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Adoption of Improved Tef Technology Packages in Northern Ethiopia: A Multivariate Probit Approach

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Abstract

This study was initiated to understand the adoption level and factors governing the adoption of improved tef technology packages in the northern part of Ethiopia. A multistage sampling procedure was used to select sample households from Amhara and Tigray region in 2018. A multivariate probit (MVP) model involving a system of five equations for the adoption decision of improved tef technologies and practices was estimated using data collected from 484 sample farm households covering ten districts- two from Tigray and eight from Amhara regional states. The result showed that the adoption level of certified tef seed, row planting, recommended weeding frequency, the recommended rate of Urea and recommended rate of DAP/NPS were 40.2%, 35.7%, 69.1%, 65.0%, and 47.5%, *respectively. The model results attested that most improved tef production technology packages are complementary; this implies that farm-level policies that affect the use of one improved agricultural technology can have spillover effects on the other technologies. The various demographic, socio-economic, and institutional variables were found to exhibit variable effects on the decision to adopt the different technology components of the improved tef technology package. The unexpected relationship between the frequency of extension contact and application of recommended fertilizer rate requires further investigation which the available data can't answer. The overall finding of the study underlined the high importance of information related services and institutional support services in the study area to enhance adoption of improved tef technology packages. Therefore, the government should work with development partners and NGOs for the improvement of such services and ease the accessibility and availability of certified seeds and fertilizers as well as the introduction of labor-saving technologies so as to achieve wider adoption of the technologies.*

Keywords: Adoption, Technology, Package, and Multivariate Probit.

Introduction

Tef (*Eragrostis tef*), a cereal crop that belongs to the grass family *Poaceae*, is endemic to Ethiopia. It has been widely cultivated in the country for centuries (Teklu and Tefera 2005). The crop can grow under diverse agro-ecological conditions and at an altitude ranging from 1800 to 2100 meters above sea level. It is mainly produced in Amhara, Oromia, Tigray, and the Southern Nations, Nationalities, and Peoples (SNNP) regions in the country by more than 7 million farm households on an area of more than 3 million hectares. It is also one of the country's most important staple crops mainly consumed as *injera* prepared from fermented tef flour and local beverages.

In Ethiopia, Tef is the most important cereal crop in terms of the area allocated, production, and consumption. The crop represents 20% and 30% of the total cereal production and area respectively in 2017/18 production season. Amhara and Tigray regional states together contribute 43% and 39% of the total tef production and area of the country respectively in the 2017/18 production season (CSA, 2017). Tef is second (to maize) in terms of quantity of production, but its market price is often two or three times higher than maize. Tef accounts for the largest share of the total value of cereal production. Many farmers grow tef as a cash crop because of its higher and more stable market price (MAFAP, 2013). This is very much so in the major production areas of the Amhara and Tigray region where alternative cash crops such as coffee, sesame, cotton, and so on are missing. The market price of tef is highly linked with its color (MAFAP, 2013). Based on color there are three types of tef. These are white (*Magna*), mixed (*Sergegna*), and red (*Dabo*). These three main types of tef have a different market price, with the white fetching the highest and red the lowest price.

Tef is adaptable to a wide range of ecological conditions in altitudes ranging from near sea level to 2800 masl. It performs well at an altitude of 1700 - 2200 masl, annual rainfall of 750 - 850 mm, and a temperature of 10˚C - 27˚C (Seyfu, 1993). In addition, tef is resistant to the two extreme water conditions namely drought and waterlogging (Teklu and Tefera 2005; Minten et al. 2013). Combined with its low vulnerability to pests and diseases, it is considered as a low-risk crop (Fufa et al. 2011; Minten et al. 2013). Tef is planted between mid-June to mid-August during the main production season (known as *Meher)* and harvested between December to mid-February. The fine grain of tef seeds is planted either by broadcasting or row planting on a well-plowed soil and lightly covered with soil until germination. During the growing period, several weeding is often required (Assefa *et al*. 2011).

In an attempt to improve the average productivity of tef at farm households' level, there have been efforts to develop improved varieties since the late 1950s. To date, more than 49 tef varieties were released and agronomic recommendations have been developed by federal and regional research centers (Tsion et al. 2020). On-station and on-farm results indicate that tef productivity can extend up to 3.4 tons ha^{-1} (Assefa et al, 2013). There are also efforts to promote the improved varieties along with their agronomic practices such as row planting and soil and water conservation practices for tef producing farmers in different parts of Ethiopia including Amhara and Tigray regional states. The massive government extension efforts together with the technology scaling up initiative by the

Ethiopian Institute of Agricultural Research were important cases in point towards improving the widespread use of the improved varieties and associated packages, particularly of tef in these two regions.

Despite concerted efforts by the government to improve uptake of improved tef varieties and associated packages, studies have indicated the presence of a variety of barriers to adoption by smallholder farmers. Vandercasteelen et al., (2018) in a study conducted to examine labor, profitability and gender impacts of adopting row planting in Ethiopia, revealed that row planting of tef seed is considered to be superior compared to the traditional broadcasting method because a reduced seed rate decreases competition between the seedlings for water and nutrients and make weeding easier. On the other hand, row planting requires more labor for making rows in which seeds are sown. Moreover, a study conducted in the Chaliya district of west Shewa zone in Ethiopia indicated that lack of knowledge of the improved agronomic practices (row planting and techniques associated with fertilizer application) stands as an important constraint (Mansingh and Bayissa, 2017). Other studies have also reported different barriers to adoption of tef production technologies including farming experience, participation in training, education level, distance to nearest marketing, technology attribute in east Wollega zone (Wordofa et al, 2021) and membership to cooperatives, extension contact, income, and credit in south Wello (Cafer, and Rikoon, 2018). Nonetheless, most previous studies suffer from two important limitations. One of the limitations with most of the adoption studies on tef is that they have limited geographical scope. Even more so are the studies conducted in the northern part of Ethiopia. These micro-level studies are often based on small samples, covering small geographical areas that lack adequate variability, which is indispensable for making generalizations at a higher level such as at a regional or national level. The second limitation has to do with the fact that the studies did not consider other technologies than improved varieties.

This study is, therefore, designed to estimate and provide an accurate picture of the adoption of tef among smallholder farmers using a relatively larger sample in a wider geographical area including the Amhara and Tigray regional states of Ethiopia that represent a significant share of the national tef production. Accordingly, the study is targeted to examine the level and extent of adoption of improved tef varieties and associated agronomic practices thereby identifying factors governing the household decision to adopt and expand the improved technologies in the study areas. The study would support researchers and development organizations to understand farmers' situation related to the level of use of improved tef technologies and most importantly driving factors influencing tef technology adoption. The study also helps to develop appropriate research and development interventions considering the existing realities in the northern part of Ethiopia.

Research Methodology

Description of the Study Area

The study has been conducted in the northern part of the country specifically in Amhara and Tigray regional states. Amhara is located at 9° to 13° 45' N and 36° to 40° 30'E. It is adjacent to the Tigray in the north, Oromia in the south, Afar in the east, and Benishangul-Gumuz in the west. Amhara extends to the western border of Ethiopia sharing a border with neighboring Sudan. The Amhara region covers an area of approximately 161,828.4 km^2. On the other side, Tigray is located at the northern tip of the country where Ethiopia shares a border with Eritrea. Tigray shares borders with Afar in the east, and Amhara in the south. The regional state also extends to the western border which Ethiopia shares with neighboring Sudan and has an estimated area of 54,569.25 square kilometers.

The annual mean temperature for most parts of Amhara falls between 15°C-21°C. In the regional state, there are highlands (above 2,300 meters above sea level), semi-highlands (1,500 to 2,300 meters above sea level) and lowlands (below 1,500 meters above sea level) accounting for 20 %, 44 %, and 28 %, respectively. The western side of Amhara enjoys annual rainfall above 1200mm. The mean annual rainfall over the whole regional state varies from 300mm to well over 2,000mm. The amount of rainfall, and also the length of the rainy season decreases north and north-eastwards from the south-western corner of the region. The highest rainfall occurs during the summer season, which starts in mid-June and ends in early September. The climatic condition of the Tigray is characterized as "*Kolla*" (semi-arid) 39%, "*Woina Dega*" (warm temperate) 49%, and "*Dega*" (temperate) 12%. The average annual rainfall of the region lies between 450-980 mm (www.ethiopia.gov.et/about-ethipia, April 25, 2019).

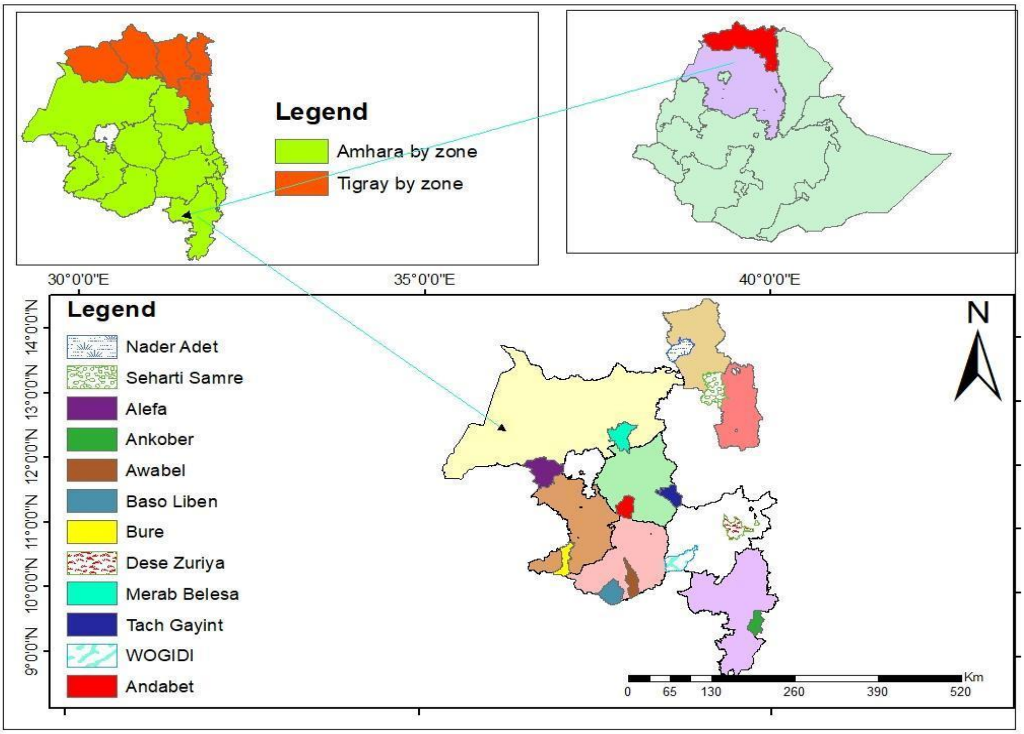

Figure 1: Map of the study area

Ethiopia is the largest teff producer (more than 90%) in the world. Despite its largest production volume, the country is not capitalizing on its crop in the international market (Tadele & Hibistu, 2021). Particularly, tef is grown mainly in Amhara and Oromia regional states, which together constitute up to 84% of the total cultivated area and production in 2017 and a smaller proportion of tef is also produced in Tigray and SNNP regional states (Table 1). The northern part of the country which includes Amhara and Tigray collectively account for 43% of the national tef area and production each.

Table 1. Status of tef production in Ethiopia

Regional states	Area in ha (area share)	Production in tons (production share)
Amhara	**1,137,844 (37.7%)**	**19,328,573 (38.5%)**
Tigray	**167,584 (5.5%)**	**2,410,116 (4.8%)**
Oromia	1,441,030 (47.8%)	24,737,963 (49.3%)
SNNPR	246,099 (8.2%)	3,412,547 (6.8%)
Benishangul	24,433 (0.8%)	303,184 (0.6%)
Others	924 (0.03%)	12,014 (0.02%)
Total	3,017,914 (100%)	50,204,400 (100%)

Source: CSA, 2016/17

Data and Survey Design

Data for the present study came from a household survey conducted in Ethiopia between April and June 2018. The geographical focus was northern Ethiopia, where tef forms an important part of the production system contributing more than 40% of the total tef production in the country. After purposely identifying the Amhara and Tigray regional states as strata to represent the northern tef production area of the country, out of 11 major tef-growing zones eight were selected using a random sampling technique. The proportion of the sample households assigned to each region was based on the density of the tef production area. Then a multistage sampling was employed to identify sample households for the study. Accordingly, first, in consultation with experts and data from Central Statistical Agency (CSA) 12 districts (10 from Amhara and 2 from Tigray) were identified using systematic random sampling after arranging the districts in descending order based on the total area covered in tef (Table 2). In the second stage, from a list containing tef growing kebeles, three were randomly selected for each one of the sampled districts. Finally, from each sampled kebele, 15 households were selected for an interview using a simple random sampling technique. The interview involved 484 farm households.

Table 2: Proportion of sample households by region

Strata (Region)	Tef Area (ha)	% Sample households drawn
Amhara	1,093,104.35	83
Tigray	162,782.73	17
Total	**1,255,887.08**	**100**

Source: CSA, 2017

Both household and plot-level data were collected through face-to-face interviews using a structured household questionnaire. A community questionnaire was also used to interview key informants (including extension workers, kebele chairpersons, progressive farmers, and local opinion leaders) regarding village-level variables including but not limited to input/output prices, distance to markets, and subjective assessments of rainfall conditions.

More than 18 experienced individuals participated as enumerators and 3 researchers (including one of the authors of this article) were involved as supervisors in the process of data collection. Three-round training (central and western Amhara, eastern Amhara, and Tigray team) were given for enumerators on the purpose and the survey tool (questionnaire) used for the study. The data was collected using computer-assisted personal interview (CAPI) after the questionnaire was converted to CSPro- a data collection application software that was loaded on the data collection machines.

The survey covered detailed community, household, and plot-level information. For each plot, the respondent recounted the tef varieties cultivated during the 2017/2018 production year. Other plot-level data collected included slope, soil fertility, plot size, plot tenure, crop production estimates, and inputs use. Important socioeconomic and demographic variables collected were age, gender, education, family size, distance from the village to nearest input/output markets and extension office, the likelihood of getting credit, and more other variables.

Table 3: Distribution of sample households interviewed by the two regional states

Region	Zone	District	Sample households
Amhara	East Gojam	Baso Liben	34
		Awabel	36
	West Gojam	Bure	44
	South Gonder	Tach Gayent	45
		Andabet	26
	Central Gonder	Alefa	36
		West Belesa	45
	South Wollo	Wogedi	45
		Desie Zuria	45
	North Shoa	Ankober	45
Tigray	Central Tigray	Nader Adit	45
	South Eastern Tigray	Seharti Semri	38
Total	**8 zones**	**12 districts**	**484**

Source: Own survey result

Data Analysis

The data obtained through interviews, focus group discussions and the review of documents were compiled, organized, and summarized using various analytical approaches. Descriptive statistics such as mean, percentage, frequency, chi-square test, and standard deviation were used to describe the adoption status of tef technology packages. It is also used to explain the different socio-economic characteristics of the sample respondent households.

In addition, a multivariate probit model was used for identifying the determinants of the choice of different improved tef technology packages while ordered probit model was estimated to examine the intensity of adoption (number of technologies adopted) and the governing factors thereof. A multivariate probit model is a generalization of the probit model used to estimate several correlated binary outcomes simultaneously (Greene, 2003). Generally, a multivariate model extends the bivariate model to more than two outcome variables just by adding equations.

Multivariate probit model

Farmers often utilize information on several practices while making decisions to adopt technologies and thus, the decision to adopt one improved agricultural technology or practice may influence the decision to adopt another. This makes adoption decisions inherently multivariate. In such a case, using univariate techniques could exclude crucial information about interdependent and simultaneous adoption decisions (Greene, 2003). The multivariate probit model helps us to determine possible complementarities (positive correlation) and substitutability (negative correlation) between the improved technologies and practices.

In addition, technology adoption decisions can be path-dependent. The recent technology adoption decision might partly be associated with earlier technology choices. Hence, the analysis of technology adoption without properly controlling for technology interdependence can either underestimate or overestimate the influences of various factors on the adoption decision (Kassie et al., 2013; Teklewold et al., 2013; Donkoh et al, 2019). Consequently, it is crucial to assess whether farmers' multiple technology adoption decisions are interrelated or not. Accordingly, this study applied a multivariate probit model to analyze the joint decisions to adopt multiple improved tef technology packages. The dependent variable in the empirical estimation for this study is the choice of improved tef technology packages including improved tef seed, row planting, as well as recommended practices of weeding frequency, application of the DAP/NPS as well as Urea fertilizer.

The multivariate probit econometric approach for this study is characterized by a set (n) of binary dependent variables y_{hpj} such that:

$$y^*_{hpj} = x'_{hpj}\beta_j + u_{hpj} j = 1, 2, 3, \dots . m. \quad (1)$$

$$\begin{cases} y_{hpj} = 1, if \;\; y^*_{hpj} > 0 \text{ or (if the farmer adopt)} \\ \quad\quad = 0, \text{ otherwise} \end{cases} \quad (2)$$

Where j=1,2,3,….m denote improved tef technology packages available; x'_{hpj} is a vector of explanatory variables, β_j denotes the vector of the parameter to be estimated, and u_{hpj} are random error terms distributed as a multivariate normal distribution with zero means and unitary variance. It is assumed that a rational h^{th} farmer has a latent variable, y^*_{hpj} which captures the unobserved preferences or demand associated with the j^{th} choice of technology packages. This latent variable is assumed to be a linear combination of observed households and other characteristics that affect the adoption of improved tef technology packages, as well as unobserved characteristics captured by the stochastic error term.

Given the latent nature of the variable, y^*_{hpj} the estimation is based on the observed variable y_{hpj} which indicates whether or not a household adopts a particular technology or practice. Since the adoption of several improved technologies is possible, the error terms in equation (1) are assumed to jointly follow a multivariate normal distribution, with zero conditional mean and variance normalized to unity. The off-diagonal elements in the covariance matrix represent the unobservable correlation between the stochastic component of the j^{th} and m^{th} type of technologies. This assumption means that equation (2) gives an MVP model that jointly represents decisions to adopt a particular technology. This specification with non-zero off-diagonal elements allows for correlation across the error terms of several latent equations, which represent unobserved characteristics that affect the choice of alternative technology packages.

Ordered probit model

The MVP model specified above only considers the probability of adoption of tef technologies but does not make any distinction between farmers who adopt one practice and those who use more than one in combination. The ordered probit model helps us to analyze the factors that govern the intensity of adoption, that is, the number of technologies adopted, and the variables that affect the probability of adoption may differently affect the intensity of adoption. As some farmers adopt only part of the package on their farms, but not others, for tef technologies as a package, it is difficult to quantify the extent of adoption, for instance by the fraction of area under the technologies, as is usually done in adoption literature. Following D'Souza et al. (1993) and Wollni et al. (2010), we use the number of tef production technologies adopted as our dependent variable measuring the extent of adoption. In this case, the dependent variable resembles more like a count data and Poisson regression model could have been the ideal option where the underlying assumption is that all events have the same probability of occurrence (Wollni et al., 2010). However, in our application, the probability of adopting the first tef production technology could differ from the probability of adopting a second or third practice/technology as the adoption of one offers farmers an experience, which can determine the decision to adopt/not additional practices. Hence, we treat the number of technologies adopted by farmers as an ordinal variable and used an ordered probit model in the estimation.

Dependent Variables

The dependent variables in the MVP model include five dummy variables corresponding to the use of improved tef technology packages. The dependent variable of the multivariate probit model takes a dichotomous value depending on the farmers' decision either to adopt or not to adopt the improved tef technologies (in this case, improved (certified) tef seed, row planting, recommended weeding practice, recommended DAP/NPS fertilizer rate, and recommended Urea fertilizer rate). Adopters are farmers who planted improved (certified) tef varieties received from a known source, used the row planting method, applied recommended rate of Urea, applied recommended rate of NPS and/or DAP and/or applied recommended weeding frequency on their tef plots while non-adopters are farmers who did not adopt those technologies in the production year (Table 3). In the MVP framework, a farmer may fully or partially adopt the technologies, or even may not adopt all the technological options. The model helps to explain such behavior based on selected independent variables including socioeconomic characteristics of the decision making household. The same independent variables will be used to identify important variables that determine the extent (number) of technologies adopted by the farmers in the framework of ordered probit model where number of technologies adopted (including using none of the technologies) as dependent variables.

Independent Variables

Independent (also known as explanatory) variables often considered in modeling the adoption decision of farmers included household and plot characteristics, and resource ownership, and institutional factors, and access to information variables (Kasie et al 2015, Yirga et al., 2015, Donkoh et al, 2019; Habte et al., 2019). In this study, based on the review of the relevant literature, a range of household, farm, and plot characteristics, institutional factors, and agro-ecology variations are hypothesized to influence the adoption of improved tef technology packages by smallholder farmers. Detailed descriptions of the explanatory variables and hypothesized effects on the adoption of improved technologies are summarized in Table 4.

Among households' demographic characteristics, sex, age, education level, and family size of the households are believed to have differential impacts on the adoption decision behavior of smallholder farmers. The biological variable, sex, can affect production decisions based on the socially constructed position of male and female farmers. Male farmers, due to their privilege associated with access to resources and exposure to information, are likely to take up new practices compared to their female counterparts. Different studies have revealed that the age of the household head plays an important role in the technology adoption of the farmers. An older household head has more experience in production practices and of the local environment that could increase the chances to adopt the technology. However, age can also be associated with short-term planning and loss of energy, as well as being more risk-averse. Thus, the impact of age on technology adoption is indeterminate. The education level of the household heads is expected to boost the readiness of the household head to accept new ideas and innovations regarding the adoption of improved technologies and practices. Large family size is normally associated with labor endowment that would enable a household to accomplish various agricultural tasks on a timely basis. Hence, a household with a large family size is more likely to adopt labor demanding technologies such as weeding frequency and row planting.

Table 4. Definition of variables and their hypothesized influence on adoption of improved technology

Variable	Description	Values	Sign
Sex	Sex of the household head	0=female, 1=male	+
Age	Age of the household head	Years	+/-
Education Level	Education level of the hhd	Years of schooling	+
Household size	Number of family members	Number	+/-
Membership	Membership in the social institutions/organizations	Index number	+
Credit	Did you have a credit access	1=Yes, 0=No	+
Visit demo	Did you ever visit tef demonstration fields?	1=Yes, 0=No	+
Host demo	Did you ever host tef demonstration	1=Yes, 0=No	+
Mobile phone	Mobile phone ownership	1=Yes, 0=No	+
Radio	Radio ownership	1=Yes, 0=No	+
Extension	Frequency of extension contact in a year	Number	+
Training	Did you received training on crop production	1=Yes, 0=No	+
Market distance	Distance to the main market	Minute	+
Own land	Total own land area	Hectare	+/-
Soil fertility	Farmer perception on the level of soil fertility status	1=fertile, 0= infertile	+/-
Crop rotation	Did you grow other than tef in your tef plot last year	1=Yes, 0=No	+/-
TLU	Livestock ownership	TLU	+
Non/off-farm	Non or off-farm income	1=Yes, 0=No	+
Region	The region in which the farmers exist	1=Amhara, 2= Tigray	+/-

Asset and resource ownership characteristics often considered to have a different influence on tef technology adoptions are total own land cultivated and livestock ownership. Own land size and livestock holding are the most important assets for rural households in most parts of Ethiopia. Land size can limit the use of agricultural production technologies while livestock ownership is one of the indicators of wealth status and very important because households get both food and income from livestock and use livestock as a source of transport, traction, and threshing power. Wealth is believed to reflect past achievements of households and their ability to bear the risk and easily access information. Thus, asset and resource ownerships are expected to be positively associated with improved technology uptakes. Land size is expected to affect technology adoption in a different way (negatively or positively). Availability of enough land can encourage trying new technologies, but it might also discourage the use of new technologies because adopting the technologies would come with extra cost (Kassie et al. 2015, Zewditu et al. 2020). Therefore, this study hypothesized that the relationship between land size and improved technology adoption may be indeterminate. On the other hand, ownership of livestock has a positive and significant impact on the probability of using improved technology adoption (Wordofa et al., 2021).. It is, therefore, hypothesized that farmers with a large number of livestock are expected to use improved tef technologies and practices.

Location, farm, and plot-related characteristics that can influence the adoption of improved tef technology packages are soil fertility status of tef plot, plot history on crop rotation, and region in which the farm household lives. Soil fertility status and crop rotation history of the plot might have a positive effect on improved seed use, and row planting while it might have a negative influence on the application of recommended rate of DAP/NPS and Urea fertilizers and recommended frequency of weeding. Regional variation is often considered as an important determinant of the adoption of tef technologies. The study was conducted in Amhara and Tigray National Regional States where there could be a regional variation in technology availability, accessibility, and extension service. The regional difference in promoting technologies and seed delivery systems might affect technology uptake. So, the influence of location dummies on the use of improved technology may be indeterminate.

Institutional factors often considered to have differential impacts on technology adoption by smallholder farmers are frequency of extension contact, access to credit, access to market, mobile phone ownership, radio ownership, non or off-farm employment, membership in social institutions, hosting, and/or participation in demonstration events. Various studies in developing countries including Ethiopia reported a strong positive relationship between access to information and the adoption behavior of farmers (Yirga et al., 2015, Donkoh et al., 2019). Hence, it is hypothesized that access to extension is more likely to favor the adoption decision. Also, studies by Atinafu et al., (2022) underscored the role of credit in enhancing the adoption of crop technologies. Market access facilitates access to information, technologies, and development institutions. Distance to the nearest main output market was used as a proxy for market access. Hence, distance to the main market is expected to have a negative influence on technology uptake.

Radio is also a common source of information for farm households. Apart from using radio as entertainment, rural households also obtain information on improved farming practices and farmers' best practices. This also increases farm households' awareness and exposure to improved farming technologies and new lifestyles (Habte et al, 2020). Therefore, mobile and radio ownership is expected to influence technology adoption positively. It is observed that farmers with off-farm income are less risk-averse than farmers without sources of off-farm income. Households that have alternative sources of income are likely to adopt improved technologies and practices because off-farm employment may widen the information horizons of the farmer about new technologies and build the financial capacity of the household. However, alternative sources of employment may also compete for time and effort with agricultural activities, reducing investment in technologies and the availability of labor (Kassie et al., 2015). Therefore, this study hypothesized that the effect of an alternative source of employment variable on adoption is not identified.

Results and Discussion

Descriptive Analysis Results

Demographic Characteristics of the Households

Demographic characteristics of the households determine the preference of the households on a given technology. The average household size for the sample households was about 5.7 persons with a standard deviation of 1.9. Among the sample households, 89% were male-headed (Table 5). The educational level of sampled household heads was believed to be an important feature that determines the readiness of the household head to accept new ideas and innovations regarding technology adoption. The survey results also show that the interviewed households' average education level was 2.2 years of schooling which had an average age of 46.6 years.

Table 5: Demographic characteristics of sampled households

Variables	Mean/proportion	SD	Min	Max
Education level (number of school years)	2.2	2.7	0	12
Sex (Male) (%)	89	32	-	-
Age (year)	46.6	12.0	18	95
Household Size (number)	5.7	1.9	1	10

Source: Own computation results, (2018)

Socioeconomic Characteristics of the Sample Households

Land is an important limiting factor for agricultural production in Ethiopia, in general, and in the study area in particular. The land tenure system in the study area includes own, shared-in, rented-in, and borrowed-in land. A system of shared-in or rented-in land use arrangement has been practiced between the owner of the land and operator farmer in a specific production year with a specified agreement on the benefits sharing. The average landholding size of sampled households is about 1.08 ha ranging from 0 to 4 hectares, and more than half of the holding (0.62 ha) was allocated for tef (Table 6). The average household level productivity of tef was 1228 kg ha^{-1}, and 949 kg ha^{-1} in Amhara and Tigray region respectively which is far below the regional (1540kg/ha in Amhara and 1790kg/ha in Tigray) and the national average (1750 kg/ha) (CSA, 2020). The landholding, among other variables, across gender and adoption status of herbicides is indicated in Table A1 and A2 (annex).

Livestock holding size is one of the indicators of wealth status and the most important asset for rural households in most parts of Ethiopia. Based on Storck *et al.* (1991) standard conversion factors, the livestock population number was converted into Tropical Livestock Unit (TLU) for ease of comparison. According to the survey result, the average livestock holding of the sample households was 4.91 TLU and the range goes from 0 to 21.22. This shows that there is a high population of livestock as well as wide variability in terms of livestock ownership among the smallholders (Table 6).

Table 6. Socioeconomic characteristics of sampled households by certified seed adoption

Variables	Average (Standard deviation)			Min	Max	Test-statistics (t-test)
	Total (N=483)	Adopters (N=136)	Non-adopters (N=347)			
Landholding (ha)	1.08 (0.69)	1.12 (0.73)	1.05 (0.66)	0	4	-1.1977
Tef Land (ha)	0.62 (0.52)	0.73 (0.61)	0.55 (0.42)	0.03	3.87	-3.9156
Tef land in improved seed (ha)	0.25 (0.42)	0.62 (0.45)	0.00 (0.00)	0	3.25	-22.7435
Tef yield (kg)	1179.9 (685.1)	1299.5 (699.9)	1096.3 (663.1)	0	3600	-3.2418
TLU	4.91 (3.27)	5.52 (3.48)	4.49 (3.05)	0	21.21	-3.6250

*Seed received from a known source

The patterns and choice of crop production and livestock rearing , and use of improved technologies can mainly be determined by the nature and development of institutional infrastructures like credit access, extension service, membership in social institutions, and input/output market. For the sample households, the average travel time to reach the nearest main market in walking time was 85.5 minutes. Comparatively, on average farmers in Tigray had better proximity (69.8 minutes) to the market than that of Amhara (88.7 minutes).

The basic information related to agriculture is crucial to enhance the knowledge and skills of farmers. Farmers might get information from different sources in various ways including personal contact with extension agents, using radio or mobile phones. The survey result shows that the average frequency of extension contact was 16.5 times per year, the corresponding result for Tigray (23) was higher than that of the Amhara regional state (15) (Table 7). The survey result also showed that 60% of the households received training on newly released improved varieties of tef in the last five years. More farmers from Tigray (76%) received training on improved varieties of tef than that of Amhara (57%). Nearly half (48%) of the sample farmers reported to have access to credit (Table 7). The availability of credit for resource-poor farmers is quite important to finance agricultural technologies and management options that help to improve their productivity. Access to credit for smallholder farmers is one way of improving their economic and ultimately adaptive capacity.

Table 7. Institutional and information related characteristics by certified seed adoption

Institution related variables	Amhara	Tigray	Over All	Test-statistics (t-test/ χ2)
Frequency of Extension contact	15.15	23.18	16.53	-1.5773
Training on tef (Yes=1)	0.57	0.76	0.60	6.9313***
Credit access (Yes=1)	0.46	0.59	0.48	12.6017***
Membership in social institutions (index (0 to 1)	0.20	0.25	0.21	16.9199***
Distance to main market (minute)	88.72	69.76	85.48	-1.1978
Mobile (Yes=1)	0.35	0.63	0.40	0.6375
Radio (Yes=1)	0.63	0.81	0.66	1.8821
Visit demonstration field (Yes=1)	0.39	0.45	0.40	1.1349
Host demonstration field (Yes=1)	0.15	0.24	0.17	7.6312***

Source: Own computation from survey results (2018)

Smallholder farmers have different social institutions and organizations (saving and credit, *Equb*, input supply cooperative, marketing cooperative, irrigation users association, seed producers cooperative, women association, youth association, and one to five group) in the study area. Membership of the sample households in the social institutions or organizations was measured as an index ranging from zero to one. The result showed that sample farmers are members in two out of ten social institutions, on average. In regards to exposure, the result also showed that nearly half of the sample farmers in general receive information through electronic media and physical participation in field demonstrations.

Improved variety of tef cultivated by sample households

The list of tef varieties cultivated by the sample households along with their spread in the study area are indicated in Table 7. The variety *Quncho* (DZ-01-387), which was released in 2006, had been widely adopted in both Amhara and Tigray regions. According to Assefa et al. (2013) apart from other factors, traits such as high yield, white seed color, and relative resistance to lodging are responsible for the comparatively wider cultivation of the Quncho variety. Following *Quncho*, *Magna* (DZ -01-196) was the next variety in terms of proportion of plots covered, but the share relatively remains far too small (6%); the remaining improved tef varieties each assumed only less than 2% of the plots. For about 30% of the tef plots, the sample households did not identify the name of the improved tef variety they planted. Around 22% of the household plots covered in tef were planted to local varieties (Table 8).

Table 8. The adoption rate of improved tef variety (% of plots)

Tef Variety	Year of release	Adoption at plot level (%)		
		Amhara	Tigray	Over All
Quncho -/Dz -Cr-387)	2006	28.4	60.0	34.9
Magna (DZ -01-196)	1970	7.7	0.0	6.1
Kora (DZ-Cr-438)	2014	0.5	6.9	1.8
Etsub (Dz -01-3186)	2008	2.0	0.0	1.6
Simada/DZ -Cr-385)	2009	1.3	0.0	1.0
Tseday (DZ-Cr-37)	1984	0.8	0.0	0.6
Worekiyu (214746A)	2014	0.3	0.6	0.4
Guduru-DZ-01-1880)	2006	0.3	0.0	0.3
Key Tena (DZ -01-1681)	2002	0.3	0.0	0.3
Enatit (DZ -01-354)	1970	0.3	0.0	0.3
Koye (DZ-01-1285)	2002	0.2	0.0	0.1
Improved but unknown	-	35.9	8.8	30.3
Local	-	22.0	23.8	22.3

Source: Own survey data (2018)

Adoption of Improved Tef Technology Packages

Farmers are rational and make use of available options to increase their crop productivity. In this study, a significant proportion of sample farmers have adopted different tef production technologies. The most common improved technology packages used by the farmers were improved/certified tef seed, row planting, recommended weeding frequency, recommended DAP/NPS and recommended Urea fertilizer. Operationally, sample farmers who used these technologies (or any one of them) in the study year are identified as adopters while farmers who did not adopt those technologies are considered as non-adopters. In the case of seed, identifying a given variety used by farmers as improved demands knowledge of the number of times it has been recycled. For crops like tef, which is not hybrid, a given variety could be planted repeatedly for some time before it loses its vigor, it is difficult to establish the number of times a farmer recycled a variety at the time of interview. This is mainly because a farmer might get seed from non-formal sources and that seed might not be fresh. In fact, if we disregard the recycling of seed, almost all of the farmers are adopters of improved seed. Therefore, this study considered households who used fresh seed from the known source as adopters of improved (certified) tef seed and others as non-adopters. The adoption rate of certified tef seed by interviewed households was higher in the Tigray region (57.8%) than in the Amhara region (37.7%). The aggregate adoption rate of certified tef seed in the northern part of Ethiopia was 41.1% (Table 9).

Planting method is one of the agronomic practices that can enhance productivity. The most common planting method is broadcasting, row planting, and transplanting. Row planting is one of the main improved tef practices that extension workers and researchers recommend for a better productivity and a significant reduction in seed rate. Moreover, row planting is one of the agronomic practices used to increase the efficient use of fertilizers, make weeding, cultivation, and other agronomic activities easier. The research finding indicated that row planting brings substantial yield increment over broadcasting (Vandercasteelen et al., 2014).. Accordingly, the row planting method is being aggressively promoted to increase adoption by smallholder farmers in Ethiopia. The interviewed households claim that row planting method has high demand for labor during the busiest period of the production season. In this study, farmers who were not growing tef in a row were considered as non-adopters, while farmers who were growing teff in row planting either tef seed or tef seedlings were considered as adopters. Thus, the adoption rate of row planting in the study area was 36.8%; it was practiced widely by farmers in Tigray (50.6%)) compared to that of Amhara (33.9%) (Table 9).

Farmlands are limited and increasing population continues to reduce the holding per household. Having smaller land size, families have to cultivate it all the time and affect the fertility and thus productivity of the land. As farm plots are tilled year in and year out, soil nutrients get depleted and soil fertility keeps on deteriorating. Erosion and continuous cultivation decrease the fertility of the soil. Farmers are using chemical fertilizers to keep the fertility/productivity of the soil. The agricultural extension system of the country encourages the farmer to apply chemical fertilizer on their cropland and increase the production and productivity of crops. Since the last two decades, fertilizer use has become popular for almost all the crops, in general, and for tef in particular. The findings have also witnessed that fertilizer use is very common especially in tef production in the study area. Almost all interviewed households use Urea and DAP/NPS fertilizer for tef production. The most common blanket fertilizer recommendation for tef and other cereal crops production in the study area is applying 100 kg of DAP/NPS and Urea. Some research findings in the Amhara and Tigray region recommended applying 34.5 to 46 kg of N and 46 kg to 69 of P_2O_5 (Abebe et al., 2020; Giday, 2014; Mihretie et al., 2021). In this study, the farmers are considered adopters of the recommended rate of Urea, and DAP/NPS fertilizers if the farmers applied 75 kg and more of Urea and 100 kg and more of DAP/NPS per hectare. The overall adoption rate of the recommended rate of Urea, and DAP/NPS in the study area was 47.4%, and 64.0% respectively. About 42.9% and 69.9% of households of Amhara and Tigray region farmers applied recommended rate of Urea on their tef farm while 59.0% and 65.1% households of Amhara and Tigray region adopted recommended rate of DAP fertilizer respectively (Table 9).

Table 9. Summary of Adoption status of improved tef technology packages across regions (%)

Regions	Zone	Certified seed	Row Planting	Recom. Weeding	Recom. use of DAP	Recom use of Urea
Amhara	East Gojam	77.1	18.6	7.1	81.4	71.4
	West Gojam	36.4	52.3	11.4	72.7	31.8
	North Shewa	22.2	31.1	95.6	68.9	20.0
	South Gonder	35.2	40.8	80.3	71.8	52.1
	Central Gonder	19.8	35.8	67.9	46.9	32.1
	South Wollo	33.3	31.1	91.1	57.8	40.0
Amhara Average		37.7	33.9	61.6	65.1	42.9
Tigray	Central Tigray	68.9	68.9	93.3	62.2	80.0
	South Eastern Tigray	44.7	28.9	65.8	55.3	57.9
Tigray Average		57.8	50.6	80.7	59.0	69.9
Over All		**41.1**	**36.8**	**64.9**	**64.0**	**47.5**

Source: own survey data (2018)

Weed management is one of the key factors that can contribute to crop productivity. Depending on the severity of weed infestation, the recommended frequency of weeding is twice at tillering and stem elongation stage. Weeding twice at tillering and stem elongation stage can increase the yield of tef by 20% over the unweeded treatments (Mihretie et al., 2021; Zewditu et al., 2020). In this study, the farmers are considered as adopters if they weed their plot at least two times, otherwise regarded as non-adopters. The overall adoption rate of recommended weeding in the study area was 64.9%. About 61.6% and 80.7% of interviewed households of Amhara and Tigray regional states (respectively) followed the recommended weeding practice (Table 9).

The details of the technologies adopted by smallholder farmers are presented in Table 10, and nearly all the sample farmers used at least one of the five technologies listed in the package. From those farmers who adopted only one technology from the package (20%), more than half adopted only recommended weeding practices. This implies that farmers had a culture of weeding their plots irrespective of the variety used. In addition, there are more farmers who used a combination of technologies which did not include the improved varieties- an indication that even with non-certified or local varieties farmers continue to apply other recommended practices. Farmers who used the full package were only 5.4% of sampled households. Those who used two or three of the technologies make up more than half of the samples. About 78% of the sampled households adopted more than one technology package.

Table 10. Number and combination of improved tef technologies adopted by sample farmers

Number of technologies adopted	Adopted technologies										**Overall adoption**	
	Seed		Row		Weed		Urea		DAP			
	n	%	n	%	n	%	n	%	N	%	**n**	**%**
None	0	0	0	0	0	0	0	0	0	0	**11**	**2.3**
One	11	2.3	7	1.4	61	12.6	2	0.4	16	3.3	**97**	**20.0**
Two	41	8.5	36	7.4	64	13.2	45	9.3	76	15.7	**131**	**27.1**
Three	69	14.3	50	10.3	87	18.0	84	17.4	112	23.1	**134**	**27.7**
Four	52	10.7	59	12.2	76	15.7	73	15.1	80	16.5	**85**	**17.6**
Five	26	5.4	26	5.4	26	5.4	26	5.4	26	5.4	**26**	**5.4**
Total	199	41.1	178	36.8	314	64.9	230	47.5	310	64.0	**484**	**100.0**

Source: Own survey data (2018)

Determinants of adoption of improved tef technology packages

Multivariate probit regression result

A multivariate probit (MVP) model was used to identify the factors that determine the adoption of improved tef technology packages in the study area. In light of declining per capita land size, intensive farming involving the use of yield-enhancing technologies is crucial. Different factors can influence tef producing farmers' decision to adopt a particular or set of technologies/practices. We have modeled five dependent variables (improved technologies and practices) over nineteen explanatory variables in the multivariate probit regression framework (Table 11).

Before running the model, the whole explanatory variables fitted to the MVP model were tested for the existence of outliers and collinearities. The variance inflation factors for all variables were less than 5, which indicate that multicollinearity is not a serious problem in this model. The MVP model is significant because the null hypothesis that the probability of the adoption of the five tef technology packages is independent was rejected at a 1% significance level. The model result also revealed that the Wald test is statically significant at the 1% level indicating that the variables included in the model explain significant portions of the variations in the dependent variables. Furthermore, the results on correlation coefficients of the error terms also indicate that there is some level of interdependence between the decisions to use the technology options by farmers. The results, therefore, support the assumption of interdependence between the different technology options and detail of the result is presented in Table 12 in the subsequent section.

The MVP results revealed that several hypothesized demographic, farm, institutional and location variables have significant effects on the decision to use improved tef technologies. Most of the estimated parameters conform to the expected signs in influencing the adoption of improved tef technology packages in the study area. We discuss the model result for each one of the technology packages. The model results are presented in Table 11.

Looking into the factors influencing the decision to adopt improved seed, we found that the education level of the household head, credit access, hosting demonstration fields, training, livestock ownership, and location dummy have significant and positive effect while non or off farm income and crop rotation practice on the tef plot are found with an opposite relationship. The positive effect of education on the decision to adopt improved/certified seed is expected given the importance of education in accessing various forms of information and the ability to decipher complex subjects. Participating in training and hosting demonstration fields offers households with theoretical and practical knowledge about improved agricultural technologies. Access to credit services and livestock ownership helps the farmers in adopting improved seed technology by reducing the financial constraints of the households to purchase the seed. Farmers living in Tigray have higher chances of using certified tef seed as compared to farmers living in Amhara regional state which could be because of the accessibility and availability of certified seed in the regions. As indicated in the descriptive statistics earlier, the sample farmers in Tigray are closer to the market than those in Amhara based on the walking distance to the main or the nearest market; this is likely to facilitate the use of certified seed. Although it can help to relax the budgetary constraints, participating in non/off-farm income (marginally significant variables), on the side, may compete for the attention as well as time which a household labor could have spent attending to tef production and associated decisions. In addition, the seed delivery and extension system in place might also contribute to the difference in the adoption decision of the farmers living in these two regional states. The negative relationship with crop rotation might be associated with the belief that use of this practice could justify non-use of improved varieties which require chemical fertilizer as a necessary element of the package. The negative relationship of this variable with use of fertilizer somehow favors this argument.

In relation to the second technology (row planting), family size, serving as a host to tef demonstration, ownership of mobile, training on crop production, and fertility status of the plot are found to be positive drivers of using the practice. On the other hand, the age of the household head and distance to the main market have a negative effect on the practice of teff row planting. Row planting is a labor demanding practice compared to the traditional practice of broadcasting. In this regard, the positive effect of family size on adopting row planting is expected. Family members are the source of household labor. Men, women, and children participate in teff row planting and transplanting of tef seedlings while only men could participate in broadcasting of tef seeds. Hosting demonstration fields, participation in training as well as having mobile phones offers households with information that can change perceptions and behaviors towards the advantage of the practice thereby encouraging the use of row planting. As row planting involves committing additional labor, older farmers might be less likely to do this and may stick to the older and less labor demanding practice until they are convinced of the worth of row planting from neighbors or other friends. Similarly, farmers who have little access to the market might have less incentive to boost production and are likely to confine their production objective to subsistence in which case little or no interest to go for yield enhancing yet labor demanding practice like row planting.

Table 11. Multivariate probit simulation results for adoption of tef technology packages

Explanatory variables	**Certified seed**	**Row Planting**	**Recom Weeding**	**Recom DAP**	**Recom Urea**
	Coef. (Robust S.E)	Coef. (Robust S.E)	Coef. (Robust S.E)	Coef. (Robust S.E)	Coef. (Robust S.E)
Sex (1=male)	0.196 (0.201)	0.044 (0.206)	-0.936*** (0.299)	0.073 (0.205)	-0.158 (0.208)
Age (years)	-0.002 (0.006)	-0.014** (0.006)	0.018*** (0.006)	-0.005 (0.006)	-0.001 (0.006)
Education level (schooling year)	0.066** (0.026)	-0.006 (0.025)	0.110*** (0.031)	-0.022 (0.026)	0.003 (0.026)
Family size (number)	-0.014 (0.038)	0.072* (0.038)	-0.016 (0.043)	-0.050 (0.037)	-0.028 (0.037)
Social membership (index)	0.403 (0.483)	-0.541 (0.491)	-0.598 (0.518)	-0.326 (0.471)	-0.826* (0.474)
Credit access (1=yes)	0.275** (0.126)	-0.017 (0.126)	-0.189 (0.144)	0.181 (0.126)	0.296** (0.125)
Visit demo field (1=yes)	-0.205 (0.155)	0.069 (0.146)	0.207 (0.166)	0.086 (0.147)	0.001 (0.148)
Host demonstration filed(1=yes)	0.363* (0.187)	0.470*** (0.178)	-0.023 (0.207)	0.126 (0.188)	0.148 (0.184)
Mobile ownership (1=yes)	-0.114 (0.135)	0.352*** (0.135)	0.002 (0.154)	0.109 (0.136)	-0.271** (0.134)
Radio ownership (1=yes)	0.071 (0.141)	0.209 (0.146)	0.024 (0.150)	0.180 (0.142)	0.224 (0.141)
Frequency of Extension contact	-0.001 (0.005)	0.000 (0.005)	0.008 (0.006)	-0.011** (0.005)	-0.010** (0.005)
Training (1=yes)	0.265* (0.142)	0.298** (0.142)	0.295* (0.162)	0.232 (0.144)	0.342** (0.142)
Distance to market (minute)	0.002 (0.001	-0.002** (0.001)	0.001 (0.001)	-0.001 (0.001)	0.000 (0.001)
Own land (continuous)	-0.041 (0.106)	-0.118 (0.110)	-0.438*** (0.113)	-0.232** (0.105)	-0.214** (0.102)
Soil fertility (1=fertile)	0.129 (0.128)	0.250* (0.128)	-0.279** (0.140)	-0.091 (0.126)	-0.067 (0.126)
Crop rotation (1=yes)	-0.625*** (0.148)	-0.022 (0.150)	0.681*** (0.163)	-0.181 (0.150)	-0.626*** (0.150)
TLU (continuous)	0.040* (0.023)	-0.008 (0.024)	-0.112*** (0.028)	0.082*** (0.027)	0.041* (0.023)
Non off farm (1=yes)	-0.232* (0.139)	0.0159 (0.133)	0.096 (0.145)	0.053 (0.132)	-0.066 (0.134)
Region (Ref=Amhara)	0.373** (0.189)	0.202 (0.184)	0.348 (0.231)	-0.279 (0.188)	0.677*** (0.194)
Constant	-1.020** (0.424)	-0.568 (0.421)	0.303 (0.479)	1.055** (0.422)	-0.133 (0.425)

***, ** and * significant at 1%, 5% and 10% probability level, respectively. Coef. = coefficient and Robust S.E = Robust standard errors in parenthes

When it comes to the recommended rate of Urea and DAP/NPS fertilizer, access to extension service, and owned land size are negatively related with the use of both types of fertilizer. On the other hand, livestock ownership is found to be a positive driver of adopting both fertilizer types. In addition, membership in social institutions, mobile ownership and crop rotation practices on the tef plot seems to discourage the use of Urea fertilizer. Crop rotation is planting different crops sequentially on the same plot to improve soil fertility and soil health. Crop rotation is a means to enhance soil fertility status, and its negative relationship with the use of inorganic fertilizer is understandable. But the sign for extension service is quite interesting as the service is supposed to encourage the use of these inputs. This might pose a question both on the quality of the service as well as on whether the extension personnel meets the farmers for a purpose different from creating awareness and promoting the use of technologies such as fertilizer. Plausibly, it could also be the case that the extension service pushes the use of organic fertilizer, about 15% of the samples were found to use organic fertilizer for their tef plot. The positive contribution of training for the use of fertilizer (it is significant for Urea in this case) stands in contrast with the sign for extension service. In fact, training is one of the extension instruments to promote awareness and encourage the use of such inputs. Ownership of larger land sizes seems to discourage using recommended fertilizer rate probably due to financial constraints to follow the recommended rate for the whole land. The positive effect of credit on the use of these fertilizers also reinforces this argument. Credit availability seems to encourage investment in the use of fertilizer. Likewise, livestock ownership which is a potential source of finance tends to facilitate the use of recommended fertilizer rates. The contrasting relationship of mobile ownership with the application of recommended Urea fertilizer (negative and significant), demands a different explanation through additional investigation. Mobile phones are a means to access information on the price and availability of inputs in the market and the negative relationship seems counter intuitive.

In addition, using the recommended frequency of tef weeding was positively and significantly affected by age, education level of the household head, training, and crop rotation of the tef plot. On the contrary, the likelihood of adopting recommended frequency of tef weeding was significantly and adversely affected by the sex of the household head, own land size, soil fertility status of the plot and livestock ownership. Older farmers are assumed to have gained knowledge and experience over time about the value of weeding the plot than younger farmers. In addition, educated and trained farmers are more able to process information and search for appropriate technologies to alleviate their production constraints. Farmers with large land size and livestock ownership had a lower probability to adopt recommended weeding frequency possibly due to labor competition for crop and livestock production. The negative relationship between being male and following recommended weeding practice sounds counterintuitive given that male are comparatively less resource constrained in a patriarchal family like in the study area. Probably due to resource constraint female farmers may not be cultivating or having larger farm sizes which may give them a chance to closely attend their plots, for example, by keeping their plots clean from weeds. Also, male farmers, instead of hand weeding, might resort to the use of herbicides to reduce the weed infestation (See Table A1 and A2). In this case, we may not observe them following the recommended manual weeding practice.

Pairwise correlations of improved tef technology packages

Pairwise correlation coefficients across the five tef technology adoption equations are also summarized in Table 12. It is a post estimation result after running a multivariate probit model. The coefficients measure the pairwise correlation between the decision to adopt any one of the five technologies with the other four technologies after the influence of the observed factors have been accounted for (Green, 2003). Essentially, these are pairwise correlations between the error terms in the system of equations in the multivariate probit model.

The likelihood (predicted probability) of households to adopt certified tef seed, row planting, recommended weeding frequency, recommended rate of DAP/NPS and recommended rate of Urea were 40.2%, 35.7%, 69.1%, 65.0%, and 47.5% respectively. The least likelihood for row planting could be associated with labor constraints emanating from a peak time competition with other enterprises. Thus, farmers may prefer to go for an age-old tradition of seed broadcasting which is relatively less demanding in terms of labor. Efforts to develop labor saving techniques for row planting could help quicker adoption of the practice and reap the benefit thereof, i.e., ease of carrying out various agronomic practices, seed saving and increasing productivity. The fact that tef is a commercial crop, a higher likelihood to stick to recommended weeding practice seems justified as weeds are likely to reduce output by up to 20%. The growing dependence on the use of fertilizer is well reflected in the higher likelihood of using them. The result also shows that the joint probability of using all technology packages was 4.8% and the joint probability of failure to adopt all tef technology packages and practices was 3.8%. Except for weeding, almost all the pairwise coefficients were positively correlated, indicating complementarity among the improved tef production technologies. Farmers who adopt anyone of the four technologies are unlikely to practice weeding. Nonetheless, most of the correlations were not statistically significant. Only a few of the technologies which are related to fertilizer and row planting exhibited their complementarity in a statistically significant manner. The use of DAP is likely to reinforce the adoption of row planting. Likewise, the use of DAP (which is often applied at planting) is likely to lead to the application of Urea fertilizer (which is applied at a different stage of the plant) (Table 11).

Table 12. Correlation matrix of the technologies from the multivariate probit model (Robust S.E)

Technologies	Certified seed	Row Planting	Recom. Weeding	Recom. DAP	Recom. Urea
	Coef. (S.E)	Coef. (S.E)	Coef. (S.E)	Coef. (S.E)	Coef. (S.E)
Row Planting	-0.034 (0.079)				
Recom Weeding	-0.093 (0.087)	-0.038 (0.087)			
Recom DAP	0.080 (0.078)	0.231^{***} (0.080)	-0.074 (0.086)		
Recom Urea	0.040 (0.079)	0.101 (0.078)	-0.012 (0.082)	0.655^{***} (0.086)	
Predicted probability	0.4021	0.3570	0.6908	0.6495	0.4754
Joint probability(success)		4.8%			
Joint probability(failure)		3.8%			
Number of observations		484			
Number of simulations		100			
Log-likelihood		-1368.19			
Wald χ2 (degree of freedom)		405.09^{***} (95)			

Coef. = coefficient and S.E = standard error

Likelihood ratio test of H_0: $Rho_{ij} = 0$; Chi2 (10) = 73.72 Prob > Chi2 = 0.00; *** refers to significance at 1% probability level

Ordered probit regression result

Table 12 shows the results from ordered probit models. The Chi-squared statistic for the ordered probit model is statistically significant [$\chi 2$ = 99.23 & p=0.000)] at less than 1% significance level, indicating that the joint test of all slope coefficients equal to zero is rejected.

Table 11. Coefficient estimates of order probit model *(Dep. Variable: Number of technologies adopted)*

Explanatory variables	**Coef.**	**Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**
Sex (1=male)	-0.148	0.164	-0.9	0.368	-0.469	0.174
Age (years)	-0.001	0.005	-0.14	0.891	-0.011	0.009
Education level (schooling year)	0.040*	0.023	1.78	0.074	-0.004	0.085
Family size (number)	-0.009	0.031	-0.31	0.757	-0.070	0.051
Social membership (index)	-0.524	0.373	-1.4	0.16	-1.256	0.207
Credit access (1=yes)	0.210**	0.099	2.12	0.034	0.016	0.404
Visit demo field (1=yes)	0.042	0.116	0.36	0.718	-0.186	0.270
Host demonstration filed(1=yes)	0.385***	0.135	2.85	0.004	0.120	0.649
Mobile (yes=1)	0.022	0.106	0.21	0.836	-0.185	0.229
Radio (yes=1)	0.234**	0.112	2.09	0.037	0.014	0.454
Frequency of Extension contact	-0.005	0.004	-1.14	0.256	-0.013	0.003
Training (1=yes)	0.425***	0.113	3.78	0.00	0.205	0.646
Distance to market (minutes)	0.000	0.001	-0.26	0.794	-0.002	0.001
Own land (ha)	-0.342***	0.084	-4.08	0.00	-0.506	-0.178
Soil fertility (1=fertile)	0.007	0.098	0.08	0.94	-0.185	0.200
Crop rotation (1=yes)	-0.319***	0.119	-2.68	0.007	-0.551	-0.086
TLU (continuous)	0.022	0.018	1.2	0.231	-0.014	0.058
Non off farm (1=yes)	-0.058	0.106	-0.55	0.582	-0.265	0.149
Region (Ref=Amhara	0.440***	0.162	2.72	0.007	0.123	0.756
/cut1 (Intercept 1)	-1.894***	0.327			-2.534	-1.254
/cut2 (Intercept 2)	-0.540*	0.309			-1.146	0.065
/cut3 (Intercept 3)	0.285	0.307			-0.316	0.886
/cut4 (Intercept 4)	1.121***	0.307			0.519	1.724
/cut5 (Intercept 5)	2.126***	0.315			1.509	2.743
Mean dependent var		2.543	SD dependent var			1.209
Pseudo r-squared		0.064	Number of obs			484
Chi-square		99.227	Prob > chi2			0.000
Akaike crit. (AIC)		1479.161	Bayesian crit. (BIC)			1579.531

The result showed that farmers are more likely to adopt a greater number of tef production technologies when they have higher level of education, can access credit, own radio, participate in hosting technology demonstration and in training. Beyond the frequency of contact with extension which sometimes may not be linked to production activities, the findings suggest that direct participation in extension activities (demos, training) and access to capital and information (radio) were found to favor adoption of more tef production technologies. Unlike the findings by Tekelewold et al., (2013) where plot ownership encourages use of greater number of sustainable agricultural practices, our result indicated that size of owned land tends to decrease the number of tef production technologies adopted. This could be due to the features of the technologies considered under these two studies. Farmers could be more interested to invest in their own land when the investment has an implication for sustainability, but a similar behavior may not be exhibited for investments that are directed for an annual return. Apart from having no direct cost of land, the cost implication for larger plots might be less motivating to use more tef technologies. Moreover, farmers practicing crop rotation are likely to use a small number of tef production technologies suggesting that farmers might consider this practice a substitute to some of the technologies such as fertilizer as noted in the output of the MVP regression result. The significant location dummy imply that farmers in Tigray are more likely to use a greater number of tef production technologies compared to those in Amhara.

Conclusions and Policy Implications

The need to apply improved technology packages and practice in the agricultural sector has become more relevant as the possibility of expanding cultivable land is getting exhausted due to population growth and urbanization in the northern part of Ethiopia. Therefore, the adoption of improved production technologies are crucial in increasing productivity and lowering the poverty levels of the farmers. The study analyzed the adoption of different improved technologies among tef producer farmers in northern Ethiopia using data from a sample of 484 tef producer households. Particularly, the adoption decision for five improved tef technology packages and practices (Certified tef seed, row planting, recommended weeding frequency, recommended DAP/NPS fertilizer and recommended Urea) are analyzed using a multivariate modeling framework which accounts for possible interdependence among individual decisions.

The study area was an important production zone where households allocated at least half of their holdings. Most of the households were male headed, have a lower level of education and livestock is also an important enterprise. About 4 and 2 out of 10 households visit or host demonstrations respectively. Following an aggressive technology scaling up activity carried out in the area, *Quncho* which was widely promoted then was found out to be the dominant tef variety cultivated by more than a third of the farmers. The average productivity in the study area, however, remains way below the national average suggesting the need for wider intervention to promote the use of improved tef production technologies.

The MVP results revealed that several hypothesized demographic, farm, institutional and location variables have a significant and differential effect on improved tef technology adoption. The decision to use each of the improved technology components in the package was influenced by different factors and at different levels of significance. Sex of the household head, age of the head, educational level of the household, household size, membership in social institutions, access to credit, hosting demonstration fields, mobile ownership, frequency of extension contact, training, distance to the nearest main market, own land size, soil fertility status of tef plot, crop rotation practice, livestock ownership, non or off-farm income and location play significant roles, partly with differing signs across improved tef technology packages.

Opportunities to visit or host demonstrations is a powerful means to convince farmers to adopt improved seed as well as practices such as row planting. Wider cultivation of the *Quncho* variety in the northern part of Ethiopia is a result of aggressive technology demonstration efforts. Therefore, similar yet coordinated demonstration activities need to be extended to the other technologies as well. The positive relationship between adoption of row planting and family size is an indication that such decisions are constrained by labor availability. Efforts to introduce labor saving technologies to encourage the use of not only row planting but also other practices such as weeding will be instrumental.

The size of landholding is found to discourage the application of recommended agronomic practices such as weeding and fertilizer. This could be a sign of budgetary constraint and credit should be made readily available to ensure that agronomic practices are observed as per the recommendation. Crop rotation can help in restoring soil fertility and reducing weed infestation, but this shouldn’t preclude the use of fertilizer as shown in its negative relationship with fertilizer application. It is important to generate information on soil based fertilizer application to minimize over- or under-application of fertilizer, nonetheless, in the absence of this information farmers need to be advised on how to harmonize crop rotation practice with fertilizer application.

It is also observed that some enterprises (livestock and crop production practices) could compete for limited resources such as labor and capital. This makes skills such as farm management very essential. While farmers have developed this skill as a function of experience, it is wise to support their experience with a more scientific one by incorporating theoretical as well as practical farm management training . This, in fact, requires special expertise in the extension system. The finding which showed that more frequent contact with extension discourage the use of both types of fertilizer needs an in-depth analysis on why the relationship happens to be counterintuitive. It might be associated with a shift to organic fertilizer, nonetheless, it requires a critical examination of the content of the extension service in this regard. . Moreover, the location based differences in terms of technology adoption indicates the need to learn from the experiences of areas where the extension and associated services are productive.

Most of the improved tef production technology packages are complementary suggesting that the adoption of one of the technology components was conditional on the adoption of the others. This implies that farm-level policies that affect one improved agricultural technology for tef production can have spillover effects on the other technologies. For example, efforts to encourage the use of DAP fertilizer is likely to lead to the application of row planting and UREA fertilizer. Therefore, interventions need to be inclusive in terms of technology (package based) or should focus on selected technologies that encourage the adoption of the other ones.

While infrastructures (road, communication and so on) remain vital to ensure accessibility and availability of technologies (certified seed and fertilizer) and information, extension activities such as training and large-scale demonstration of improved tef technology packages continues to be necessary not only to enhance the adoption but also the use of more number of tef production technologies/ practices in the study area. In addition, the mechanization of some of the labor intensive practices such as row planting and weeding can facilitate adoption while minimizing labor competition with other enterprises.

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Appendix

A1. Gender based descriptive statistics

Variables	Sex of the household head (Standard Deviation)			Test-statistics (t-test)
	Total (N=484)	Male (N=430)	Female (N=54)	
Landholding (ha)	1.077 (0.689)	1.109 (0.709)	0.821 (0.419)	-2.9151***
Weeding frequency (number)	1.912 (0.844)	1.855 (0.851)	2.370 (0.624)	4.3004***
Tef land in improved seed (ha)	0.439 (0.496)	0. 454 (0.511)	0.318 (0.338)	-1.9016**
Livestock holding (TLU)	4.91 (3.27)	5.18 (3.30)	2.76 (2.01)	-5.2634***

Table A2. Herbicide use practice

Variables	Herbicide use (Standard Deviation)			Test-statistics (t-test)
	Total (N=484)	Yes (N=167)	No (N=317)	
Landholding (ha)	1.077 (0.689)	1.172 (0.721)	1.026 (0.667)	-2.2232***
Weeding frequency (number)	1.912 (0.844)	1.622 (0.806)	2.065 (0.824)	5.6551***
TLU	4.912 (3.274)	5.552 (3.467)	4.575 (3.122)	-3.1500***