the country. It is identified by high rainfall, undulating topography, a huge area of forest, and large trees. Coffee and *enset* dominate the southern part while coffee and maize lead the southwestern and western part of the farming system. It is also characterized by land degradation, population pressure, subsistence farming, unsustainable production and productivity.

Improved agricultural technologies were introduced in the whole parts of the country including coffee based farming systems through agricultural research systems, universities, agriculture offices, NGOs and have been promoted to the farmers to address problems related to production and productivity in a sustainable manner. For instance, minimum tillage and retention of crop residue is one of the key agricultural practices that have been promoted in Ethiopia since 1998 (FAO, 2016). Technologies including conservation agriculture, organic fertilizers, improved crop varieties, improved livestock and improved feeding practices, and soil and water conservation practices have been promoted to farmers by stakeholders like the Ministry of agriculture, research and NGOs (CIAT, 2017).

Some efforts had been made to study adoption of agricultural technologies in coffee based farming system though these studies were either location specific or focused on single technology adoption and did not considered the nature of simultaneity of adoption decision among agricultural technologies. Evidences is scanty to indicate adoption and correlation of adoption decision among agricultural technologies in the coffee based farming system of the country. This study therefore, initiated with the purpose of generating information on the level of adoption of major agricultural technologies and the interdependence of adoption decisions.

Methodology of the Study

Study areas

The study was conducted using quantitative primary data collected from major coffee-growing regional states of the country: Oromia and SNNP which were selected for their representativeness of coffee production in the country. Gedeo, Sidama, Kafa, and Sheka zones from the SNNP region and Ilubabor, Jimma, West Wollega, and Kellem Wollega zones from the Oromia region were also selected for their representativeness of the typical coffee production in the country.

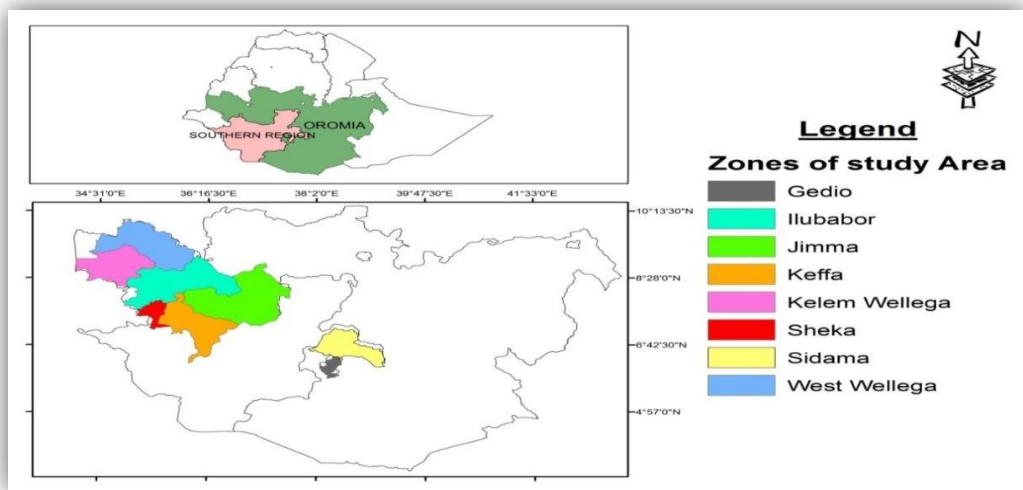

Figure 1. Map of the study area

Method of Sampling

Multistage sampling technique was involved to select samples of regions, zones, districts, kebeles and households. Almost all of the coffee growing regions of the country were included in this study, because Oromia and SNNP National Regional States alone accounted for 89% of coffee growers, 97% of the coffee area, and 99% of coffee production in the country (CSA, 2018). In the second stage, coffee producing zones were stratified into two based on leading production practices including coffee-*enset* and coffee-maize based category. After stratification, samples of zones were selected randomly from each of the categories for this study. In the third stage, districts and peasant associations (*kebeles*) were again selected from each of the selected zones using a random sampling technique. Households were also randomly chosen from the sampling frame of coffee growers at the peasant association levels using systematic random sampling technique. The required sample size was determined by using Kothari (2004) as follow:

$$N = \frac{Z^2 pq}{e^2} = \frac{(1.96)^2\ (0.5)(0.5)}{(0.0318)^2} = 950 \qquad (1)$$

Where N is the sample size needed, Z is the inverse of the standard cumulative distribution that corresponds to the level of confidence, e is the desired level of precision, p is the estimated proportion of an attribute that is present in the population, and q = 1-p. The value of Z is found from the statistical table. Eventually, the data was collected from 954 sample households (584 from SNNPR and 370 from Oromia Region) (Table 1). Four more sample households were included in cases of missing or non-responses of selected samples.

Table: 1 Sample distribution along the study zones

Farming system	Zone	Total sample size	% of the total
Coffee-*enset* based	Gedeo	200	21
	Sidama	200	21
	Sheka	81	8
	Sub-total	481	50
Coffee-maize based	Ilubabor	121	13
	Jimma	107	11
	West Wollega	105	11
	Kellem Wollega	36	4
	Kafa	104	11
	Sub-total	473	50
Grand Total		954	100

Types of data and method of collection

Both quantitative and qualitative types of data were collected from primary data sources. Secondary data sources were also utilized to substantiate and elucidate the results of the study. The required data was collected from the sampled households through a structured questionnaire administered to sampled farmers. The questionnaire was pretested before data collection. Trained enumerators were also used to collect the data with close supervision of researchers. The data was collected using CSPro data collection software to minimize non-sampling errors and improve data quality.

Method of data analysis

Description of socio-economic, demographic and farm characteristics of sample households were made along with appropriate statistical methods for better illustration of variables.

This study utilized the random utility theory specified in Green (2003) as base for the econometric analysis. Suppose U^a and U^b represent an individual's utility of two choices, the observed choice between the two reveals which one provides greater utility, but not unobservable utilities. Hence, the observed indicator equals 1 if $U^a > U^b$ and 0 if $U^a \leq U^b$. Accordingly, the rational farmer adopts a given new technology if the expected utility obtained from the new technology is higher than that of the previous one.

Following Sodjinou and Henningsen (2012), Let U_{im1} represents the expected utility that a given farmer *i* would receive from adopting agricultural technology *m* and U_{im0} the expected utility gained from using the alternative or old practice. The i^{th} farmer more likely adopts the agricultural technology *m* if $U_{im1} > U_{im0}$. For each farmer *i*, we can write the expected utility difference (y_{im}^{*}) between adopting and not adopting agricultural technology as a function of observed farm household and location characteristics x_{im} and unobserved characteristics (z_{im}) and the use of other technologies, because other technologies might be complements or substitutes to technology *m*. Therefore, utility difference (y_{im}^{*}) is specified as (Sodjinou and Henningsen, 2012):

$$y_{im}^{*} = U_{im1} - U_{im0} = f(x_{im}, z_{im}, y_{im\sim}), \qquad (1)$$

Where $y_{im}^{\sim} = (y_{i1},\ldots, y_{im-1}, y_{im+1},\ldots, y_{iM})'$ is a vector of zeros and ones indicating whether other technologies are used and M is the total number of technologies. Thus, for a given agricultural technology *m*, farmer *i* faced with a choice between two alternatives:-

$y_{im} = 1$, if $y_{im}^{*} > 0$ (Adopting the agricultural technology) or

$y_{im} = 0$, if $y_{im}^{*} \leq 0$ (Not adopting it).

Given specification of utility differences in equation (1) and assuming a linear functional form of $f(.)$, we get the following equation system:

$$\begin{aligned} y^{*}_{i1} &= \beta_1' x_i + \gamma_1' z_i + \delta_1' y_i \\ &. \\ &. \qquad (2) \\ &. \\ y^{*}_{iM} &= \beta_M' x_i + \gamma_M' z_i + \delta_M' y_i \quad ' \end{aligned}$$

where x_i is a vector that includes all observed characteristics in at least one of $x_{i1},\ldots, x_{iM}$, z_i is a vector that includes all unobserved characteristics in at least one of $z_{i1},\ldots, z_{iM}$, $y_i = (y_{i1},\ldots, y_{iM})'$ is a vector that indicates which technologies are currently in use, and $\beta_1,\ldots,\beta_M$, $\gamma_1,\ldots,\gamma_M$ and $\delta_1,\ldots,\delta_M$ are parameter vectors, where the m^{th} element of each δ_{im} is zero for m=1,…,M. We can re-write equation system (2) in matrix form:

$$y^{*}_{i} = \beta' x_i + \gamma z_i + \delta y_i \qquad (3)$$

where $\beta = (\beta_1,\ldots,\beta_M)'$, $\gamma = (\gamma_1,\ldots,\gamma_M)'$ and $\delta = (\delta_1,\ldots,\delta_M)'$ are parameter matrices, where all diagonal elements of δ are zero. Defining $\varepsilon_i^{*} = y_i - y_i^{*}$ and replacing y_i *by* $y_i^{*} + \varepsilon_i^{*}$ in (3), we get the following simultaneous equation system:

$$y_i^* = \beta x_i + \gamma z_i + \delta y_i^* + \delta \varepsilon i^* \quad (4)$$

Solving this system for y^*, we get the following reduced form:

$$y_i^* = (I - \delta)^{-1} \beta x_i + (I - \delta)^{-1} \gamma z_i + (I - \delta)^{-1} \delta \varepsilon_i^*, \quad (5)$$

Where, I is an $M \times M$ identity matrix.

Given that z_i and ε_i^* are unobserved, we can estimate the following system as a multivariate probit model:

$$y_i^* = \beta^* xi + \varepsilon_i \quad (6)$$

$y_{im} = 1$ if $y_{im}^* > 0$, and 0 otherwise,

(m= minimum tillage (Mt), soil and water conservation practices (SWc) and manure application (Mn))

$\varepsilon_i \sim N_M [0, \Omega]$,

where, $\beta^* = (I-\delta)^{-1} \beta$ is the coefficient matrix to be estimated and $\varepsilon_i = (I - \delta)^{-1} \gamma z_i + (I - \delta)^{-1} \varepsilon_i^*$ is the vector of disturbance terms, which is assumed to follow a multivariate normal distribution with mean 0 and variance-covariance matrix Ω.

In this model with the possibility of adopting multiple agricultural technologies, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity (Aryal *et al*., 2018). This model allows us to identify factors influencing adoption of the technologies and assess the interconnectedness of adoption of technologies through their correlations. Therefore, adoption of multiple technologies is better analyzed with a multivariate probit model rather than with separate univariate probit models, because the former can account for correlations between the disturbance terms (Sodjinou and Henningsen, 2012). i.e. the pairwise correlation coefficient of the error terms corresponding to any two agricultural technologies in the off-diagonal elements in the covariance matrix become non-zero, which justifies the application of a multivariate probit instead of a univariate probit for each individual technology (Aryal *et al*., 2018).

This study focused on adoption of four major agricultural technologies; i.e. minimum tillage (Mt), soil and water conservation practices (SWc), Adoption of pure or cross-bred livestock (ILiv) and improved crop varieties (IVar). Adopter of a given technology is the farmer who is using the technology at the time of the survey. Table 2 reveals the dependent and independent variables included in the model and their descriptions.

Table 2: Definition of dependent and independent variables used in the model

Variables	Definitions	
Dependent variables		
Minimum tillage (Mt)	1= if farmer adopts minimum tillage or zero tillage, 0 = otherwise	
Soil and water conservation practices (SWc)	1= if the farmer adopts soil and water conservation practices, 0 = otherwise	
Pure or cross breed livestock (ILiv)	1= if the farmer adopts pure or cross breeds for cattle or sheep or goat, 0 = otherwise	
Improved crop varieties (IVar)	1= if the farmer used improved variety (certified seed recycled not more than five times for cereals) for at least one of the major crops produced in the study areas (coffee, maize, wheat, barley and teff) , 0= otherwise	
Independent variables		**Hypothesized relationship**
Sex	1= if the household head is male, 0 otherwise	+/-
Age	Age of the household head in years	+/-
Education	Education level of the household head in completed years	+
Region	1= if the household head lives in Oromia, 0 SNNPR	+/-
Land size	The size of land owned by the household in hectare	+
Livestock	The number of livestock owned by the household in TLU	+
Television	1= if the household have functional television, 0 otherwise	+
Radio	1= if the household have functional radio, 0 otherwise	+
Field days	1= if the household participated on farmers field day, 0 otherwise	+
Extension	1= if the household has got advice from DAs in the survey year, 0 otherwise	+
Credit access	1= if the household ever got credit, 0 otherwise	+
Training	1= if the household took training on improved agricultural management practices, 0 otherwise	+
Off-farm	1= if the family members of the household participated in off-farm activities, 0 otherwise	+/-
Intercropping	1= if the household has been practicing intercropping, 0 otherwise	+/-
Grow improved forage	1= if the household has been growing improved forages, 0 otherwise	+/-
Distance to *woreda* town	The distance of households residence to *woreda* town in kilometer	-

Results and Discussion

Descriptive analysis

Rate of adoption of major agricultural technologies in coffee based farming system

It was recognized that 91% of the farmers in coffee-growing areas of the two regions adopted at least one of the considered agricultural technologies (minimum tillage, soil and water conservation practices, improved livestock or improved varieties of major crops). As illustrated in Table 3, the proportion of households who adopted the four technologies at a time (minimum tillage, soil and water conservation practices, improved livestock breeds and improved crop varieties) was 7%. On the other hand, 18% of the households adopted the three technologies, including minimum tillage, soil and water conservation practices and improved crop varieties. However, 19% adopted only a single technology, which is either of the four technologies. The proportion of households who adopted minimum tillage alone but not others was 5%. In the same way, 11% of the households adopted improved crop varieties alone but not others.

Figure 2 provides adoption status of major agricultural technologies in SNNP and Oromia national regional states. It indicated 63.9% of the farmers in SNNP region adopted minimum tillage compared to 33.2% in Oromia. This might be due to land shortage in SNNP region where the farmers in coffee based farming systems practice hand hoeing to plant crops in the open spaces of coffee plants and shade trees. On the other hand, the proportion of improved variety adopters was significantly higher for Oromia region (89.2%) than SNNP (71.8%).

Table: 3 Combined and single adoption rates of agricultural technologies

Combinations	Frequency (N=954)	Percent
Mt_1, SWc_1, $ILiv_0$, $IVar_1$	167	18
Mt_0, SWc_1, $ILiv_0$, $IVar_1$	140	15
Mt_0, SWc_0, $ILiv_0$, $IVar_1$	101	11
Mt_0, SWc_1, $ILiv_1$, $IVar_1$	78	8
Mt_1, SWc_0, $ILiv_0$, $IVar_1$	81	8
Mt_1, SWc_1, $ILiv_1$, $IVar_1$	65	7
Mt_0, SWc_0, $ILiv_1$, $IVar_1$	45	5
Mt_1, SWc_1, $ILiv_0$, $IVar_0$	47	5
Mt_1, SWc_0, $ILiv_0$, $IVar_0$	51	5
Mt_0, SWc_0, $ILiv_0$, $IVar_0$	38	4
Mt_1, SWc_0, $ILiv_1$, $IVar_1$	32	3
Mt_0, SWc_1, $ILiv_0$, $IVar_0$	25	3
Mt_1, SWc_1, $ILiv_1$, $IVar_0$	7	1
Mt_1, SWc_0, $ILiv_1$, $IVar_0$	7	1
Mt_0, SWc_1, $ILiv_1$, $IVar_0$	6	1
Mt_0, SWc_0, $ILiv_1$, $IVar_0$	2	0

Note: $_1$=adoption, $_0$= non adoption; Minimum tillage =Mt, soil and water conservation practices =SWc, Adoption of pure or cross-bred livestock =ILiv and improved crop varieties =IVar.

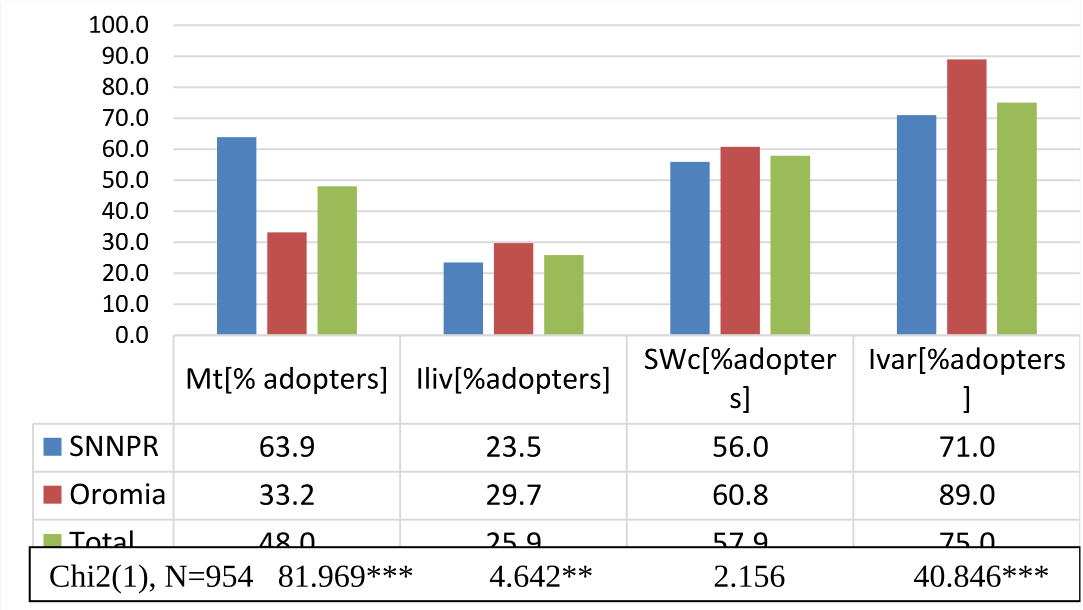

Figure 2.Adoption of major agricultural technologies across regional states

Five soil and water conservation practices were identified in the study areas of Oromia and SNNP regions. Soil bund was the most adopted practice by 70% of the households followed by stone bund (48%) and terracing (46%). On the other hand, Fanyaju (7%) and gully stabilization (2%) were the least adopted practices.

Description of independent variables

Table 4 provides description of independent variables across adopter and non-adopter households. Farmers with access to formal education are assumed to make informed decisions and thus education facilitates adoption of new practices and technologies. The level of education of farmers was significantly higher for adopters of improved livestock and crop varieties than non-adopters. The findings also indicated that adopters of soil and water conservation practices owned smaller sizes of farmland than non-adopters whereas adopters of improved crop varieties owned larger sizes of farmland than non-adopters. Adopters of minimum tillage and soil and water conservation practices owned smaller numbers of livestock whereas adopters of improved livestock and improved crop varieties owned larger numbers of livestock. The number of adopter farmers who participated on agricultural field days and those who got extension services was significantly higher than non-adopters. Most of the agricultural technology adopters had access to training related to agricultural management. It was noted that most of the adopters of minimum tillage and soil and water conservation technologies were also engaged in intercropping.

Table: 4 Description of independent variables across adopters and non-adopters of major agricultural technologies

Variables	Minimum tillage			Soil and water conservation			Improved livestock			Improved crop varieties		
	Adopters N=457	Non adopters N=435	Total N=892	Adopters N=552	Non adopters N=402	Total N=954	Adopters N=247	Non adopters N=707	Total N=954	Adopters N=721	Non adopters N=233	Total N=954
Sex (% male)	88.4	92.6	90.4**	92.3	89.1	91.0*	94.3	89.8	91.0**	92.9	83.7	91.0***
Age (years)	41.8	43.8	42.8*	43.2	42.5	43.0	43.3	42.8	43.0	43.1	42.2	43.0
Education (years)	4.5	4.8	4.7	4.6	4.8	4.7	5.6	4.4	4.7***	4.9	4.2	4.7***
Region (% Oromia)	26.7	56.6	41.3***	40.7	36.1	38.8	44.5	36.8	38.8**	44.1	19.5	38.8***
Land size (ha)	1.8	1.7	1.8	1.6	2.2	1.8***	2.1	1.8	1.8*	1.9	1.3	1.8***
Livestock (TLU)	3.7	4.3	4.0**	3.1	5.6	4.2***	6.1	3.5	4.2***	4.6	2.4	4.2***
Own ox (% yes)	39.2	46.8	42.8**	39.7	50.8	44.3***	49.8	42.4	44.3**	48.2	30.2	44.3***
Television (% yes)	9.6	10.6	10.1	9.4	12.2	10.6	16.2	8.6	10.6***	10.3	11.7	10.6
Radio (% yes)	48.2	59.9	53.9***	51.6	58.0	54.3	57.3	53.3	54.3	57.0	44.3	54.3***
Field days (% yes)	25.1	15.2	20.2***	23.3	18.7	21.4	29.1	18.6	21.4***	23.8	12.0	21.4***
Extension (% yes)	96.1	94.0	95.1	97.3	91.9	95.1***	98.4	94.0	95.1***	96.0	91.9	95.1**
Credit access (% yes)	41.6	51.5	46.4***	49.3	41.3	45.9**	46.2	45.8	46.0	49.3	33.7	45.9***
Training(% yes)	63.4	67.2	65.5	68.8	62.1	66.1**	74.7	62.9	66.1***	67.9	59.0	66.1**
Off-farm (% yes)	24.5	40.2	32.2***	29.0	31.8	30.2	37.3	27.7	30.2***	27.2	41.0	30.2***
Intercropping (% yes)	35.5	22.8	29.3***	32.6	21.9	28.1***	22.7	30.0	28.1**	24.8	40.0	28.1***
Grow improved forage (% yes)	-	-	-	53.1	44.4	49.7*	60.4	44.0	49.7***	-	-	-
Distance to *woreda* town (km)	8.8	9.8	9.3**	9.3	9.4	9.3	9.5	9.3	9.4	9.5	8.6	9.4

*** p<0.01, ** p<0.05, * p<0.1

Econometric Results

Determinants of adoption of agricultural technologies in coffee based farming system

The model fit diagnosis, Wald test for multivariate probit that tests the hypothesis 'all coefficients in each equation are jointly equal to zero', was rejected suggesting independent variables in the model explained the variations in the dependent variables (Table 5). Pearson's correlation coefficient was also used to check whether there was serious correlation among independent variables or not. Accordingly, we transformed size of land into its square root and dropped the variables family size and mobile owned by the household.

Minimum tillage

This study revealed sex, age, training and participation in off farm activities negatively and significantly influenced adoption of minimum tillage whereas land size and participation in field day positively and significantly influenced it (Table 5). Female-headed farmers were found more likely to adopt minimum tillage than male headed households. The reason behind this might be minimum tillage avoids the laborious activity of frequent plowing that demands oxen ownership and more physical engagement. Minimum tillage saves the time and labor of women who are already overburdened by domestic work. The likelihood of minimum tillage adoption decreased for male headed households' significantly at 5% level of significance. The negative relationship between age of household head and minimum tillage implied that farmers with increased age are less likely to adopt minimum tillage. This might be associated with limited information access and risk aversion behaviors as aged farmers are mostly engaged in limited agricultural activities and stick to traditional farming instead of adjusting them to the new technologies. The same result was reported by Assefa and Gezahegn (2010) for improved wheat adoption. The negative and significant relationship between training and adoption of minimum tillage could be associated with the focus that minimum tillage had got in the training. Training was given to the farmers at the beginning of production seasons when the farmers prepared their farm before the planting time and this was sometimes done in the form of campaigns in Ethiopia. Agricultural technology packages (newly developed) gave little consideration for minimum tillage to be included as an alternative agricultural technology package and thus missed in training (MOA, 2007).

Field days are important ways of technology promotion and dissemination in which farmers visually and practically evaluate technologies. Adoption of minimum tillage and participation of farmers in field days had positive and significant relationships as expected. Therefore, the extension system has to utilize the opportunity which field days offer through its already established farmer training centers to promote adoption of minimum tillage.

Soil and water conservation practices

Livestock holding and participation in off farm activities negatively and significantly influenced adoption of soil and water conservation practices whereas training, participation in field days and growing improved forage positively and significantly influenced the practices (Table 5). The study showed training and field days promoted adoption of soil and water conservation practices. Trainings and field days are the means of technology and knowledge transfer that prominently support the adoption of new technologies. The positive and significant relationship that participation in training and field days had with soil and water conservation practices confirm the same. The result was in conformity with the findings of Chilot *et al*. (2015). The negative influence of participation in off farm activities on soil and water conservation practices could be related to unbalanced emphasis that the farmer gave to off-farm activities. Off farm activities could boost income of the farmers on the one side while it shares the focus and time given to farming activities, searching for improved technologies and access to information on improved agricultural technologies on the other. Therefore the balance between the two scenarios has to be considered and tuned through appropriate awareness creation systems. Marenya *et al.* (2017) have also found similar results in their study of minimum tillage adoption in Ethiopia, Kenya and Tanzania. Growing improved forage was found to have a positive and significant ($p< 0.01$) influence on the adoption of soil and water conservation practices. This could be interpreted as growing improved forage could decrease free grazing of livestock through improving feed availability and keeping soil and water conservation structures undamaged thus encouraging farmers to adopt soil and water conservation structures.

Improved livestock

Adoption of improved livestock was influenced positively and significantly by education, number of livestock owned, field days, growing improved forage and participation in off farm activities (Table 5). Field days create visual impressions and better opportunities for farmers to evaluate technologies. Growing improved forage alleviates the shortage of feed faced due to adoption of pure breed or cross breed livestock and encourages farmers to adopt improved livestock. It needs relatively larger initial capital to own purebred and crossbred livestock and that may be the reason behind the positive and significant ($p< 0.05$) influence of participation in off farm activities on adoption of improved livestock.

Table 5: Factors affecting adoption of improved agricultural technologies

Variables	Mt	SWc	ILiv	IVar
Sex [male]	-0.554**	-0.450	0.197	-0.202
	(0.265)	(0.269)	(0.274)	(0.288)
Age [years]	-0.011**	0.003	0.006	0.004
	(0.005)	(0.004)	(0.005)	(0.006)
Education [years]	0.004	-0.010	0.050**	0.083***
	(0.021)	(0.022)	(0.022)	(0.027)
Region [Oromia]	-0.682***	0.486***	0.017	0.983***
	(0.156)	(0.173)	(0.167)	(0.216)
Land(sqrt) [ha]	0.243**	0.119	-0.143	0.232
	(0.118)	(0.129)	(0.123)	(0.170)
Livestock [TLU]	-0.011	-0.149***	0.095***	0.050**
	(0.017)	(0.020)	(0.018)	(0.026)
Television [yes]	0.001	-0.179	0.742***	-0.153
	(0.208)	(0.210)	(0.211)	(0.260)
Radio[yes]	-0.091	-0.043	-0.126	0.024
	(0.127)	(0.132)	(0.133)	(0.157)
Training [yes]	-0.579***	0.260*	0.069	0.199
	(0.139)	(0.145)	(0.145)	(0.173)
Credit access [yes]	-0.048	0.184	0.018	-0.098
	(0.122)	(0.129)	(0.128)	(0.152)
Extension [yes]	0.007	0.004	-0.130	-0.465
	(0.403)	(0.419)	(0.433)	(0.573)
Field days [yes]	0.383**	0.340**	0.450***	0.575***
	(0.150)	(0.164)	(0.151)	(0.223)
Off-farm [yes]	-0.486***	-0.343**	0.286**	-0.349**
	(0.131)	(0.137)	(0.135)	(0.163)
Intercropping [yes]	0.056	0.050	0.115	0.333*
	(0.163)	(0.168)	(0.168)	(0.191)
Grow improved forage [yes]		0.487***	0.345**	
		(0.141)	(0.139)	
Distance to woreda town [Km]	-0.001	-0.012	-0.008	-0.022*
	(0.009)	(0.010)	(0.010)	(0.012)
Constant	1.646***	0.766	-1.663***	0.364
	(0.618)	(0.612)	(0.634)	(0.782)
Observations	488	488	488	488
Wald chi2(62) = 283.53				
Log likelihood = -1006.5803				
Prob > chi2 = 0.0000				

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Improved crop varieties

Education, location, number of livestock, field days and intercropping influenced adoption of improved crop varieties positively and significantly. The positive association between livestock holding and adoption of crop varieties might be through increased income obtained from livestock. The number of livestock increases the ability of farmers to buy new crop technologies through boosting income of farmers from sales of livestock. On the other hand, livestock could be used as insurance during crop failure and develop the confidence of farmers to try new crop varieties. The result is consistent with the findings of Chilot *et al*. (2015). Intercropping boosts the confidence of producers through decreasing vulnerability to food shortage caused by crop failure as diversification could decrease the probability to lose all crop harvests at a time. Off-farm activities and distance to *woreda* town influenced adoption of improved crop varieties negatively and significantly (Table 5). The distance to *woreda* town negatively ($p<0.1$) influenced the adoption of improved crop varieties. *Woreda* town is the center of input distribution and market destination. Thus the distance of farmers' residence from *woreda* town influenced adoption of improved crop varieties negatively because it affects timely and adequate supplies of the required inputs which also entail high costs of transaction. The result is consistent with the findings of Marenya *et al.* (2017).

Minimum tillage and soil and water conservation practices were shown to have a positive and significant correlation, implying that the probability of minimum tillage adoption increases the likelihood of adoption of soil and water conservation practices (Table 6). There was also a positive and significant relationship between adoption of improved livestock and soil and water conservation practices which indicated the supplementary effect between the technologies. Improved livestock could increase the ability of farmers to install soil and water conservation structures through generation of additional income. Farmers could get better income from dairy production and live animal sale compared to indigenous animals that could support building soil and water conservation structures on their farm land. Adoption of improved crop varieties was found to be complementary with adoption of improved livestock and soil and water conservation practices. Adoption of improved livestock creates additional income for the farmers and the income obtained enables them to buy new inputs and employ labor to build soil and water conservation structures. Similar previous studies also indicated that agricultural technologies were often adopted and implemented in combination (Kurgat BK *et al*., 2020; Hailemariam *et al.*, 2018).

Table 6: Estimates of correlation coefficient for the error terms from multivariate probit

Parameter	Coefficient	Standard Error	Z-value
$\rho 21$	0.139*	0.081	1.700
$\rho 31$	-0.012	0.082	-0.140
$\rho 41$	-0.163	0.102	-1.600
$\rho 32$	0.296***	0.084	3.540
$\rho 42$	0.292***	0.091	3.200
$\rho 43$	0.217**	0.107	2.030

Likelihood ratio test of $\rho 21 = \rho 31 = \rho 41 = \rho 32 = \rho 42 = \rho 43 = 0$:
chi2(6) = 29.881 Prob > chi2 = 0.000

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: 1=Minimum tillage, 2=soil and water conservation practice, 3= Improved livestock and 4= Improved crop varieties

Conclusion and Implications

There were only less than 10% of the farmers who used all the four technologies in combination. The proportion reaches close to 40% if we consider the farmers using three or more technologies and about 75% used at least two technologies. Improved crop varieties were the most dominantly used technologies in all combinations. Single technology adopters accounted for 19% of the farmers. Use of combination of technologies were likely to happen with strong promotional efforts such as through use of field days which is observed to positively drive the adoption decision for most of the technologies. In addition, adoption of low cost conservation agricultural practices such as minimum tillage can be increased by including them in the trainings and extension manuals. The study implied existence of complementarity effect among major improved agricultural technologies which has to be used as an opportunity to enhance the adoption of multiple technologies with considerably low cost and shorter period of time.

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