Assaye et al. Agriculture & Food Security (2023) 12:9
https://doi.org/10.1186/s40066-023-00412-w

Agriculture & Food Security

RESEARCH

Open Access

Adoption of improved rice technologies in major rice producing areas of Ethiopia: a multivariate probit approach

Abebaw Assaye[1*], Endeshaw Habte[2] and Seiichi Sakurai[1]

Abstract

Background The need for adopting improved rice technologies and practices has become more important in Ethiopia as the national self-sufficiency gap has increased. This article examines the adoption level and factors governing the adoption of improved rice technology packages and practices using data collected from 594 rice-producing household heads in Ethiopia. A multivariate probit (MVP) model involving a system of five equations was used to assess the determinant for the decision to adopt improved rice technologies and practices.

Results The results showed that the adoption levels of improved rice varieties, row planting, recommended rate of urea fertilizer, recommended rate of DAP/NPS fertilizer, and recommended weeding frequency was 24.4%, 23.4%, 40.9%, 38.6%, and 52.4%, respectively. The model results attested that improved rice production technology packages are complementary. This finding implies that farm-level policies that affect the use of one improved agricultural technology can have a positive effect on the other technologies. The various demographic, socioeconomic, and institutional variables were found to influence the decisions to adopt different technologies of improved rice technology packages with different signs.

Conclusions Therefore, the government should devise ways to ease the accessibility of improved seeds and fertilizers along with the introduction of labor-saving technologies to promote row planting and achieve wider adoption of the technologies. Policies and interventions that are informed about such factors are required to accelerate the adoption of improved rice technology packages in Ethiopia to realize green revolution and secure self-sufficiency of rice sustainably.

Keywords Adoption, Ethiopia, Improved rice, Smallholder farmers

Introduction

Rice is an important global economic and staple food crop providing nutrition and calories for more than half of the world's population [1, 2]. The Green Revolution in Asian countries helped to achieve self-sufficiency in rice production through the introduction of high-yielding varieties and through the adoption of improved agricultural production techniques [3, 4]. Productivity improvement for rice is, therefore, possible through the adoption of improved agricultural techniques [1]. Adoption of modern agricultural technologies (improved varieties and inorganic fertilizer) and integrated farm management system is considered as an essential component of productivity growth for the agriculture sector.

Cultivation of rice in Ethiopia is a recent phenomenon. It is linked with the introduction and testing of improved

*Correspondence:
Abebaw Assaye
abebawal@gmail.com
[1] Food and Resource Economics Program, Graduate School of Horticulture, Chiba University, 648 Matsudo, Matsudo 271-8510, Japan
[2] Agricultural Economics Research Directorate, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia

varieties in the early 1970s in different parts of the country to address various challenges of different public interventions during the Derge regime [5]. These challenges were related mainly to settlement and food security. The first areas of rice introduction were Gambella (1973–1982), Pawe (1985–1988), and Fogera Plain (early 1980s). Because of its high productivity, good market price, adaptability, and compatibility with the prevailing farming systems, rice production in the country in general, and in Amhara, Benishangul Gumuz (BG), Oromia, and South West Ethiopia Peoples' (SWEP)[1] regional states, in particular, has increased dramatically during the last two decades. This increase has brought many changes in the rice production and marketing system.

Rice is among the targeted commodities which received due attention in transforming agricultural production in the country. The Ethiopian Ministry of Agriculture recognized the importance of rice, considering it as the "millennium crop" that is expected to ensure food security in the country. Since its introduction, rice production has shown rapid and widespread expansion to various parts of the country. The expansion has been greatest since the mid-1990s following rice research initiatives and consequent generation of high-yielding improved varieties. The total area under rice production has increased from about 29,866 ha in 2011 to over 57,576 ha in 2020. The production during the same period has increased from 90,412 tons to more than 170,630 tons [6]. Rice productivity also reached close to 3 t/ha in 2020 from 1.8 t/ha in 2005. The proliferation of improved rice production technologies over the last three-to-four decades is believed to have contributed to productivity growth.

Increasing agricultural productivity through the adoption and diffusion of modern agricultural technologies is a key pathway for economic growth and agricultural transformation in developing countries [7–12]. This is particularly relevant for many sub-Saharan African countries in general, and for Ethiopia in particular, where the performance of the agriculture sector determines the livelihood of more than eighty million of the population. Meaningful change in agricultural productivity through improved technologies, for example, can be one means of ensuring food security by way of increased production and reduced food prices.

Increasing rice productivity and production is essential to ensure national food security, reduce foreign currency spent for rice imports, and safeguard against rice market volatility. The use of high-yielding crop varieties along with other recommended technology packages can increase rice production and consequently facilitate the growth of agro-processing enterprises and non-farm sectors. Availability of improved technologies is not a sufficient condition for increasing productivity. They need to be used by the farmers. While there were efforts made to examine the extent to which the technologies are used, most earlier studies on rice adoption in Ethiopia were limited to a specific location (district or zone[2]) and relied on small sample sizes [13–16]. Information that explains the adoption and diffusion of improved rice technology packages and agronomic practices at a relatively wider scale is not available. This study was designed to provide information on the adoption of rice technologies in major production areas in the country along with factors that govern the farm household's decisions to use or not to use the technologies.

Methodology

Description of the study area

The study was conducted in major rice-producing areas of the country (Fig. 1). The area allocated for rice in 2018 was considered to determine the share of sampled household heads to be drawn in the study area. Among regional states of Ethiopia, four major rice-growing regional states, namely, Amhara, Benishangul Gumuz, Oromia, and SWEP together, constitute up to 98% of the total cultivated area of rice in the country [17]. The rice farming system in Ethiopia constitutes complex production units involving a diversity of interdependent mixed cropping and livestock activities and is mainly characterized by rain-fed agriculture. Rice is the dominant crop followed by maize and grass pea. According to this study result, rice, maize, grass pea, soybean, and millet took up 39%, 12%, 10%, 7%, and 7% share of cultivated crop area, respectively. As to total production, rice has the highest share and contributed 54% of the total grain production of the households. Rice is grown under rain-fed conditions and is planted and harvested once a year, from early June to early November. Besides, livestock production is an important means of livelihood next to crop production in the area.

A diverse topographic condition which consists of undulating terrain, gentle sloping lowlands, gorges and small rounded hills characterizes the study area. The study area mainly lies in moist *Woina Dega* (cool sub-humid) and *Kolla* (warm semi-arid) agro-ecological zones and experiences both high temperature and rainfall. Its altitude ranges between 985 and 2049 m above sea

[1] The South West Ethiopia Peoples' Region (SWEP) is a regional state in southwestern Ethiopia. It was split off from the Southern Nations, Nationalities, and Peoples' Region (SNNP) on 23 November 2021 after a successful referendum (Wikipedia).

[2] Zone is the next lower administrative tier after regional states. The highest tier is the Federal state.

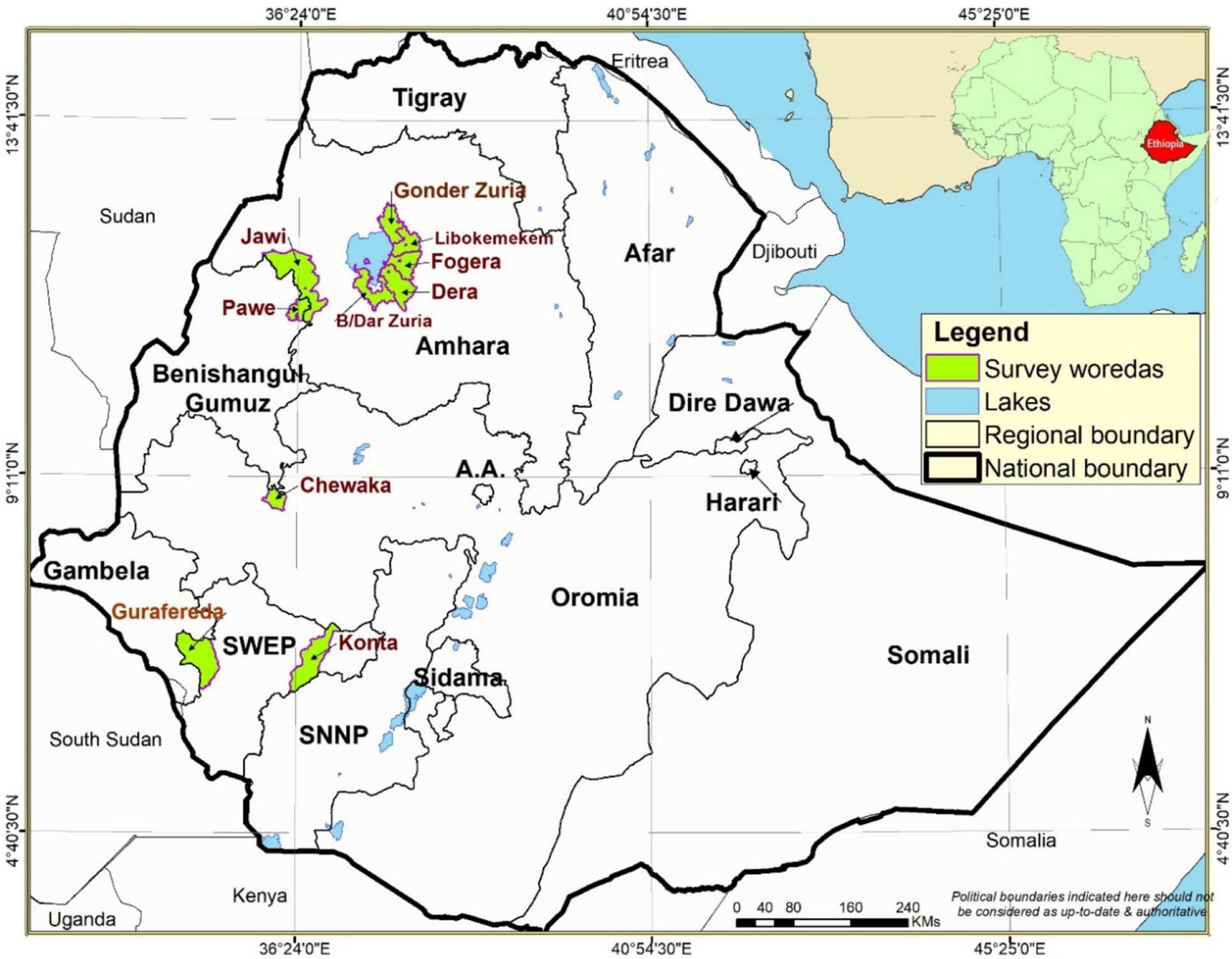

Fig. 1 Map of study areas

level. The area receives the maximum rain in June, July, August, September, and October. The area is mainly covered by Vertisols, Luvisols, and Lithosols, and it has huge potential for forests, woodlands, and grasslands [18].

Data and survey design

This study was based on cross-sectional data collected from rice-based farming systems in the four regional states of Ethiopia during the 2018 production year. The proportion of the sample household heads assigned to each regional state (considered here as a strata) was based on the density of the rice production area. The primary data were collected from sample household heads using structured questionnaires through the interview method. Relevant secondary data were also collected from different organizations, including the Ministry of Agriculture (MoA), CSA, FAOSTAT, ITC, and other published and unpublished sources. The target population for this study was all agricultural household heads who participated in rice production in 2018 and were permanent residents of the selected *kebeles*[3] in the study districts. Farm households who produced rice in the Amhara, Benishangul Gumuz, Oromia, and SWEP regional states constituted the population (N) from which the sample was drawn.

The sampling technique employed to select sample household heads for the study involved both purposive and random sampling techniques. The four regional states were selected purposely based on the share of area allocated for rice production in the country and were used as strata. A multistage sampling approach was followed to identify farm households in which districts were the primary sampling unit; kebeles the secondary, and household heads the tertiary sampling unit. The sampling frame includes information about the list of rice growing

[3] *Kebele* is the smallest administrative unit in Ethiopia. It is equivalent to a village in some countries.

Table 1 Study area and the sampling distribution of the household survey

Regional state	Share (%) from the total rice		No of rice growing zones	Name of selected zones	Name of selected districts	No of sampled Kebeles	No of sampled households
	Area	Production					
Amhara	57.9	63.0	8 (S. Gondar, C.Gondar, N.Gondar, W.Gondar, W.Gojam, Awi, N. Wollo and N.Shewa)	South Gondar	Fogera	13	269
					Libokemkem	6	109
					Dera	2	31
				Central Gondar	Gonder Zuria	2	30
				West Gojam	B/Dar zuria	1	14
				Awi	Jawi	2	37
BG	22.2	19.3	1 (Metekel)	Metekel	Pawe	3	48
Oromia	13.2	11.9	5 (Ilu Aba Bora, Buno Bedele, Jima, W. Welega, E. Welega and K. Welega)	Ilu Aba Bora	Chewaka	2	19
SWEP	6.0	5.2	5 (Bench Maji, Gamo Gofa, Kefa, dawero, Konta)	Benchi Maji	Guraferda	2	17
				Konta Woreda	Konta	2	20
						35	594

Source: Survey result, 2018.

districts in each of the strata, a list of *kebeles* in the sample districts and roster of rice producing farm household heads in the sample *kebele*s. A *kebele* consists of about 248-1835 rice-producing households. Accordingly, we sampled 594 householders for this study which is determined based on the sample size determination technique outlined by Yemane [19]. The proportions of the sample households assigned to each stratum were based on the density of the rice production area in the respective strata. Accordingly, 11 out of 26 rice-growing districts were selected using a random sampling technique. Then, 35 *kebeles* were selected randomly from the sampled districts. Finally, a systematic random sampling technique was used to identify 594 respondent farmers from the list of household head rosters at the *kebele* level (Table 1). Expecting unavailability and rejection of participation in the survey, we included five extra sample households as a reserve from each *kebele*.

Detailed household and plot-level data were collected using structured questionnaires administered to sampled farmers. Before the actual survey, the questionnaire was pretested in non-sampled villages to control validity, and modifications were made to address the relevant issues. Necessary data were also collected from various sources including secondary sources, community surveys, and focused formal household surveys. In addition, important information related to recommended rates of fertilizer and timing of its application, weeding frequency and so on were collected from secondary sources. The community survey was aimed at collecting community-level data from focused group discussions with community leaders and key informants. The information from the community survey provided useful insights into the farming systems of the areas (Table 1).

Analytical framework

The data were analyzed using STATA 17 and R statistical software packages for descriptive and econometric statistics. The data obtained through interviews, and the review of documents were compiled, organized, summarized, and interpreted. Descriptive statistics such as mean, percentage, frequency, chi-square test, and standard deviation were used to assess rice technology packages. It was also used to explain the different socio-economic characteristics of the sample respondent households about their adoption statuses.

Multivariate probit (MVP) regression was used to estimate the factors that influenced the adoption decision of improved agricultural technologies for rice production. Statisticians and econometricians view the multivariate probit model as a generalization of the probit model used to estimate several correlated binary outcomes simultaneously [20]. In general, a multivariate model can be extended to more than two outcome variables merely by adding equations. Farmers often use diverse information from different sources when making decisions to adopt improved technologies. Therefore, the decision to adopt one improved agricultural technology or practice might influence the decision to adopt another, which makes adoption decisions inherently multivariate. In such cases, using univariate techniques can exclude crucial information about interdependent and simultaneous adoption decisions. 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 decisions might be partly 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 related to the adoption decision [21–24]. Consequently, it is crucially important to assess whether farmers' multiple technology adoption decisions are interrelated or not. In an acknowledgment of these issues, this study applied a multivariate probit model to analyze the joint decisions to adopt multiple improved rice technology packages. The applied multivariate probit model accommodates the possibility of correlation between adoption decisions across different technology practices.

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

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

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

where j = 1,2, 3,...m denote improved rice 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 unit 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 rice technology packages, as well as unobserved characteristics captured by the stochastic error term.

The Wald test in the MVP probit model is often used to test the null hypothesis of no correlation across equations [25]. Lack of statistical evidence to reject the null hypothesis suggests that the choices are mutually independent, implying that we could equivalently fit m independent univariate probit models for each improved technology package and practice. In contrast, if the null hypothesis is rejected, it suggests that estimation of m independent univariate probit models for each improved technology package and practice would engender to inefficient estimates.

The dependent variables in the MVP model include five dummy variables corresponding to the use of improved rice technology packages. The dependent variable in the empirical estimation for this study is the choice of rice technology packages from the set of rice technology packages: improved rice variety, row planting, using recommended Urea and DAP/NPS fertilizer rate, and recommended weeding frequency. Adopters are farmers who used one or more of the technology packages including improved rice varieties, row planting, recommended rate of urea, recommended rate of DAP/NPS, and recommended rate of weeding frequency, whereas non-adopters are farmers who did not adopt those technologies in the production year.

The explanatory variables, often considered in modeling the adoption decision of farmers included household and farm characteristics, attribute the technology, resource ownership, institutional factors, and access to information variables [22, 26–28]. For this study, based on the review of the relevant literatures, a range of household, farm, and plot characteristics, and institutional factors are hypothesized to influence the adoption of improved rice technology use by smallholder farmers in rice-based farming systems of Ethiopia. Detailed definitions of the explanatory variables and hypotheses about the effects on the adoption of technologies are presented in Table 2.

Results and discussion

Results of descriptive analysis

Demographic characteristics of the households

Age is one of the demographic factors, which can influence a household's use of new technologies and practices. According to the findings, the average age of a household head was 43.6 years, ranging from 22 to 80 years. The sampled farm household heads had rich experience in farming (23 years), in general, and rice farming (11 years) in particular. Most of the demographic variables have comparable figures across adoption status. The family size of the total sample respondents ranged from 1 to 12 persons, with an average family size of 5.6. A large family size might assist rice producing farmers for better participation in rice production, because rice production often requires more labor for cultivation than other cereal production does (Table 3). Among the sampled household heads, 89% were male headed. In both theoretical and practical situations, education plays an immense role in ensuring households access to basic information that helps for decision-making. Not only the education level of the head of the household affects the decision of the household but also the education level of the family member might contribute to technology uptake. The overall average education level of the family members was 2.6 years of schooling. The average educational

Table 2 Definition of variables hypothesized to influence the adoption of improved rice technology packages

Variable	Description	Values	Sign
Demographic characteristics			
Gender	Gender of the household head	0 = female, 1 = male	±
Age	Age of the household head	Years	±
Rice experience	Experience of the household in rice farming	Years	+
Family Education	Average education level of the family	Years of schooling	+
Household size	Number of family members	Number	±
Asset Ownership			
Total cultivated land	Cultivated area	Area in ha	±
Rice area	Total area covered by rice	Area in ha	±
TLU	Livestock ownership	TLU	+
Rice income	Income from sale of rice	Birr	+
Mobile phone	Mobile phone ownership	1 = Yes, 0 = No	+
Radio	Radio ownership	1 = Yes, 0 = No	+
Non/off-farm	Non or off-farm income	1 = Yes, 0 = No	±
Institutional Variables			
Extension	Frequency of extension contact in a year	Count	+
Receive credit	Did you receive credit last year	1 = Yes, 0 = No	+
Irrigation access	Did you have access to irrigation	1 = Yes, 0 = No	+
Market distance	distance to main market in walking minutes	Walking minutes	-
Coop membership	Membership of the HH on cooperative	1 = Yes, 0 = No	+
Social capital index (The social capital index is an index number calculated using the membership of the household heads in local and social institutions or organizations Equb, Edir, Debo, Kebele administration, development committee, and religious group) ranging from zero to one.)	Index of social capital	Number	+
Plot characteristics			
Soil fertility	Soil fertility status perception	0 = fertile,1 = medium, 2 = infertile	±
Plot distance	Rice plot distance from the residence	Distance in km	−
Crop rotation	Crop rotation practice in the plot	1 = Yes, 0 = No	±
Rice ecosystem	Rice ecology	1 = lowland, 0 = upland	±

Table 3 Demographic characteristics of the sampled households

Household characteristics	Regional state					Improved seed	
	Amhara	Oromia	SWEP	BG	Overall	Adopters	Non adopters
Age of the household head	43.8	40.1	39.7	45.5	43.6	42.2	44.0
Farming experience	23.3	22.0	20.8	24.6	23.2	22.8	13.4
Rice farming experience	11.6	8.6	7.3	12.4	11.3	12.1	11.0
Education level of the head	1.7	3.7	2.9	2.4	1.9	2.3	1.7
Average family's education	2.4	4.3	3.3	3.5	2.6	3.1	2.5
Household size	5.5	6.4	5.4	5.5	5.6	5.7	5.5

Source: Own survey result.

level of the household members was 4.3, 3.5, 3.3, and 2.4 in Oromia, Benishangul Gumuz, SNNP, and Amhara, respectively. The literacy level of rice-producing farmers' families is the lowest in the Amhara region than others in the study area. The literacy level also follows a similar pattern when the educational level of the head is considered.

Table 4 Land tenure system across regional states

Regional states	Own land (ha)	Shared in (ha)	Rented in (ha)
Amhara	1.17	0.13	0.08
Oromia	1.65	0.11	0.43
SWEP	2.65	0.20	0.17
Benishangul	3.20	0.37	0.70
Total	1.44	0.16	0.15

Source: Own computation results, 2018.

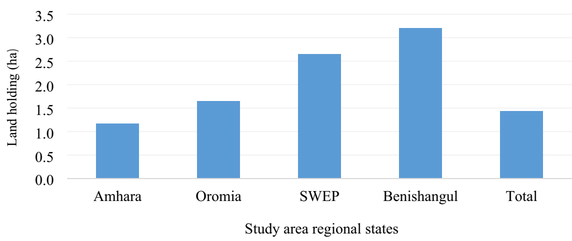

Fig. 2 Average landholding across regional states

Economic characteristics of sample households

Land ownership and tenure system One of the most important factors that influence crop production is land availability. The major land tenure system was owned, shared-in, and rented-in lands. Farmers who are unable to cultivate their land for different reasons (illness, shortage of draft animal or labor), share or rent their land. Mostly female-headed households and elderly people use sharecropping arrangements, whereas those who have sufficient land and who want to change the main occupation use renting arrangements (Table 4).

Landholding varies considerably across study regions, reflecting differences in population density, availability of arable land, and frequency of land redistribution. The average landholding size for the sample households is about 1.44 ha, with considerable variability across regional states. As depicted in Fig. 2, the highest average landholding size was in Benishangul Gumuz with 3.20 ha per household, whereas land pressure is more evident in Amhara and Oromia regions, respectively, with 1.17 and 1.65 ha per household.

Access to institutional services

The patterns of crop production, livestock rearing, choice, and use of improved technologies of the smallholder farmers can be determined mainly by the nature and development of institutional infrastructure, such as credit, extension services, distance to market, and membership in cooperatives. Credit availability for resource poor farmers is quite important to finance agricultural technologies and management options that could enable them to increase farm productivity. From the sampled farmers, the highest proportion of farmers in Amhara regional state took credit (25%) compared to Oromia (11%) and Benishangul Gumuz (10%). Among the sampled farm household heads, nearly half reported that they were members of agricultural farmers' cooperatives. As depicted in Table 5, farmers' cooperative membership is high in the Amhara (54%) and Benishangul Gumuz (35%). In addition to input and market-related services, cooperatives provide basic information related to agriculture and enhance farmers' knowledge and skills. Extension services provide rice farmers in Oromia and SWEP with more frequent contact than those in the other regional states. For sampled farmers, the average travel time to reach the nearest main market in walking time was 100.6 min. On average, farmers in Oromia (35.3 min) and SWEP (36.5 min) had better proximity to the market than farmers of Benishangul (70.7 min) or Amhara (110.9 min). Smallholder farmers have different social

Table 5 Access to basic services

Region	Amhara	Oromia	SWEP	Benishangul	Total
Credit received (%)	25.9	10.5	13.5	10.4	23.4
Coop membership (%)	53.9	26.3	27	35.4	49.8
Frequency of extension contacts (number)	12.1	25.6	20.1	11.0	12.9
Distance to main market (minute)	110.9	35.3	36.5	70.7	100.6
Membership in social institutions (index)	0.38	0.59	0.54	0.46	0.40

Source: Own survey result.

Table 6 Main sources of information for improved seed

Main Source of information	Percentage of respondents				
	Amhara	Oromia	SWEP	Benishangul Gumuz	Total
Another farmer (relative)	61.6	21.4	60.4	35.6	58.9
Government extension	28.4	46.4	14.6	37.3	28.8
Farmer coop or groups	4.4	25.0	18.8	10.2	6.0
Other household members	3.6	0.0	0.0	0.0	3.1
Research center	0.6	7.1	4.2	16.9	1.9
NGOs	0.8	0.0	2.1	0.0	0.8
Other source	0.6	0.0	0.0	0.0	0.5
Radio/TV/News paper	0.1	0.0	0.0	0.0	0.1

Source: Own survey result

institutions and organizations (*Equb,*[4] *Edir,*[5] *Debo,*[6] *Kebele* administration, development committee, and religious group) in the study area. Membership of the sample household heads in these social institutions or organizations was measured as an index ranging from zero to one (Table 5).

Sources of information about improved rice varieties and practices Farmers in the study area receive information related to improved rice varieties and complementary farm practices from various sources. The survey results showed that about 59% of the respondents learned about improved rice varieties from other farmers. The next important source of such information was government extension (29%). Farmer organizations were also described as sources of advice, but they were sought by fewer than 7% of all farmers (Table 6). The importance of other household members, research centers, and NGOs as sources of advice was quite notable in the study areas. Looking into the regional disparity in terms of information sources for rice farmers, while other farmers are important source in regions, such as Amhara and SWEP, the government extension is a major source of information in Oromia and in Benishangul Gumuz.

Sources of improved seed Rice-producing farmers obtained seeds of improved varieties from various sources. Once the farmers received improved rice seed from any source, customarily, they recycle it for up to 3–5 years. Accordingly, results of the study indicated that the first sources of seed for the respondents were farmer to farmer seed exchange (41%) and local market (29%). About 46%, 36%, and 11% of the respondents of the Oromia region, on average, received rice seed through the office of agriculture, farmers' cooperative, and other farmers, respectively. While farmers of the Benishangul Gumuz region get improved rice seed from other farmers through seed exchange (42.4%) and from the agricultural research center (28.8%) (Table 7).

Rice varieties cultivated by sample households in the study area

Based on the area covered in different rice varieties, the distribution of varieties in the study area differs mainly due to rice ecology differences (Table 8). Comparing across the regions X-Jigna was the dominant rice variety cultivated in Amhara region covering 72.6% of the rice area. The varieties known as Superica-1 and Chewaka were more popular in the Oromia region covering 57.0% and 36.2% of the rice land area, respectively. Pawe-1 and Nerica-4 varieties were widely cultivated in Benishangul Gumz and SWEP regions covering 35.1% and 27.2% rice land area, respectively.

An older rice variety known as X-Jigna was the most popular variety planted in 57% of the total area of rice cultivated by the sample household heads. The next popular variety was Gumara (8%) followed by Pawe-1 (5%) and NERICA-4 (4%). About 7% and 14% of areas covered by rice were identified as improved and old local varieties, but the farmers were not able to identify them by particular name. The popular variety, X-Jigena is not registered under formal rice varieties in Ethiopia. However, farmers' demand for this variety was very high. Most of the remaining newly released rice varieties such as Shaga, Wanzaye, Abay, Rib, Edget, Fogera-1, and others had not been received well by the farmers. The varietal importance in terms of coverage suggests that new varieties are not going fast and that expansion is limited to the old varieties. This can be related to a dysfunctional seed

[4] Ekub is a local institution used for saving money regularly depending on the agreement of the members.

[5] Edir is a local institution by which people help each other in case of emergency (death, funeral).

[6] Debo is also a local institution that helps people to work together during the peak season of crop production.

Table 7 Main sources of information for improved seed

Main source of the first seed	Percent				
	Amhara	Oromia	SWEP	Benishangul	Total
Farmer to farmer seed exchange	41.9	10.7	41.7	42.4	41.1
Local market	32.5	3.6	12.5	10.2	29.4
Government extension	16.4	46.4	10.4	10.2	16.6
Research center	3.1	3.6	6.3	28.8	4.8
Local seed producer	3.7	0.0	2.1	1.7	3.4
Farmer groups/coops	1.0	35.7	18.8	6.8	3.2
Other	1.4	0.0	6.3	0.0	1.5
NGOs	0.0	0.0	2.1	0.0	0.1

Source: Own survey result

Table 8 Varietal distribution (by percent of area coverage of rice) of rice in the study area

Rice varieties	Amhara	Oromia	SWEP	Benishangul	Overall
X-Jigena	72.6	0.0	0.0	20.8	57.4
Gumara	9.8	0.0	0.0	1.3	7.6
Pawe-1	0.0	0.0	0.0	35.1	4.6
NERICA-4	0.9	0.0	27.2	8.1	4.0
SUPERICA-1	0.0	57.0	0.0	0.0	2.4
Chewaqa	0.0	36.2	0.0	0.0	1.2
Shaga	1.3	0.0	0.0	0.0	1.0
Ediget	0.3	0.0	0.0	0.0	0.3
NERICA-15	0.2	0.0	0.0	0.0	0.1
Erib	0.3	0.0	0.0	0.0	0.2
NERICA-1	0.0	0.0	0.3	0.0	0.1
Wanzaye	0.1	0.0	0.0	0.0	0.1
Getachew	0.0	0.0	0.0	0.0	0.0
Improved rice (but do not know)	4.3	0.0	29.9	13.3	7.4
Old rice variety (do not know)	10.2	6.8	36.8	21.4	13.8
Total	100.0	100.0	100.0	100.0	100.0

Source: Own survey result

systems and technology promotion for rice. Among more than 40 rice varieties released in Ethiopia, only about 15 (including two unidentified) varieties were adopted by farmers and are currently under production. Few varieties such as X-Jigena, Gumera, Pawe-1, Nerica-4, and Superica-1 were the dominant varieties in rice production. Of the 13 varieties adopted by the farmers, 5 belong to the lowland production system and the remaining 8 to the upland production system.

Farmer's preference to rice varietal attributes

Farmers decide to adopt a particular variety based on the traits (attributes) of the variety which they value most. Respondent farmers were asked to identify their most preferred varietal attributes of rice by putting them in their preferred position. Accordingly, about 84% of the sample farmers reported grain yield as the first most preferred trait, followed by grain color and straw yield (Table 9).

Adoption of improved rice technology packages

Different improved agricultural technologies and practices are used by smallholder farmers in the study area to improve rice productivity. A significant proportion of sample farmers adopted different rice production technologies. The most common improved rice production technology packages used by the farmers were improved rice variety, row planting, recommended fertilizer (Urea and DAP), and weeding frequency. Operationally, for our study, sample farmers who used these

Table 9 Main attributes for varietal adoption across regions (%)

REGION	Amhara	Oromia	SWEP	Benishangul	Overall
Grain yield	80.4	100.0	100.0	95.8	83.5
Grain color	60.4	84.2	97.3	62.5	63.6
Straw yield	36.3	36.8	40.5	25.0	35.7
Injera making quality	36.7	0.0	0.0	50.0	34.3
Grain yield stability	26.5	100.0	75.7	50.0	33.8
Grain size	24.9	78.9	83.8	41.7	31.6

Source: Own survey result

Table 10 Summary of adoption status of improved rice technology packages across regions (%)

Technologies and practices	Amhara	Oromia	SWEP	BG	Total
Improved seed	23.1	47.4	27.0	27.1	24.4
Row planting	21.8	73.7	5.4	33.3	23.4
Recommended use of Urea	46.9	21.1	0.0	18.8	40.9
Recommended use of DAP/NPS	37.3	84.2	18.9	47.9	38.6
Recommended weeding frequency	56.3	78.9	35.1	14.6	52.4

Source: Own survey data (2018).

technologies in the study year are identified as adopters, whereas farmers who did not adopt those technologies are considered as non-adopters.

The interviewed household heads had indicated that the adoption of improved rice varieties had increased steadily in the study area. The old rice variety "X-Jigena" with its high yielding, white seed color, compatibility for *injera* making (a staple food made of indigenous cereal crop known as tef (*Eragrostis tef*)), and high biomass varietal attributes, had been adopted most widely in the study areas. A given variety is expected to lose its productivity when it is reused beyond the optimal number of times in which case it is difficult to consider it as improved. Nonetheless, it is difficult to know the number of times a farmer recycled a variety at the time of interview, mainly because a farmer might get seed from non-formal sources and that seed might not be fresh. Therefore, in light of this constraint, for this study purpose, we considered farmers who used fresh rice seed from the known source as an adopter of improved variety and others as non-adopters. Accordingly, the adoption rate of improved rice varieties was the highest in Oromia (47.4%) followed by Benishangul Gumuz (27.1%). The aggregate adoption rate of improved rice varieties was 24.4% (Table 10).

Planting method is one of the agronomic practices that can enhance productivity. Diverse planting methods are used for rice production throughout the world, such as hand transplanting, mechanical transplanting, direct hand row seeding, mechanical seeding, and broadcast seeding [29]. The most common planting method of crops in the study area was broadcasting, row planting, and transplanting. Row planting is one of the main improved rice technology packages that extension workers and researchers recommend for better productivity and significant reduction in seed rate. Moreover, row planting is one of the agronomic practices used to make weeding, cultivation, and other agronomic activities easier, and increase the efficient use of fertilizers, and water [29–31]. The research finding conducted in Fogera indicated that row planting brings substantial yield increment over broadcasting [32]. The interviewed household heads describe that row planting demands much labor and time during the busiest period of planting. The adoption rate of row planting in the study area was 23%, and was practiced widely by farmers in Oromia (84%) followed by Benishangul Gumuz (48%) (Table 10).

The agricultural extension system of the country encourages farmers to apply chemical fertilizer to their cropland. Rice was not included in the agricultural extension package until 2018 but researchers and agricultural extension workers have tried to promote the use of fertilizer in the study area. The findings also witnessed that fertilizer use is very common especially for rice production. Almost all interviewed farmers use some amount of fertilizer for rice production. Appropriate fertilizer application is an important management practice for improving soil fertility and rice production [33]. The recommended rate of fertilizer was 60 kg N and 20 kg P_2O_5 for upland rice production in Metama, Amhara and 69 kg N and 23 kg P_2O_5 rate per hectare in Tigray. The economic analysis of fertilizer in Fogera indicated 69 kg N and 23 kg P_2O_5 rate per hectare as the most profitable rate [33, 34]. In this study, the farmers are considered as adopters of recommended rate of Urea, and DAP/NPS fertilizers if the farmers applied 120 kg and more of Urea and 40 kg and more of DAP/NPS per hectare. The overall adoption rate of the recommended Urea and DAP/NPS in the study area were 40.9% and 38.6%, respectively. About 47% of interviewed household heads from Amhara applied the recommended rate of urea on their rice farms, whereas households of SWEP did not apply the recommended rate of fertilizer. Almost 84% of sample household heads from Oromia use the recommended rate of NPS/DAP, while the corresponding proportions of household heads for SWEP were 47.9%, Amhara, 37.3%, and Benishangul Gumuz, 38.6% (Table 10).

Weed management is much more demanding for rice production than it is for other field crops. Rice is a weak competitor against weeds. Moreover, it is sown at close spacing, which makes mechanical weed control difficult,

Table 11 Yield and income mean differences across technology adopters

Improved rice technology packages	Rice yield in kg (overall mean = 3464.4)			Rice income in USD (overall mean = 319.2)		
	Adopters	Non-adopters	*t*-stat	Adopters	Non-adopters	*t*-stat
Improved rice seed	4144.3	3244.9	− 6.36	425.9	284.8	− 5.84
Row planting	4100.1	3270.2	− 5.75	449.5	279.4	− 7.03
Recommended weeding frequency	4056.6	2813.7	− 10.83	393.6	237.5	− 7.67
Recommended rate of Urea	4117.4	3012.4	− 9.26	399.8	263.5	− 6.50
Recommended rate of DAP/NPS	3730.3	3297.6	− 3.39	375.6	283.8	− 4.25

Source: Own computation results, (2018).

1 USD = 29.21 Birr when the survey was conducted.

thereby resulting in high yield reduction [35–37]. Different studies have demonstrated that weeds significantly reduce crop productivity. Weeds aggressively compete for water, nutrients, and sunlight, thereby affecting crop yield and quality. Weeds also serve as alternative hosts for insects and diseases [38–40]. In the study area, among rice farming activities, weeding followed by harvesting requires extra hired labor in addition to family labor. In this study, the farmers are regarded as adopters of a recommended weeding practice if the farmers weed their plots three or more times over a production season; otherwise, they are regarded as non-adopters. The overall adoption rate of the recommended frequency of weeding in the study area was 52.4%. About 78.9% and 56.3% of interviewed household heads in Oromia and Amhara did weed their rice plot three and more times, whereas only 14.6% of the household heads of Benishangul Gumuz applied the weeding recommendations (Table 10).

In general, on average, 23.4–52.4% of household heads across the four regional states adopted improved rice technology packages and practices on their rice plots during the study year. However, adoption rates of the improved rice technology package varied across locations. In general, the highest adoption rate among the rice production technologies was for the recommended weeding practice (52.4%). Row planting (23.4%) and improved rice seed (24.4%) were comparatively the least used technology packages in the study area (Table 10).

Returns from improved rice technologies

The descriptive statistics result showed that the mean productivity of rice for adopters of improved rice variety was 4,144.3 kg/ha and 3,244.9 kg/ha for non-adopters, with an extra yield of 900 kg/ha yield advantage for adopters. Similarly, there was a significant mean difference in the average income of rice between adopters and non-adopters of improved rice varieties. The results also revealed that the adoption of row planting, recommended frequency of weeding, recommended rate of fertilizer (Urea and DAP/NPS) had significantly higher mean rice productivity and income from rice than non-adoption (Table 11).

Table 12 Yield and income gains across the number of technologies adopted

No. of technologies adopted	Adopters (%)	Rice yield in kg	Rice income in USD
None	20.7	2326.1	172.2
One	25.4	3344.4	289.7
Two	23.6	3601.3	324.3
Three	18.2	3751.9	342.5
Four	8.1	4680.0	566.3
All	4.0	5497.2	629.6
Total	100	3463.1	319.2

Source: Own computation results, (2018).

The majority of farmers (79.3%) adopted at least one improved rice technology package in the study area. As indicated in Table 12, our sample farmers adopted improved rice technologies in combinations rather than adopting a single technology. Around 54% of the farmers simultaneously adopted two and more improved technology packages in their rice field. Interestingly, farmers who adopted a combination of improved rice technology packages get better yield and income from rice sales. The productivity of rice increases as the number of adopted improved rice technology increases. Rice farm households who adopted improved rice technologies in combinations harvested higher yield and income than those who adopted a single technology. For example, those who adopt four of the technologies can get twice as much yield as the non-adopters. In general, the adoption of multiple complementary improved rice technologies (improved seeds, row planting, recommended weeding frequency, recommended rate of Urea, and DAP/NPS fertilizer) can

Table 13 Multivariate probit simulation results for adoption of rice technology packages

Explanatory variables	Improved seed Coef. (Rob. S.E)	Row Planting Coef. (Rob. S.E)	Recom Urea Coef.(Rob. S.E)	Recom DAP Coef.(Rob. S.E)	Recom Weeding Coef.(Rob. S.E)
Gender (male)	0.219 (0.235)	0.003 (0.219)	0.537*** (0.202)	− 0.231 (0.199)	0.255 (0.202)
Age (years)	− 0.009 (0.006)	0.009 (0.006)	− 0.006 (0.006)	0.009* (0.005)	− 0.009* (0.006)
Rice experience (years)	0.015 (0.011)	0.007 (0.011)	0.007 (0.009)	− 0.011 (0.010)	0.001 (0.011)
Family size (number)	− 0.055 (0.035)	− 0.048 (0.035)	− 0.017 (0.032)	− 0.005 (0.032)	0.070** (0.032)
Family education	0.109*** (0.035)	0.060* (0.036)	0.057* (0.032)	− 0.008 (0.033)	0.066** (0.033)
Credit (1 = used)	− 0.009 (0.146)	0.080 (0.140)	− 0.255* (0.133)	− 0.193 (0.135)	− 0.141 (0.129)
Irrigation access (1 = yes)	− 0.079 (0.128)	− 0.018 (0.128)	0.003 (0.118)	0.067 (0.117)	− 0.288** (0.118)
Mobile ownership (1 = yes)	0.309** (0.146)	0.193 (0.142)	− 0.147 (0.130)	0.131 (0.127)	− 0.117 (0.128)
Radio ownership (1 = yes)	0.170 (0.140)	− 0.036 (0.140)	0.115 (0.133)	− 0.046 (0.132)	− 0.005 (0.136)
Extension frequency	0.011** (0.005)	0.006 (0.005)	− 0.004 (0.005)	0.008 (0.005)	− 0.002 (0.005)
Non/off farm income	0.018 (0.154)	0.270* (0.147)	− 0.052 (0.139)	− 0.342** (0.141)	0.083 (0.134)
Sqr of Rice area (ha)	− 0.658** (0.327)	− 1.319*** (0.394)	− 1.110*** (0.357)	− 1.028*** (0.334)	− 0.385 (0.326)
Sqr of Plot distance (minute)	− 0.092** 0.036)	0.030 (0.035)	− 0.032 (0.032)	0.092*** (0.032)	− 0.002 (0.032)
Soil fertility	0.011 (0.100)	− 0.252** (0.107)	− 0.093 (0.091)	0.133 (0.091)	− 0.147 (0.100)
Crop rotation	− 0.096 (0.156)	0.221 (0.145)	− 0.314** (0.135)	0.278** (0.133)	0.119 (0.133)
Sqr of TLU	0.181** (0.089)	0.036 (0.090)	0.115 (0.080)	0.103 (0.081)	− 0.071 (0.082)
Log cultivated land	− 0.162 (0.122)	0.077 (0.119)	− 0.500*** (0.114)	0.114 (0.107)	− 0.561*** (0.12)
Social capital	0.445 (0.289)	0.816*** (0.314)	− 0.375 (0.281)	0.759*** (0.270)	0.135 (0.277)
Rice ecosystem (1 = lowland)	− 0.266* (0.137)	0.396*** (0.130)	− 0.271** (0.130)	0.067 (0.121)	− 0.243** (0.123)
Market distance	− 0.002* (0.001)	− 0.002 (0.001)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)
Sqr of rice income	0.008*** (0.002)	0.012*** (0.002)	0.007*** (0.002)	0.007*** (0.002)	0.008*** (0.002)
Coop member	0.077 (0.133)	− 0.239* (0.138)	0.088 (0.119)	0.029 (0.119)	0.041 (0.120)
Constant	− 0.940* (0.559)	− 1.820*** (0.527)	0.512 (0.494)	− 1.481*** (0.487)	0.178 (0.492)

Wald test of overall coefficient significance χ^2 (110) = 641.81, Prob > χ^2 = 0.000.

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

substantively increase the productivity of rice and the income derived from it..

Determinants of adoption of improved rice technologies packages

Several factors can influence rice-producing farmers' decision to adopt a particular technology or practice. We have modeled five dependent variables (improved rice technology packages) over 22 explanatory variables in the multivariate probit regression framework (Table 13). Before running the model, the explanatory variables fitted to the MVP model were tested for the existence of outliers and collinearities. The existence of outliers was checked for basic explanatory variables. The variance inflation factors for all variables were less than 5, which indicate that multicollinearity is not a serious problem of this model.

The MVP model is significant, because the null hypothesis that the probabilities of adoption of the five rice technology packages are independent were rejected at the 1% significance level. The model results revealed that the Wald test (Wald chi2 (110) = 641.81; Prob > chi^2 = 0.000)) is significant at the 1% level, which indicates that the subset of coefficients of the model is jointly significant and that the explanatory power of the factors included in the model is satisfactory. Furthermore, the results of correlation coefficients of the error terms also indicate interdependence among the decisions to use technology options by farmers. The results support the assumption of interdependence between the different technology options. The maximum likelihood method of estimation results suggested a positive and significant interdependence between household decisions to adopt improved rice seed, row planting, recommended rate of Urea, recommended rate of DAP, and recommended weeding frequency.

The results revealed that several hypothesized demographic, farm, institutional, and resource ownership variables have a significant effect on decisions to use improved rice technologies. Furthermore, most of the estimated parameters confirmed the expectations for influencing the adoption of improved rice technology packages. Table 13 presents the model results and the conditional and unconditional marginal effect results of the MVP model on the adoption of improved rice technology packages are presented in Appendix Tables 15, 16, and 17.

Improved rice variety adoption

The results showed that the average education level of the household members, frequency of extension contacts, mobile ownership, livestock ownership, and income from the sale of rice have a significant and positive effect on improved rice variety adoption, while the area of land covered by rice, rice plot distance and rice ecosystem have an opposite relation. The positive effects of education, frequency of extension contacts and mobile phone ownership on the decision to adopt improved rice variety are expected given the importance of awareness and access to various forms of information from different sources, which enhances farmers' willingness to the use of improved rice varieties. The result is consistent with the findings reported earlier in the related literature [22, 27, 41–43]. Cost and risk-related issues are important factors for adopting agricultural technologies. Income from the sale of rice and livestock help the farmers to adopt improved seed technology by reducing the financial constraints of the households to purchase seed of improved rice varieties. This finding is also consistent with many reports of earlier work [23, 43–46]. In contrast, the total area of rice cultivation, distance to rice plots and distance to the main market have significant and negative effect on decisions to adopt improved rice varieties. The total area of rice farms was significant and had a negative relationship with the adoption of improved rice variety. This might be due to tendency to either thinly spread the limited resources or competition from other enterprises. The result is in line with the studies reported by Kassie et al. [23] and by Donkoh et al. [22], suggesting that land scarcity motivates agricultural intensification through the adoption of improved technologies. The results contradicted earlier reported findings of Donkor et al. [30], a large farm provides sufficient space for farmers to experiment with the technology and to assume some risks of adoption, but this holds when the household can afford investing extra resources. Rice farm plot distance to home in walking minutes increases the costs of production because of time spent commuting to the plot. Farmers who live far away from market centers could have less access to information related to improved technologies. Therefore, they are unlikely to adopt new technologies. Distance in this particular case could also mean, distance from urban centers, which serve as market outlets for the produce of the farmers. The result is consistent with the hypothesized sign and earlier findings reported in the literature [42, 43, 47, 48].

Row planting

The average education level of family members, non-farm and off-farm income, membership in social institutions, rice ecosystems and income from the sale of rice are found to be positive drivers of using the row planting practices in rice production. The positive effects of education in adopting row-planting practices are related to the ability to decipher the value of this practice. Therefore, educated households are more likely to practice row planting. Additional income from non-farm or off-farm income reduces the cost-related constraints for row planting. Row planting is a labor-demanding practice compared to the traditional practice of broadcasting. Those households who have access to non-farm or off-farm income might use the income for employing hired labor for row planting. These results corroborate earlier reported findings [42, 49] indicating that education, receipt of off-farm or non-farm income, and total farm income increase the likelihood of adoption of row planting technology. Membership in social institutions helps the farmers to get labor at the peak season of rice production. Sometimes, when there is a need for more labor, such as at peak times of rice planting, weeding and harvesting, lower and medium-income households often require support of relatives and members of social institutions (neighbors, friends, etc.) for exchange labor. Exchange labor is a practice by which neighboring households' team up and works in turns on each other's farms until all the members receive similar labor services. In addition, such kinds of social networks can help farmers to access information about improved production packages and share their experiences. The result is consistent with previous studies reported by Kassie et al. [23], suggested that social capital and network variables are important for explaining the adoption decision of improved agricultural technologies.

The total cultivated area of rice, soil fertility status of rice plot, and the rice ecosystem influenced the decision to adopt row-planting practices significantly and negatively. Farmers with large farm sizes had a lower probability to adopt row planting because of proportionally higher labor demand of row planting. Moreover, farmers might expect good harvests from fertile soil irrespective of the planting method. Competition between plants might not be fierce given the fertility conditions. Lowland rice-producing farmers use row-planting method more than upland rice growers, probably because of heavy rains and flooding problems of lowland ecosystems for direct sowing. Farmers prefer to adopt transplanting using row to reduce waterlogging effects on the direct planting.

Urea fertilizer

Adoption of improved varieties alone is not sufficient to exploit the yield potential of rice varieties unless combined with the application of inorganic fertilizer (Urea and NPS/DAP). Obviously, simultaneous adoption of improved varieties and inorganic fertilizer was the core technology of the green revolution in Asia and Latin America [19]. Gender of the household head, average education level of family members and income from the sale of rice significantly and positively increase the probability of applying recommended rate of urea fertilizer on rice fields. Male-headed households are more likely to adopt recommended urea fertilizer than female-headed households. This might be attributed to the greater chance of exposure of male-headed households to information and improved agricultural technologies than female-headed households. Bezu et al. [22], Aryal et al. [41], and Donkoh et al. [50] found that male headed household head has a positive and significant influence on the adoption of improved agricultural technologies. The positive contribution of education and income from the sale of rice for the use of recommended rate of urea fertilizer could be related to the awareness and availability of funds for purchasing urea fertilizer. These results corroborate the findings of Donkoh et al. [22] and Kassie et al. [23] which revealed that education and income have positive contribution for farmers' decision to apply fertilizer at the recommended rate. In addition, the total area of land cultivated in rice, total cultivated land, crop rotation practice in rice fields, and credit use are significantly and negatively associated with adoption of the recommended rate of urea application in rice plots. Larger farms have higher costs of applying the recommended rate of fertilizer. Therefore, farmers might opt for applying below the recommendation rate. This result agrees with results reported from several studies [19, 22, 23], which indicated that land scarcity can induce agricultural intensification through the adoption of improved technologies. Farmers who had experienced crop rotation practices in rice plots are less likely to apply recommended rate of urea fertilizer. Crop rotation is the planting of different crops sequentially on the same plot to improve soil fertility and soil health. Crop rotation, as a means to enhance soil fertility status, can be seen to have a negative relation with the use of urea fertilizers. Although marginally significant, the sign for credit use is quite interesting: credit services are presumed to encourage technology adoption. Maybe farmers seldom use credit for acquisition of fertilizer for rice plots, yet further investigation is necessary to explain this behavior as there may be competing enterprises for this input.

DAP/NPS fertilizer

Total income from rice sales, crop rotation practices, membership in social institutions, and rice plot distance have a significant and positive effect on the adoption of recommended rate of DAP/NPS fertilizer, whereas the total area of rice, and off-farm and non-farm income have a negative effect on the adoption of recommended rate of DAP/NPS fertilizer on their rice plots. Rice plots found far from the resident might not receive farmyard manure because of the distance involved. This distance effect might be the reason for application of the recommended rate of DAP/NPS fertilizer for the distant rice plots. This finding is consistent with the study of Tesfaye [51], fertilizer adoption correlates negatively with plot distance.

The positive effect of income from rice sales and membership in social institutions on fertilizer application is understandable, because they might be used as a source of information and funds for acquiring fertilizer. The total area of land covered by rice was significant and had a negative relationship with adoption of the recommended rate of DAP/NPS fertilizer. This could be due to the extra cost required to manage larger rice farms. This result accords with those reported from earlier studies [22, 23]. Off-farm or non-farm income helps farmers to increase capital availability and financial resources to invest in new inputs, practices or technologies [23]. However, in our study, farmers who participate in non/off-farm income are less likely to adopt the recommended rate of DAP/NPS fertilizer. The findings of the negative non/off-farm income effect on fertilizer expenditure agrees with the results reported by [52–54], which indicate that participation in off-farm/non-farm income tends to reduce the amount of fertilizer applied. This could be probably because either the income derived is too small or targeted to a different input, say more to the labor cost (note the positive relationship with row planting) instead of capital inputs in this case fertilizer. Moreover, households might prefer to invest in an option that have better returns, given the risk involved in agriculture.

Weeding

The family size of the household, average education level of the family members and income from rice sales are positive drivers of decisions to apply recommended frequency of weeding practices. Rice weeding is the most labor-demanding practice among rice cultivation activities. According to Abera and Assaye [55], rice weeding activity takes more than 40% of the total rice cultivation labor hour share. The justification could be that the households with larger family size have the necessary labor to apply the recommended frequency of weeding on their rice farm plots. Family members are the main source of household labor for rice cultivation. In this regard, the positive effects of family size on adopting recommended frequency of weeding are expected. These results corroborate the findings of Genet and Feyso [56], Teklewold et al. [24], and Kassie et al. [23] that established a positive correlation between the adoption of improved technologies and household size. In addition to family labor, hired labor is more important for

Table 14 Correlation matrix of the technologies from the multivariate probit model (Robust S.E)

Improved technologies	Improved seed Coef. (Rob. S.E)	Row Planting Coef. (Rob. S.E)	Recom Urea Coef. (Rob. S.E)	Recom DAP Coef. (Rob. S.E)	Recom Weeding Coef. (Rob. S.E)
Row Planting	0.490*** (0.088)				
Recom Urea	0.388*** (0.084)	0.213*** (0.078)			
Recom DAP	0.214*** (0.081)	0.491*** (0.082)	0.352*** (0.076)		
Recom Weeding	0.313*** (0.080)	0.206*** (0.079)	0.280*** (0.073)	0.217*** (0.073)	
Predicted probability	0.1988	0.1922	0.3870	0.3737	0.5193
Joint probability (success)			3.9%		
Joint probability (failure)			20.2%		
Number of observations			594		
Number of simulations			100		
Log-likelihood			− 1537.5869		
Wald Chi2 (degree of freedom)			641.81***(110)		

LR test of overall significance of correlation coefficients χ^2 (10) = 138.249, Prob > χ^2 = 0.000.

Robust standard errors in parentheses, ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$

rice production in the study area. The farmers might use income from rice sales to hire labor for weeding. Moreover, education helps a household to interpret complex data and information, thereby making appropriate decisions about the use of practices, such as weeding. However, access to irrigation, total cultivation land, and rice ecosystems negatively and significantly affect the implementation of recommended rate of weeding frequency in the rice field. Access to irrigation helps a farmer to grow different crops two or more times in the same plot in a year. It increases crop rotation practices that can help to reduce weed infestation. Farmers with large cultivated land size had a lower probability of adopting the recommended weeding frequency likely due to increased labor cost incurred. Furthermore, upland rice growing farmers weed their rice plots more than lowland rice producers as weed incidences are more likely in the latter as lowland rice grows under flooded land, which might help to suppress weeds thereby reducing the need for frequent weeding.

After running the MVP regression, we did post estimation to look at the pairwise correlation among the dependent variables (adoption of rice production technologies). The correlation matrix of the technologies from the MVP model also showed that farmers have adopted a number of improved rice technology packages simultaneously. This finding was tested using pairwise correlation coefficients across the residuals of the multivariate probit model. The coefficients measure the correlation between the adoption decisions of rice technologies considered, after the influence of the observed factors has been accounted for [20]. The results support the hypothesis that error terms of multiple improved rice technology adoption decision equations are correlated. All pairwise coefficients were positively correlated and significant, indicating complementarity among the improved rice production technologies (Table 14).

Conclusions and implications

The adoption of improved agricultural technology packages is necessary to increase the agricultural sector production and productivity in Ethiopia. Rice technologies offer higher gains when used in combination than independently. This study assessed the likelihood of smallholder farmers to adopt improved rice technologies and practices and its determinant factors in Ethiopia using primary data collected from a sample of 594 rice-producing household heads. The study described herein used a multivariate probit model to estimate factors that influenced the adoption decision of improved agricultural technologies for rice production. Complementarity exists among improved rice production technologies and practices (improved rice variety, row planting, using recommended fertilizer rate, and recommended weeding frequency), meaning that the adoption of a given improved agricultural technology was conditional on the adoption of the others. In fact, more number of technology use is associated with better yield.

The study has revealed that variables affecting farmers' decisions to adopt improved technology packages differ among technologies and practices. Some explanatory variables are strongly significant in affecting decisions made by farmers about particular improved rice technology packages and it might be insignificant for other technology packages. Consequently, multivariate probit analysis results revealed that the decision of each rice technology packages was influenced by different sets of factors and at different levels of significance by the same factor. Results of MVP analyses demonstrate that most of the estimated parameters conform to expectations in influencing the adoption of improved rice technology packages in the study area.

The MVP regression results show that the demographic and institutional characteristics of the households, including gender, age, rice farming experience, average education level of family members, extension services, membership in social institutions, credit use, cooperative membership, and distance to the main market are key factors affecting decisions to adopt improved rice technology packages. In addition, resource ownership, and plot characteristics of the households such as rice area, distance to rice plots, crop rotation practices, soil fertility status, access to irrigation, livestock ownership, access to non-farm or off-farm income, mobile ownership, total cultivated land, rice income and ecology of rice play significant roles with different signs in adoption decisions across improved rice technology packages. More importantly, farmers with larger plots seems to have a tendency to compromise recommended practices either due to capital or labor constraints. This can result in underutilization of scarce resources, such as land. In this regards, it is important to design technologies that can save labor or provide access to finance to meet the costs required to adopt the improved practices.

The study also provides critical insights which might be useful in promoting agricultural technology adoption among smallholder farmers. Complementarity among improved rice technologies shows that policy instruments that affect one technology are likely to influence other related technologies. Thus, improved agricultural technologies can be scaled by promoting these technologies as a package. It should also be recognized that other institutional and economic factors might affect the adoption of improved technology packages, such as the price of inputs (improved rice seed, urea, NPS, and daily labor wage) and availability of institutional structures that facilitate the accessibility of the inputs. Therefore, governmental and developmental partners must strive to promote improved rice technology packages and support the accessibility of improved technologies at affordable prices. The national rice-research program should also specifically examine development of varieties that can meet the preferences of farmers (yield, color (marketability), straw yield, and other important traits). In addition, researchers should work on improving varieties following the farmer-preferred characteristics embedded by the local varieties.

Appendix

See Tables 15, 16, and 17.

Table 15 Marginal effects on the adoption of improved rice technologies (unconditional marginal effects, calculated at the mean)

Explanatory variables	Improved seed	Row planting	Recom urea	Recom DAP	Recom weeding
Sex of HH	0.055 (0.074)	− 0.004 (0.078)	0.184** (0.075)	− 0.092 (0.097)	**0.098 (0.091)**
Age of HH	− 0.002 (0.002)	0.003 (0.002)	− 0.002 (0.002)	0.003 (0.002)	**− 0.004 (0.002)**
Rice experience	0.004 (0.004)	0.002 (0.004)	0.003 (0.004)	− 0.004 (0.004)	**0.001 (0.004)**
Household size	− 0.015 (0.012)	− 0.013 (0.011)	− 0.007 (0.014)	− 0.002 (0.013)	**0.028* (0.014)**
Education	0.031*** (0.012)	0.017 (0.011)	0.022 (0.015)	− 0.003 (0.014)	**0.026* (0.016)**
Received credit	− 0.002 (0.046)	0.025 (0.048)	− 0.094 (0.057)	− 0.07 (0.055)	**− 0.055 (0.06)**
Irrigation access	− 0.022 (0.043)	− 0.007 (0.042)	0 (0.05)	0.026 (0.05)	**− 0.115** (0.051)**
Mobile	0.085 (0.046)	0.053 (0.049)	− 0.056 (0.058)	0.049 (0.057)	**− 0.047 (0.059)**
Radio	0.05 (0.047)	− 0.01 (0.046)	0.044 (0.063)	− 0.018 (0.057)	**0 (0.06)**
Extension contact	0.003* (0.002)	0.002 (0.002)	− 0.002 (0.002)	0.003 (0.002)	**− 0.001 (0.002)**
Off farm	0.004 (0.044)	0.078 (0.052)	− 0.019 (0.055)	− 0.124** (0.052)	**0.032 (0.061)**
Rice area	− 0.186 (0.119)	− 0.369*** (0.111)	− 0.429*** (0.146)	− 0.395*** (0.14)	**− 0.158 (0.144)**
Plot distance	− 0.026** (0.013)	0.008 (0.012)	− 0.012 (0.014)	0.036*** (0.014)	**0 (0.014)**
Soil fertility	0.004 (0.036)	− 0.068** (0.034)	− 0.033 (0.042)	0.052 (0.04)	**− 0.056 (0.044)**
Last year rice	− 0.027 (0.045)	0.063 (0.052)	− 0.118** (0.06)	0.106* (0.057)	**0.047 (0.062)**
Livestock ownership	0.051* (0.031)	0.01 (0.028)	0.044 (0.04)	0.039 (0.035)	**− 0.029 (0.036)**
Cultivated land	− 0.045 (0.044)	0.021 (0.042)	− 0.190*** (0.05)	0.045 (0.047)	**− 0.223*** (0.046)**
Social capital	0.126 (0.096)	0.229*** (0.089)	− 0.139 (0.119)	0.288** (0.119)	**0.06 (0.123)**
Market distance	0	0	0	0	**0**
Rice income	0.002*** (0.001)	0.003*** (0.001)	0.003*** (0.001)	0.003*** (0.001)	**0.003*** (0.001)**
Cooperative membership	0.022 (0.044)	− 0.066 (0.043)	0.034 (0.055)	0.01 (0.052)	**0.016 (0.053)**

Figures in parenthesis are standard errors

***Significant at 1%, **Significant at 5%, *Significant at 10%

Table 16 Conditional marginal effects, calculated at the mean assuming that all other dependent variables are zero

Variables	Certified Seed	Row planting	Urea recommendation	DAP recommendation	Weeding recommendation
Gender (male)	0.015 (0.038)	− 0.001 (0.04)	0.131*** (0.051)	− 0.112 (0.088)	**0.077 (0.084)**
Age (years)	− 0.001 (0.001)	0.001 (0.001)	− 0.002 (0.002)	0.003 (0.002)	**− 0.004 (0.002)**
Rice experience	0.002 (0.002)	0.001 (0.002)	0.002 (0.003)	− 0.004 (0.003)	**0 (0.004)**
Family size (number)	− 0.008 (0.006)	− 0.006 (0.006)	− 0.006 (0.011)	0 (0.011)	**0.031** (0.014)**
Education	0.012** (0.006)	0.006 (0.006)	0.012 (0.011)	− 0.01 (0.011)	**0.02 (0.015)**
Credit received	0.006 (0.024)	0.023 (0.026)	− 0.061 (0.044)	− 0.046 (0.042)	**− 0.04 (0.058)**
Irrigation access	− 0.005 (0.022)	− 0.002 (0.021)	0.011 (0.039)	0.03 (0.04)	**− 0.113** (0.049)**
Mobile	0.045* (0.023)	0.018 (0.025)	− 0.057 (0.047)	0.04 (0.044)	**− 0.055 (0.059)**
Radio	0.025 (0.026)	− 0.008 (0.023)	0.033 (0.053)	− 0.019 (0.046)	**− 0.009 (0.059)**
Extension contact	0.002* (0.001)	0 (0.001)	− 0.002 (0.002)	0.002 (0.002)	**− 0.001 (0.002)**
Non Off farm	− 0.004 (0.022)	0.057* (0.034)	− 0.006 (0.044)	− 0.109*** (0.038)	**0.04 (0.062)**
Rice area	− 0.031 (0.062)	− 0.136** (0.069)	− 0.257** (0.122)	− 0.194 (0.121)	**− 0.043 (0.147)**
Plot distance	− 0.014** (0.007)	0.003 (0.006)	− 0.012 (0.011)	0.03*** (0.011)	**0.001 (0.014)**
Soil fertility	0.012 (0.018)	− 0.039** (0.019)	− 0.027 (0.033)	0.062* (0.032)	**− 0.054 (0.044)**
Crop rotation	− 0.015 (0.022)	0.025 (0.029)	− 0.109** (0.045)	0.089* (0.05)	**0.053 (0.062)**
Livestock ownership	0.025 (0.016)	− 0.002 (0.014)	0.028 (0.03)	0.026 (0.029)	**− 0.042 (0.034)**
Cultivated land	− 0.002 (0.024)	0.017 (0.022)	− 0.132*** (0.044)	0.071* (0.039)	**− 0.2*** (0.048)**
Social capital	0.05 (0.05)	0.084*(0.049)	− 0.172* (0.096)	0.208** (0.097)	**0.032 (0.122)**
Rice ecosystem	− 0.038 (0.031)	0.064*** (0.024)	− 0.071 (0.045)	0.022 (0.04)	**− 0.082 (0.056)**
Market distance	0(0)	0(0)	0(0)	0(0)	**0(0)**
Rice income	0.001 (0)	0.001*** (0)	0.001** (0.001)	0.001* (0.001)	**0.002*** (0.001)**
Cooperative membership	0.014 (0.022)	− 0.038 (0.024)	0.023 (0.043)	0.015 (0.042)	0.012 (0.052)

Figures in parenthesis are standard errors

*** Significant at 1%, ** Significant at 5%, * Significant at 10%

Table 17 Conditional marginal effects, calculated at the mean assuming that all other dependent variables are one

Variables	Certified seed	Row planting	Urea recommendation	DAP recommendation	Weeding recommendation
Gender (male)	0.042 (0.144)	− 0.014 (0.13)	0.2* (0.115)	− 0.108 (0.069)	**0.053 (0.077)**
Age (years)	− 0.004 (0.004)	0.005 (0.003)	− 0.002 (0.002)	0.003 (0.002)	**− 0.003 (0.002)**
Rice experience	0.005 (0.005)	0.002 (0.006)	0.002 (0.004)	− 0.005 (0.004)	**0 (0.003)**
Family size (number)	− 0.02 (0.019)	− 0.015 (0.018)	− 0.004 (0.013)	0.003 (0.013)	**0.026** (0.011)**
Education	0.034* (0.018)	0.013 (0.017)	0.01 (0.014)	− 0.014 (0.014)	**0.012 (0.013)**
Credit received	0.009 (0.073)	0.065 (0.07)	− 0.079 (0.063)	− 0.062 (0.055)	**− 0.032 (0.048)**
Irrigation access	− 0.018 (0.07)	− 0.005 (0.068)	0.012 (0.046)	0.032 (0.046)	**− 0.088** (0.042)**
Mobile	0.128* (0.077)	0.034 (0.08)	− 0.082 (0.054)	0.037 (0.053)	**− 0.052 (0.045)**
Radio	0.073 (0.068)	− 0.035 (0.075)	0.032 (0.059)	− 0.018 (0.057)	**− 0.011 (0.046)**
Extension contact	0.004* (0.003)	0.001 (0.003)	− 0.003 (0.002)	0.002 (0.002)	**− 0.001 (0.002)**
Non Off farm	− 0.03 (0.07)	0.156** (0.073)	− 0.001 (0.055)	− 0.161*** (0.062)	**0.029 (0.046)**
Rice Area	− 0.02 (0.182)	− 0.399** (0.187)	− 0.283* (0.152)	− 0.153 (0.156)	**− 0.011 (0.12)**
Plot distance	− 0.043** (0.02)	0.016 (0.02)	− 0.01 (0.013)	0.032** (0.013)	**0.003 (0.011)**
Soil fertility	0.054 (0.058)	− 0.129** (0.058)	− 0.036 (0.04)	0.086** (0.038)	**− 0.04 (0.036)**
Crop rotation	− 0.054 (0.072)	0.081 (0.079)	− 0.133** (0.064)	0.088* (0.052)	**0.043 (0.047)**
Livestock ownership	0.073 (0.046)	− 0.019 (0.045)	0.024 (0.036)	0.028 (0.035)	**− 0.038 (0.027)**
Cultivated land	− 0.019 (0.072)	0.051 (0.068)	− 0.16*** (0.055)	0.073 (0.048)	**− 0.152*** (0.044)**
Social capital	0.113 (0.151)	0.232 (0.145)	− 0.222** (0.113)	0.199* (0.12)	**0.008 (0.098)**
Rice ecosystem	− 0.145 (0.097)	0.214*** (0.074)	− 0.076 (0.056)	− 0.002 (0.048)	**− 0.06 (0.048)**
Market distance	− 0.001 (0.001)	− 0.001 (0.001)	0 (0)	0 (0)	**0 (0)**
Rice Income	0.001 (0.001)	0.003*** (0.001)	0.001* (0.001)	0.001 (0.001)	**0.002** (0.001)**
Cooperative membership	0.059 (0.069)	− 0.123** (0.069)	0.024 (0.053)	0.032 (0.05)	**0.009 (0.041)**

Figures in parenthesis are standard errors

*** Significant at 1%, ** Significant at 5%, * Significant at 10%

Abbreviations

MoA	Ministry of agriculture
MVP	Multivariate probit
SWEP	Southern nations nationalities and people
TLU	Tropical livestock unit

Acknowledgements
We wish to express our profound gratitude to the Ethiopian Institute of Agricultural Research for financial support in accomplishing this study. Our acknowledgment is also extended to an outstanding survey team, including enumerators and the supervisors (Mrs. Shewaye Abera, Mr. Wolay Tesfaye, Mr. Afework Hagos, Mr. Takele Mebratu, and Mr. Abdu Mohammed), our farmer respondents, and extension workers who facilitated the survey work. Furthermore, we are also grateful to Mr. Tesfaye Solomon and Mr. Tadele Mamo for their support in generating marginal effect of the MVP model results and Mr. Demeke Nigussie for his contribution on the study area map of this paper.

Author contributions
AB contributed to the survey design, data collection, cleaned the data, analyzed the data and wrote the first draft of the manuscript. EH initiated the research question, designed the study, interpreted the data and contributed to the writing of the manuscript. In addition, SS contributed by reading, editing, and structuring of the manuscript. All authors read and approved the final manuscript.

Funding
This research work was financed by the Ethiopian Institute of Agricultural Research (EIAR).

Availability of data and materials
Data used for the analyses described in this article are available from the corresponding author upon request.

Declarations

Declarations
The paper is an original paper. No part of the manuscript has been published before, nor is any part of it under consideration for publication in another journal. In addition, we affirm that all the authors have approved the manuscript for submission.

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 24 January 2022 Accepted: 13 February 2023
Published online: 27 April 2023

References

1. Abdulai S, Zakariah A, Donkoh SA. Adoption of rice cultivation technologies and its effect on technical efficiency in Sagnarigu District of Ghana. Cogent Food Agric. 2018;4(1):1424296. https://doi.org/10.1080/23311932.2018.1424296.
2. Ndagi AH, Kolo IN, Yabagi AA, Garba Y. Adoption of production technologies by lowland rice farmers in. Int J Agric Ext. 2016;04(01):49–56.
3. Abate T. Would the green revolution ever come to Africa? Academia Lett. 2021;1705:1–5.
4. Eliazer Nelson ARL, Ravichandran K, Antony U. The impact of the green revolution on indigenous crops of India. J Ethnic Foods. 2019;6(1):1–10. https://doi.org/10.1186/s42779-019-0011-9.
5. Alemu D, Tesfaye A, Assaye A, Addis D. 2018 A Historical Analysis of Rice Commercialisation in Ethiopia: the Case of the Fogera Plain. APRA Working Paper 18.1–7.
6. CSA (Central Statistics Agency). The federal democratic republic of Ethiopia central statistical agency report on private peasant holdings. Addis Ababa: Meher Season; 2020.
7. Pingali PL. Green revolution: impacts, limits, and the path ahead. Proc Natl Acad Sci USA. 2012;109(31):12302–8. https://doi.org/10.1073/pnas.0912953109.
8. Yirga C and Alemu D (2016) Adoption of Crop Technologies among SmallholderFarmers in Ethiopia: Implications for Research and Development. EIAR 50th Year Jubilee Anniversary Special Issue:1–16.
9. Evenson RE, Gollin D. Assessing the impact of the green revolution, 1960 to 2000. Science. 2003;300(5620):758–62. https://doi.org/10.1126/science.1078710.
10. Jaleta M, Kassie M, Marenya P, Yirga C, Erenstein O. Impact of improved maize adoption on household food security of maize producing smallholder farmers in Ethiopia. Food Secur. 2018;10(1):81–93. https://doi.org/10.1007/s12571-017-0759-y.
11. Shiferaw B, Kassie M, Jaleta M, Yirga C. Adoption of improved wheat varieties and impacts on household food security in Ethiopia. Food Policy. 2014;44:272–84. https://doi.org/10.1016/j.foodpol.2013.09.012.
12. Sileshi M, Kadigi R, Mutabazi K, Sieber S. Impact of soil and water conservation practices on household vulnerability to food insecurity in eastern Ethiopia: endogenous switching regression and propensity score matching approach. Food Security. 2019;11(4):797–815. https://doi.org/10.1007/s12571-019-00943-w.
13. Asmelash Y. Determinants of adoption of upland rice varieties in Fogera district, South Gondar, Ethiopia. J Agric Ext Rural Develop. 2014;8(12):332–8.
14. Belayneh T, Tekle J. Review on adoption, trend, potential and constraints of rice production to livelihood in Ethiopia. Int J Res Granthaalayah. 2017;5(6):644–58. https://doi.org/10.29121/granthaalayah.v5.i6.2017.2097.
15. Hagos A, Zemedu L. Determinants of improved rice varieties adoption in Fogera district of Ethiopia. Sci Technol Arts Res J. 2015;4(1):221. https://doi.org/10.4314/star.v4i1.35.
16. Takahashi K, Muraoka R, Otsuka K. Technology adoption impact and extension in developing countries' agriculture: a review of the recent literature. Agric Econom. 2020;51(1):31–45. https://doi.org/10.18884/00001002.
17. CSA. Ethoipian agricultural sample survey statistical report on area and production of major crops in 2017/18 (2010 EC). Addis Ababa, Ethiopia: Statistical Bull; 2018. p. 1–121.
18. Ali A, Erkossa T, Gudeta K, Abera W, Mesfin E, Mekete T, Haile M, Haile W, Abegaz A, Tafesse D, Belay G, Getahun M, Beyene S, Assen M, Regassa A, Gebre Selassie Y, Tadesse S, Abebe D, Walde Y, Hussien N, Yirdaw A, Mera A, Adma T, Wakoya F, Legesse A, Tessema N, Abebe A, Gebremariam S, Aregaw Y, Abebaw B, Bekele D, Zewdie E, Schulz S, Tamene L, Elias E. Reference soil groups map of ethiopia based on legacy data and machine learning technique: EthioSoilGrids 1.0. 2022. EGUsphere. https://doi.org/10.5194/egusphere-2022-301.
19. Yamane T. Statistics: an introductory analysis. 2nd ed. New York: Harper and Row; 1967.
20. Greene WH. Econometric analysis fifth edition book. New York, USA: Macmillan; 2002.
21. Assaye A, Ketema M, Bekele A. Smallholder Farmers' adaptation strategies to climate change: the case of Ankesha Guagusa District of Awi Zone, Northwestern Ethiopia. J Agric Econom Rural Develop. 2020;6(2):760–72.
22. Donkoh SA, Azumah SB, Awuni JA. Adoption of improved agricultural technologies among rice farmers in Ghana: a multivariate probit approach. Ghana J Develop Stud. 2019;16(1):46–67. https://doi.org/10.4314/gjds.v16i1.3.
23. Kassie M, Teklewold H, Jaleta M, Marenya P, Erenstein O. Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. Land Use Policy. 2015;42:400–11. https://doi.org/10.1016/j.landusepol.2014.08.016.
24. Teklewold H, Kassie M, Shiferaw B, Köhlin G. Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts

on household income, agrochemical use and demand for labor. Ecol Econ. 2013;93:85–93. https://doi.org/10.1016/j.ecolecon.2013.05.002.
25. Hauseman JA. Specification tests in econometrics. Econometrica. 1978;46(6):1251–71.
26. Araya GB. Impact of Ethiopia's productive safety net program on manure use by rural households: Evidence from Tigrai Northern Ethiopia. Agricu Econom. 2020;51(5):725–42. https://doi.org/10.1111/agec.12588.
27. Habte E, Tesfaye A, Zemedu L, Mussema R. Results of Agricultural Economics Results of Agricultural Economics Abebaw Assaye and Agajie Tesfaye Characterizations & Dynamism of Northern Highlands Farming Systems of Ethiopia. Addis Ababa, Ethiopia: Agricultural economics proceedings; 2020.
28. Yirga C, Atnafe Y, Awhassan A. A multivariate analysis of factors affecting adoption of improved varieties of multiple crops: a case study from Ethiopian highlands. Ethiopian J Agric Sci. 2015;25(2):29–45.
29. Bian JL, Xu FF, Han C, Qiu S, Ge JL, Xu J, Zhang HC, Wei HY. Effects of planting methods on yield and quality of different types of japonica rice in northern Jiangsu plain. China J Integrat Agric. 2018;17(12):2624–35. https://doi.org/10.1016/S2095-3119(18)62141-0.
30. Donkor E, Owusu-Sekyere E, Owusu V, Jordaan H. Impact of row-planting adoption on productivity of rice farming in Northern Ghana. Rev Agric Appl Econom. 2016;19(02):19–28. https://doi.org/10.22004/ag.econ.254154.
31. Nasrin S, Lodin JB, Jirström M, Holmquist B, Djurfeldt AA. Drivers of rice production: evidence from five Sub-Saharan African countries. Agric Food Secur. 2015. https://doi.org/10.1186/s40066-015-0032-6.
32. Tadesse T, Liben M, Assefa A, Tadesse Z. Effect of transplanting on rice in Northwestern Ethiopia. Ethiopian J Sci Technol. 2013;6(1):47–54.
33. Redda A, Redda A, Hailegebriel K, Yirgalem T, Redae W, Welegerima G, Husien S. Effects of N and P fertilizer application rates on yield and economic performance of upland rice in Tselemti District of NW Tigray Ethiopia. Rice Res Open Access. 2018;06(02):1–8. https://doi.org/10.4172/2375-4338.1000191.
34. Tadesse T, Tadesse Z. Review of rice response to fertilizer rates and time of nitrogen application in Ethiopia. Int J Appl Agric Sci. 2019;5(6):129. https://doi.org/10.11648/j.ijaas.20190506.11.
35. Becker M, Johnson DE, Wopereis MCS, Sow A. Rice yield gaps in irrigated systems along an agro-ecological gradient in West Africa. J Plant Nutr Soil Sci. 2003;166(1):61–7. https://doi.org/10.1002/jpln.200390013.
36. Johnson J, Rodenburg J, Tanaka A, Senthilkumar K, Ahounton K, Dieng I, Saito K. Farmers' perceptions on mechanical weeders for rice production in sub-Saharan Africa. Exp Agric. 2018. https://doi.org/10.1017/S001447971700059X.
37. Sureshkumar R, Reddy Y, Ravichandran S. Effect of weeds and their management in transplanted rice—a review. IMPACT Int J Res Appl Nat Soc Sci. 2016;4(11):165–80.
38. Amare T. Effect of weed management methods on weeds and wheat (Triticum aestivum L.) yield. African J Agric Res. 2014;9(24):1914–20.
39. Masset E, García HJ. Impact of the SADA-Northern Ghana Millennium village project on multidimensional poverty: a comparison of dashboard and index approaches. Oxford: The Oxford Poverty and Human Development Initiative (OPHI); 2019.
40. Zewditu D, Berhanu LR, Amare G. Effect of ploughing and weeding frequencies on growth, yield and yield components of Teff [Eragrostis tef (Zucc) Trotter] in Mirab Abaya Area, Southern Ethiopia. African J Agric Res. 2020;16(12):1691–9. https://doi.org/10.5897/ajar2020.15181.
41. Bezu S, Kassie GT, Shiferaw B, Ricker-Gilbert J. Impact of improved maize adoption on welfare of farm households in malawi: a panel data analysis. World Dev. 2014;59:120–31. https://doi.org/10.1016/j.worlddev.2014.01.023.
42. Giziew A, Mebrate B. Determinants of the role of gender on adoption of row planting of tef [Eragrostis tef (Zucc.) Trotter] in central Ethiopia. Ethiopian J Sci Technol. 2019;12(1):19–43. https://doi.org/10.4314/ejst.v12i1.2.
43. Donkoh SA. Rice Commercialisation and improved agricultural technology adoption in northern Ghana: endogenous switching Poisson approach. Alanya Akademik Bakış. 2020;2030(1):105–21. https://doi.org/10.29023/alanyaakademik.600275.
44. Yokamo S. Adoption of improved agricultural technologies in developing countries: literature review. Int J Food Sci Agric. 2020;4(2):183–90. https://doi.org/10.26855/ijfsa.2020.06.010.
45. Leake G, Adam B. Factors determining allocation of land for improved wheat variety by smallholder farmers of northern Ethiopia. J Dev Agric Econ. 2015;7(3):105–12. https://doi.org/10.5897/jdae2014.0621.
46. Atinafu A, Lejebo M, Alemu A. Adoption of improved wheat production technology in Gorche district. Ethiopia Agric Food Secur. 2022;1–8:2022. https://doi.org/10.1186/s40066-021-00343-4.
47. Hagos H, Ndemo E, Yosuf J. Factors affecting adoption of upland rice in Tselemti district, northern Ethiopia. Agric Food Secur. 2018;7(1):1–9. https://doi.org/10.1186/s40066-018-0210-4.
48. Assefa A, Gezahegn A. Adoption of improved technology in Ethiopia. Ethiopian J Econom. 2010;19(1):155–80. https://doi.org/10.22004/ag.econ.258726.
49. Amare Y. Determinants of Adoption of Wheat Row Planting: The Case of Wogera District, North Gondar Zone, Amhara Regional State. J Agri Sci Food Res. 2018;9:250.
50. Aryal JP, Rahut B, Maharjan S, Erenstein O. Factors affecting the adoption of multiple climate-smart agricultural practices in the indo-Gangetic plains of India. Nat Res Forum. 2018;42:141–58. https://doi.org/10.1111/1477-8947.12152.
51. Tesfay MG. Does fertilizer adoption enhance smallholders' commercialization ? An endogenous switching regression model from northern Ethiopia. Agric Food Secur. 2020. https://doi.org/10.1186/s40066-020-0256-y.
52. Mathenge MK, Smale M, Tschirley D. Off-farm employment and input intensification among smallholder maize farmers in Kenya. J Agric Econom. 2015;66(2):519–36.
53. Chang HH, Mishra AK. Chemical usage in production agriculture: do crop insurance and off-farm work play a part? J Environ Manage. 2012;105:76–82.
54. Shi X, Heerink N, Qu F. China economic review does off-farm employment contribute to agriculture-based environmental pollution? New insights from a village-level analysis in Jiangxi. China Econ Rev. 2011;22(4):524–33. https://doi.org/10.1016/j.chieco.2010.08.003.
55. Abera S, Assaye A. Profitability analysis of rain fed upland rice production under smallholder farmers in Libokemkem district. Int J Agric Econom. 2021;69(3):111–5. https://doi.org/10.11648/j.ijae.20210603.13.
56. Genet Y, Feyso T. Evaluation of the adoption of improved agricultural practices and factors that affect adoption of Tef (Eragrostis tef (Zucc) Trotter) in Ethiopia. Int J Agric Econom. 2020;5(6):293–303. https://doi.org/10.11648/j.ijae.20200506.18.

Publisher's Note