Adoption of Improved Agricultural Technologies among Rice Farmers in Ghana: A Multivariate Probit Approach

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ABSTRACT

The need for practising modern techniques in rice production has become increasingly important in Ghana as the per capita cultivable land continues to shrink. This study employed a multivariate probit model to estimate the determinants of adoption of improved agricultural technologies using household data collected from 543 rice farmers in the Upper East and Northern region of Ghana. There was complementarity among all the improved rice production technologies (i.e. nursery establishment, harrowing, line planting, spacing, urea briquette, irrigation, and bunding). Among the socio-economic variables, education, household size, experience, farm size, sex, and age of the farmer play significant roles, with differing signs across technologies. Among the institutional factors, membership of farmer-based organisation, access to research service, training and credit were significant with differing signs across the improved technologies. Location also had significant and differing influence on adoption. Also, demonstration, TV, radio, video, mobile phones, and household extension methods had significant and differing influence on the adoption of improved technologies, providing significant justification for the review

of the agricultural extension methods and approaches of Ghana to include new ICT and mass media approaches. To improve the output of rice, farmers are advised to jointly adopt the identified improved rice production technologies.

INTRODUCTION

In Ghana, rice imports continue to surge ahead of production. Increasing rice yields has therefore become a priority and necessity for stakeholders in the rice value chain. Annual per capita consumption of rice in Ghana grew from 17.5 kg during 1999–2001 to 24 kg during 2010–2011 (MoFA, 2013; Ragasa et al., 2014). This has seen a further increase to about 32kg for 2015 (MoFA, 2016). Also, the demand for rice is projected to grow at an annual growth rate of 11.8%, exceeding that of maize (2.6%) in the medium term (MiDA, 2010). As only 5% of global production is traded, local production would also protect consumers from price shocks in the world rice market (World Bank, 2013). While substantial investments in national rice production have been made, local production is still not able to keep up with the growing demand for rice in Ghana. Although local production of milled rice recently grew by 10.5% annually, from 242,000 metric tons (MT) in 2004 to 481,000 MT in 2012, most of this growth in production had come from expansion in farm sizes (7.5%), with the remaining 3.0% coming from productivity improvements. Despite these efforts, Ghana imported 508, 587 MT of rice in 2013 alone, translating into about USD$ 639.4 million, to compensate for domestic production shortfall (MoFA, 2013). This has increased further by about 22% to 620,811 MT for the 2015/2016 production season (MoFA, 2016).

Clearly, the challenge of Ghana's rice sector could be compounded by several factors including the changing climate, hence, the need for farmers to adopt and use improved agricultural technologies to reverse the poor trends in local rice production and consumption. For instance, the average rice yield in Ghana is estimated to be 2.5 MT/ha, while the achievable yield based on on-farm trials is about 6.5 MT/ha (MoFA, 2013). Low adoption of inputs and improved technologies is often cited as the major reason for this gap.

There exists some technology transfer and adoption challenges which must be addressed if we are to make a headway with the rice production sector in northern Ghana. For instance, to determine technology adoption levels and better understand the constraints to and incentives for adoption, a nationally representative survey of 576 rice farmers in 23 districts in 10 regions in Ghana was implemented in 2013

by Ragasa et al. (2013). This study provided analysis on the patterns of adoption of improved technologies for rice in Ghana. Ragasa et al. (2013) reported of a low adoption level of 48% for improved modern rice variety from certified sources for the northern savannah zone as compared with the national rate of 58% (which was also lower than the average for south Sahara Africa). About 34% of the total area under rice production in the northern savannah zone was planted with modern rice variety from certified source, with another 13% of the land area for rice planted in rows.

Against this backdrop, several interventions have been implemented to arrest the bad situation. Climate smart agriculture and improved agricultural technologies have been introduced to rice farmers through interventions such as the Feed the Future (FTF) USAID-Ghana Agriculture Technology Transfer project (ATT Project), ADVANCE I and II projects, The Rice Sector Support Project (RSSP), the Quality Rice Project, just to mention a few. These supports have come in the form of improved seed and innovative agronomic practices such as harrowing, line planting, urea deep placement (UDP), bunding and proper spacing. Neglecting the inter-relationships among the improved practices may result in bias estimates of factors influencing adoption of improved technologies (Wu & Babcock, 1998). To account for such interdependent relationship, MVP regression approach was employed to jointly analyse the factors affecting the probability of adopting each of the improved rice production technique in northern Ghana.

Harrowing is meant to teach farmers about proper conditioning of the soil and to enhance levelling. Line planting on the other hand, is meant to ensure proper arrangement of the plant on the farm to allow for easy maintenance of farm hygiene and to ensure the right cropping density per unit area. Line planting when done together with proper spacing at 20cm x 20cm also allows for proper aeration on the farm. The main goal of the UDP technology is to improve nitrogen use efficiency in rice production which is expected to improve output (Rahman & Barmon, 2015). UDP technology is made up of two key components. First, is a fertilizer 'briquette' produced by compacting prilled urea fertilizer into Urea Super Granules or USG that weighs about 1-3 grams per briquette. The second key component of the UDP technology is the placement of USG below the soil surface at the root zone of the plant. The briquettes are centred between four rice plants at a spacing of 20cm x 20cm and at a depth of between 7cm and 10cm. Bunding provides demarcation for farm lands and helps to control water losses on rice fields.

METHODOLOGY

Study Area

The study was conducted in northern Ghana. Farmers from the Upper East Region and Northern Region who produced rice constituted the population *(N)* from which the sample was drawn. The two regions are agrarian and among the largest producers of paddy rice in Ghana, producing up to 290,000 tons annually (MoFA, 2016), and yet, among the poorest regions in Ghana (GSS, 2014). Paddy yields in the two regions are still below national average. Two main climatic conditions or seasons pertain in the study area. These are the wet season and the dry season. The wet season commences in April through to October/November each year. The dry season begins from November each year through to April the following year. The dry season usually peaks in February showing signs of severe harmattan characterised by dry winds.

Sampling and Data Collection

Rice farmers in the Guinea Savannah ecological zone constituted the population *(N)* for this study. Rice farmers located in areas of vast natural rice valleys were considered. The Ghana Living Standard Survey (GLSS) round 6 (2014) puts the number of households in the Guinea Savannah zone who produce rice at 296,489. However, the entire population of rice farmers could not be surveyed due to financial and time constraints. Hence, the need for sample size determination.

The determination of the sample size follows Slovin's (1960) formula used to calculate sample size when little information is available for the population (Ryan, 2013; and Ariola, 2006). This was applied as follows in Equation 1:

$$n = \frac{N}{1 + Ne^2}$$ .... (1)

Where *n* is the sample size, *e* is the margin of error (which is 0.05 with confidence level of 95%). *N* is the population of rice farmers, which is 296,489 for this study. By substitution, the sample size *(n)* is computed as 400. The sample size was, however, adjusted to 550 to cater for some design effect that might have arisen. However, 543 of the returned questionnaires contained all the necessary information for the purpose of this study. About 68% of the respondents were from the Northern Region. The rest of the 32% of the respondents were from the Upper East Region. The proportion of the sample assigned to each region was based on the density of rice production points in the two regions, with the Northern Region being dominant in the production of the commodity.

Multistage sampling method was adopted to select the respondents from rice growing communities in the two regions for the study. As the name suggests, the multistage sampling procedure involves a combination of more than two sampling procedures. In the first stage of the sampling procedure, the two northern regions (Northern and Upper East) were purposively selected based on their high nominal contribution to the rice sector of Ghana, and also because productivity for rice was lower in these two regions (MoFA, 2013). The regions have dominant and vast natural lowlands suitable for rice production.

In the second stage, simple random sampling through balloting was used to select five districts in each of the two regions. Simple random was used to select 4-7 communities in each of the selected districts. In all, a total of 62 farming communities were selected for this study. Again, simple random sampling was used to select 543 farmers as the final respondents for the study.

Cross sectional primary data was used for the study. A questionnaire was designed to collect primary data from rice farmers. The questionnaire included questions on the socio-economic and demographic information of the respondents, technology application and adoption characteristics of rice farmers as well as the level and costs of inputs used for production and the output levels of the farmers. Some focus group discussions were also organised to validate some of the responses from farmers for qualitative analyses. Interview guides and checklists were developed and used to collect data from NGOs and sector actors who are involved in agricultural technology transfer and the rice value chain.

Pretesting of the questionnaire was conducted using 20 rice farmers selected randomly from the study area. A test for consistency and reliability using Cronbach coefficient alpha test produced alpha value of 0.807. DeVellis (2012) consider a Cronbach alpha value between 0.8 and 0.9 to be good and acceptable.

The data was collected by 10 trained research assistants and supervised by the researcher. The officers were fluent both in the English language and the local dialects of the participating communities/districts. The data was collected between January and March 2017. It covered information related to the 2016 production season of the rice farmers which ended technically in December 2016.

Analytical Framework – the Multivariate Probit Model

Multivariate probit (MVP) regression was used to estimate the factors that influenced the adoption of improved agricultural technologies for rice production. Statisticians and econometricians view the multivariate probit model as a generalisation of the probit model used to estimate several correlated binary

outcomes simultaneously (Greene, 2002). Generally, a multivariate model extends to more than two outcome variables just by adding equations.The study identified seven improved rice production techniques (i.e. nursery establishment, harrowing, spacing, line planting, use of urea briquette, bunding and irrigation) and farmers are more likely to jointly adopt a mix of these techniques to deal with their production constraints than to adopt a single practice[2].

Neglecting the inter-relationships among the improved practices may result in bias estimates of factors influencing adoption of these improved technologies (Wu & Babcock, 1998). To account for such interdependent relationship, MVP regression approach was employed to jointly analyse the factors affecting the probability of adopting each improved rice production technique.

The MVP estimation technique considers the correlation in the error terms by jointly modelling the effects of a set of covariates on each of the improved agricultural technologies and estimates a set of binary probit models. It allows the relationship between the adoption of different improved production practices to be established, as well as potential correlations between unobserved disturbances (Ahmed, 2015; Kassie et al., 2009). Univariate models such as probit and logit ignore the correlation in the error terms of the adoption equation. Application of such models is therefore inappropriate when adoption practices are interrelated (Belderbos et al., 2004). Failure to account for such unobserved factors and the interdependent relationship of adoption decisions on different technological practices may provide inefficient and bias estimates (Greene, 2008).

Following Danso-Abbeam and Baiyegunhi (2017), as in Kassie et al. (2013) and Mulwa et al. (2017), a heptavariate probit model with the seven sets of binary dependent variables (i.e. nursery establishment, harrowing, spacing, line planting, use of urea briquette, bunding and irrigation), was formulated as indicated by Equation 2, such that:

$$Y^*_{ik} = \beta_k X_{ik} + \alpha_k A_{ik} + \varepsilon_k \qquad (2)$$

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2   To determine the choice of model, the following hypotheses were set: H_o: the error terms across the seven adoption decisions are not correlated; H_A: there is mutual interdependence among the improved agricultural technologies. First, the likelihood ratio test of the independence of the error terms was conducted, which was significantly different from zero at 1% *(Chi² (21) = 731.941; Prob > Chi² = 0.0000)*, thereby, allowing us to reject the null hypothesis that the error terms across the seven adoption decisions are not correlated. Therefore, the alternate hypothesis of mutual interdependence among the improved agricultural technologies was adopted. The results (see Table 3) therefore support the use of a multivariate probit model applied in this study as a heptavariate model.

(k = nursery establishment (N), harrowing (H), spacing (S), line planting (L), use of urea briquette (U), irrigation (I) and bunding (B)). Equation 3 indicates the specification of the binary dependent variable.

$$Y_{ik}=1 \text{ if } Y^*_{ik} > 0 \text{ and otherwise} \qquad (3)$$

Where Y^*_{ik} is a latent variable which captures the observed and unobserved preferences associated with the kth improved agricultural technology, and Y_{ik} represents the binary dependent variables. X_{ik} represents the observed household and farm-specific characteristics, as well as institutional variables. A_{ik} represents plot characteristics to account unobserved heterogeneity. β_k and α_k are parameters to be estimated. ε_k represents the multivariate normally distributed stochastic error term (Wooldridge, 2003). In our multivariate probit framework, the error terms jointly follow a multivariate normal distribution with zero conditional mean. The variance is normalised to unity, where $(\mu_N, \mu_H, \mu_S, \mu_L, \mu_B, \mu_I, \mu_B) \approx$ MVN (0, Ω) and the symmetric variance covariance matrix Ω is specified by equation 4:

$$\Omega = \begin{bmatrix} 1 & \rho NH & . & \rho NB \\ \rho HN & 1 & . & . \\ . & . & 1 & IB \\ \rho IN & . & BI & 1 \end{bmatrix} \pm \qquad (4)$$

ρ is the pairwise correlation coefficient of the error terms with regards to any two of the estimated adoption equations in the model. The correlation between the stochastic components of different improved technologies adopted is represented by the off-diagonal elements (e.g. ρNH, ρNH) in the variance-covariance matrix (Danso-Abbeam & Baiyegunhi, 2017). The correlation is based on the principle that adoption of a particular improved practice may depend on another (complementarity or positive correlation) or may be influenced by an available set of substitutes (negative correlation) (Khanna, 2001).

RESULTS AND DISCUSSION

Definition and Descriptive Statistics of Variables

Table 1 provides a summary of definitions for the variables used in this study. In all, there are 17 variables. Relatively, a small percentage of farmers had access to information via video (36%). However, majority of the farmers (72% and 63% respectively) had information on improved production technologies via radio and also through their mobile phones respectively. While 42% of the farmers had access to information on improved technologies via the household extension method, about 73% also had information through attending technology demonstration field

days. Only 29% of the farmers had access to Television sets which could assist them in learning improved farming techniques.

Male farmers (83%) participated more in rice production as compared to their female counterparts. This finding does not however suggest that females were least involved in rice production, focus group discussions conducted with female and male rice farmers in the two regions revealed that the activities in rice production appeared led by the males because they own the lands on which production activities are carried out. Female household members assist their male counterparts in providing labour for transplanting, weeding and harvesting. Females are also mainly responsible for value addition such as parboiling and processing of rice for onward sale in local markets, and are said to be contributing up to 60-80 percentage of the labour for agriculture in Africa (FAO, 2011).

The results reveal that 68% of the respondents were from the Northern Region. The rest of the 32% of the respondents are from the Upper East Region of Ghana. The proportion of the sample assigned to each region was based on the density of rice production points in the two regions. The average age of a rice farmer was found to be 38.51 years (see Table 1). This indicates a relatively youthful age for rice farmers in the study area as MoFA (2013) reports the average age of farmers to be 55 years in Ghana. The finding is good for agricultural development in Northern Ghana, considering that agricultural activities around the area involve much labour because mechanisation is still a challenge.

Only 55% of the farmers had access to extension and research service the previous season. The poor agricultural extension system in Ghana could be attributed to the low investment by the government in the agriculture sector. Notably, graduates from the agriculture training colleges and universities in Ghana are no more automatically recruited into the Ministry of Food and Agriculture (MoFA) to provide extension services to farmers like it used to be in the 1980s and 1990s. This has widened the agriculture extension agent farmer ratio to about 1:3000 (GSS, 2014), leaving industry players in the NGO sector to provide trainings on improved technologies to farmers in the area. Sadly, the uncoordinated manner in which the NGO sector delivers its services to the farmers culminate into transmitting several conflicting information to the same farmers depending on the individual interest of these NGOs.

On the average, a farmer had up to only 4.05 years of formal education. This finding indicates a low level of formal education among rice farmers in the northern part of Ghana. The results revealed that rice farmers in the study area were very experienced as the average farmer possessed more than a decade of knowledge

in rice production. The result from Table 1 revealed that 64% of the farmers were members of farmer groups, which is positive as the farmers strive to formalise their operations.

The average household size was found to be 9.35, indicating that household sizes in the study area were relatively high compared with Ghana's national average of 4.0 (GSS, 2014). The average land holding per rice farmer was found to be to be 2.42 acres (translating into 0.96 hectares). This indicates that the average land holding for rice production was low in the area. On an average, a farmer adopted 3.5 technologies.

About 12% of the farmers had access to production credit in the previous season. This is an indication of low level of financing for agricultural activities in the area. Climate change is now evident in the area, making investments into the agricultural sector riskier than ever, a possible justification by financial institutions to shy away from funding production activities of rice farmers in the area. A high percentage of the farmers (72%) had received training on improved agricultural technologies for rice production the previous season, an effort that may be attributed to the many donor-led agricultural and development interventions in the study area.

Table 1: Definition of variables and descriptive statistics

Variable	Definition	Mean	SD
Region	Dummy: 1 for a farmer in northern region, 0 for a farmer in upper east region	0.68	0.47
HH. Ext method	Dummy: 1 for a farmer who accessed information via HH extension method, 0 if otherwise	0.42	0.49
Demos	Dummy: 1 for a farmer who accessed information via farmer led field technology demonstration method, 0 if otherwise	0.73	0.45
TV	Dummy: 1 for a farmer who accessed information via TV, 0 if otherwise	0.29	0.45
Radio	Dummy: 1 for a farmer who accessed information via radio, 0 if otherwise	0.72	0.45
Video	Dummy: 1 for a farmer who accessed information via video, 0 if otherwise	0.36	0.48
Mobile phone	Dummy: 1 for a farmer who accessed information via mobile phone, 0 if otherwise	0.63	0.48
Education	Number of years spent in formal schooling.	4.05	5.14
Experience	The total number of years a farmer has been cultivating rice.	11.72	7.66
FBO	Dummy: 1 for if the farmer belongs to a farmer group, 0 if otherwise	0.64	0.48
Research access	Dummy: 1 for access to research service in the last season, 0 if otherwise	0.55	0.5
Training	Dummy: 1 if farmer had access to trainings last season, 0 if otherwise.	0.71	0.45
Credit access	Dummy: 1 for access to credit in the last growing season, 0 if otherwise.	0.12	0.32
Farm size	Natural log of farm size (measured in the total hectares of land under rice production)	2.42	3.62
HH size	Total number of people in housing unit that feed from the same source	9.35	6.23
Sex	Dummy: 1 for male, 0 if otherwise	0.83	0.37
Age	The total number of years from birth of a farmer.	38.51	10.67
Adoption Int.	Number of improved agricultural technologies adopted (from 1 to 7)	3.52	2.35

Source: Analysis of field data, 2017

Adoption Rate of Improved Agricultural Technologies by Rice Farmers

This section first looks at the nature of the relationship between the improved rice production technologies. Secondly, the results from the individual probit equations to allow for comparison are presented. Table 2 presents various improved agricultural technologies and levels of adoption and practice among rice farmers in the study area. The results reveal that about 59% of the respondents practiced nursery. This was followed by proper spacing of rice plants (about 53%) and line planting (about 52%). About 51% of the farmers adopted bunding. The technologies with adoption rates below the midpoint of 50% were harrowing, irrigation and urea briquette with adoption rates of 43.65%, 41.07%, and 34.81% respectively.

Table 2: Improved agricultural technologies

Improved technology*	Freq. (No. of farmers practicing)	%
Nursery	321	59.12
Harrowing	237	43.65
Line planting	281	51.75
Spacing (20cm x 20cm)	287	52.85
Urea briquette	189	34.81
Irrigation	223	41.07
Bunding	276	50.83
N=543		

*Multiple responses

Source: Analysis of field data, 2017

The Relationship between the Improved Agricultural Technologies – Pairwise Correlations

Table 3 presents the results of the correlation matrix from the multivariate regression. The results indicate that the joint probability of adopting all the improved technologies is 11.1%, while the joint probability of using none of the improved technologies is 11.2%. From the linear predictions, the probabilities of a rice farmer adopting nursery, harrowing, spacing, and line planting are 34.8%, – 22.7%, 11.5%, and 5.8% respectively. The probability of adopting urea briquette, irrigation, and bunding are – 60.2%, 24.9%, and 3.1% respectively. All the pairwise coefficients were positively correlated, indicating complementarity among the improved rice production technologies. The relationship among all the complementary technologies were significant except for harrowing and nursery, harrowing and spacing, harrowing and line planting, and harrowing and urea

briquette. The highest positive correlation was between spacing and line planting (97.5%), while the lowest was between harrowing and nursery (3.4%).

Table 3: Correlation matrix of the technologies from the multivariate probit model

	Nursery	Harrowing	Spacing	Line planting	Urea briquette	Irrigation	Bunding
Nursery	1						
Harrowing	0.034 (0.092)	1					
Spacing	0.686 (0.053)^c	0.127 (0.088)	1				
Line planting	0.671 (0.051)^c	0.062 (0.087)	0.975 (0.009)^c	1			
Urea briquette	0.665 (0.067)^c	0.057 (0.089)	0.693 (0.055)^c	0.668 (0.058)^c	1		
Irrigation	0.798 (0.042)^c	0.219 (0.089)^b	0.590 (0.060)^c	0.539 (0.062)^c	0.491 (0.074)^c	1	
Bunding	0.462 (0.074)^c	0.226 (0.082)^c	0.529 (0.062)^c	0.473 (0.068)^c	0.391 (0.072)^c	0.578 (0.057)^c	1
Linear prediction for the equations	0.348	-0.227	0.115	0.058	-0.602	0.249	0.031
Joint probability (success)	0.111						
Joint probability (failure)	0.112						
Log likelihood	-1301.0687						
Wald chi2 (119)	757.66^c						

Likelihood ratio test of Rho_{ij} = 0. Chi² (21) = 731.941 Prob > Chi² = 0.0000
^{a}, ^{b}, and ^{c} represent 10%, 5%, and 1% level of significance respectively.
Source: Analysis of field data, 2017

Parameter Estimates of the Multivariate Probit Model

Several factors can influence rice farmers' decision to adopt one particular technology or the other. This section identifies the variables which determine the adoption of improved agricultural technologies by rice farmers using multivariate probit. The model contained seven dependent variables (improved technologies) (see Table 4). Seventeen explanatory variables, of which twelve were dummy and five continuous, were included in the model. Some variables such as other sources of information to farmers, as well as socio-economic variables were dropped because they were extremely skewed.

The location variable (region) showed a significant but negative relationship with rice farmers' decision to adopt harrowing, spacing, line planting, urea briquette, and bunding. This means that farmers in the Upper East Region tended to adopt these technologies more than their counterparts in the Northern region. Communicating improved agricultural technologies to farmers is critical in influencing productivity through the adoption of these technologies. Thus, four agricultural extension methods were included in the model.

Household extension method was significant and negatively related to the decision to adopt nursery, spacing, line planting, urea briquette, irrigation and bunding. This finding did not meet the *a priori* expectation since agricultural extension is meant to influence technology uptake by farmers. However, Anandajayasekeram et al. (2008) posit that, the household extension method does not promote cross learning and experience sharing among farmers from different homes and background since it as carried out only within the household of the person transmitting the information.

TV had positive and significant relationship with nursery establishment, line planting, urea briquette and bunding, meaning, farmers with access to TV had a higher probability of adopting these technologies. Radio and video had significant relationship with the adoption of nursery, spacing, line planting, urea briquette, irrigation, and bunding. While radio had a positive association with all six technologies, video had a positive association with nursery, irrigation and bunding and a negative relationship with spacing, line planting and urea briquette. The implication of this finding is that, rice farmers who receive information through a radio network had a higher propensity to adopt nursery, spacing, line planting, urea briquette, irrigation, and bunding more than farmers with no or less access to a radio network. Farmers who have watched videos on nursery, irrigation and bunding have a higher tendency of adopting these technologies than those with less or no access to videos. However, those with access to watching videos had a lower tendency of adopting proper spacing, line planting and urea briquette. Radio

and TV programmes regularly feature weather and agricultural information in developing countries, and rural telecentres have provided information on education and agricultural issues (Aker, 2011).

Access to mobile phone was only significant in explaining the adoption of harrowing and line planting but had a negative relationship. Meaning that farmers who had access to or owned mobile phones had less probability of adopting harrowing and line planting. To verify this finding, the researchers sought explanations from MoFA and agricultural NGOs operating in the area, who confirmed that the two technologies (harrowing and line planting) require (practical) field sessions to train farmers on. The activities involved require visualization and practice on how they are done on the field. Accessing them via mobile phone will therefore not offer the farmers the practical experience and could be counter-productive. Considering the nature of poverty among farmers in the study area, they are not able to afford smart phones that have the functions to show pictures and videos with better graphics on the technologies. The low levels of education among farmers in the study area could also limit the effective use of smart phones which requires some level of intellect.

Demonstration was not significant for two of the technologies (nursery and irrigation) but was significant with positive relationship for harrowing, spacing, line planting, urea briquette, and bunding. Perhaps, these technologies were considered technical by the farmers, hence their participation in demonstrations to acquaint themselves with the processes involved in carrying out these activities.

Education was found to have a positive and significant relationship with the adoption of nursery, proper spacing, and urea briquette, but failed to explain the adoption decision of harrowing, line planting, irrigation and bunding. This result means that higher educational status increases farmers' awareness about the benefits of adopting nursery, proper spacing, and the use of urea briquettes. All these three technologies have theoretical underpinnings. Using urea briquettes for instance, requires some basic understanding of soil physics because of the nature of operation of the urea tablet while underneath water. Some level of education is also required to understand the protocols in the application of urea deep placement technology (Azumah & Adzawla, 2017). Danso-Abbeam and Baiyegunhi (2017), using multivariate probit model to study adoption interdependency among cocoa farmers in Ghana concluded that education increases farmers' awareness of improved technologies. A similar study by Ahmed (2015) on the adoption of multiple technologies by farmers of the central rift valley of Ethiopia also found education to influence adoption decisions of farmers. Brick and Visser (2015), underscored the fact that educated people tend to be less risk averse, and so have a higher tendency of adopting improved technologies (Mulwa et al., 2017).

Experience was positive and significantly related to only irrigation and bunding but insignificant in explaining the adoption of the other technologies. Ahmed (2016) and Azumah, Tindjina, Obanyi and Wood (2017), also found experience to be redundant in explaining the adoption of improved production technologies. However, Azumah, Donkoh and Ansah (2017), found experience to significantly and positively influence farmers' adoption of climate smart coping strategies in Northern Ghana.

Consistent with the finding of Ahmed (2015), membership of FBOs was found to significantly and positively influence the adoption of nursery, line planting, urea briquette, and irrigation. However, FBO membership bore a significant and negative relationship with harrowing, corroborating Mulwa et al. (2017), who found a negative relationship between membership of FBO and the adoption of improved technologies. Access to research service significantly and positively influenced the adoption of harrowing. Farmers' access to extension agents should increase technical flow of information from agents to the farmers. Contrary to our *a priori* expectation, however, access to research service had a significant but negative relationship with the adoption of nursery, urea briquette, irrigation, and bunding, contradicting the findings of Danso-Abbeam and Baiyegunhi (2017), but corroborating that of Anang and Amikuzuno (2015), and Denkyiral et al. (2016). Perhaps, the research officers in the study area do not provide extension services on the selected improved technologies to rice farmers. The weakness in the state-led research and agricultural extension systems has also led to the arrogation of responsibility of investigating and disseminating information to farmers by the NGO sector in the study area.

Recent studies by Azumah, Tindjina, Obanyi, and Wood (2017), and Danso-Abbeam and Baiyegunhi (2017), have shown that agricultural trainings received by farmers have enhanced farmers' adoption of improved agricultural practices. This study indicates that farmers' access to agricultural trainings significantly and positively influenced their adoption of nursery, spacing, line planting, urea briquette, irrigation and bunding. The education variable had a negative and significant relationship with only harrowing. Studies by Onumadu and Osahon (2014), Gyinadu, Bakang, and Osei (2015), and Mmbando and Baiyegunhi (2016) have shown that inadequate access to farm credit impedes the adoption of improved technologies by farmers. Credit constrained rice farmers were found to be more likely to adopt nursery, spacing and irrigation, but less likely to adopt harrowing. This finding contradicts the work of Ahmed (2015), who found the credit variable to be redundant in explaining adoption decisions of farmers. Meanwhile, Kassie et al. (2015), found that credit was necessary to assist farmers in Malawi and Ethiopia

to adopt minimum tillage practice. Mulwa et al. (2017), found access to credit as a major determinant of farmers' decision to adapt to climate change.

Farm size was significant and had a negative relationship with all the technologies except harrowing. Meaning, farmers with bigger farm sizes had lower probability to adopt nursery, spacing, line planting, urea briquette, irrigation and bunding compared with those who had smaller farm sizes. This could be so because adopting these technologies would come with extra cost aside cost of seed and ploughing. This result is in line with the study of Kassie et al. (2015), who suggested that the scarcity of land can induce agricultural intensification through the adoption of improved technologies. The finding, however, contradicts the study of Bezu et al. (2014), and Danso-Abbeam and Baiyegunhi (2017), who found farm size to be significant and positively influence the adoption of improved technologies. Household size had negative and insignificant relationship with most of the improved technologies. It was significant and correlated positively with only bunding. The justification could be that larger size households have the necessary labour to construct bunds on their farm lands to improve water retention. Kassie et al. (2013; 2015) and Teklewold et al. (2013), in their previous studies, have established some correlation between the adoption of improved technologies and household size.

The sex of the farmer was positive and significantly influenced only nursery, spacing and line planting, but redundant in explaining the adoption of the other technologies. This means that male farmers were more likely to adopt nursery, spacing and line planting compared to their counterpart female rice farmers. Mulwa et al. (2017), and Ragasa et al. (2013), found the sex variable to be positive and significantly influence the adoption of improved agricultural technologies. The age of the farmer was also significant and positively related to the adoption of nursery, spacing, line planting, and urea briquette, but did not explain the adoption of harrowing, irrigation and bunding. The impact of this result is that, older farmers had a higher probability of adopting nursery, spacing, line planting, and urea briquette than younger rice farmers. Simtowe, Asfaw and Abate (2016), and Danso-Abbeam and Baiyegunhi (2017), found a positive and significant relationship between the age of a farmer and the adoption of agricultural technology. However, Denkyirah et al. (2016) found a negative effect of age on adoption of pesticides.

Table 4: Factors influencing the adoption of improved rice production technologies – results of multivariate probit regression

Covariate	Nursery Coef.	Std. Err	Harrowing Coef.	Std. Err	Spacing Coef.	Std. Err	Line planting Coef.	Std. Err	Urea Briquette Coef.	Std. Err	Irrigation Coef.	Std. Err	Bunding Coef.	Std. Err
Region	0.254	0.190	-2.181[c]	0.261	-0.931[c]	0.182	-0.960[c]	0.179	-0.932[c]	0.193	-0.044	0.185	-0.917[c]	0.184
HH. Ext mthd	-0.753[c]	0.151	0.408[c]	0.167	-0.663[c]	0.150	-0.553[c]	0.149	-1.171[c]	0.160	-0.668[c]	0.152	-0.365[b]	0.154
Demos	0.054	0.162	0.769[c]	0.193	0.529[c]	0.160	0.695[c]	0.152	0.855[c]	0.190	0.248	0.172	0.523[c]	0.160
TV	0.292[a]	0.183	0.220	0.193	0.169	0.180	0.298[a]	0.178	0.312[a]	0.190	-0.054	0.198	0.397[b]	0.189
Radio	0.382[b]	0.154	0.023	0.183	0.417[c]	0.152	0.465[c]	0.147	0.490[c]	0.166	0.310[b]	0.154	0.517[c]	0.159
Video	0.266[a]	0.166	0.241	0.169	-0.568[c]	0.156	-0.674[c]	0.149	-0.373[b]	0.161	1.034[c]	0.176	0.540[c]	0.171
Mobile phone[2]	0.075	0.157	-0.302[a]	0.159	-0.121	0.152	-0.232[a]	0.154	0.010	0.153	0.020	0.150	-0.109	0.151
Education	0.025[a]	0.015	-0.009	0.015	0.022[a]	0.014	0.014	0.013	0.031[b]	0.014	0.022	0.014	0.004	0.014
Experience	0.005	0.011	-0.001	0.011	-0.002	0.011	-0.013	0.010	0.013	0.010	0.022[b]	0.011	0.028[c]	0.011
FBO	0.255[a]	0.156	-0.791[c]	0.155	0.121	0.155	0.478[c]	0.153	0.520[c]	0.160	0.364[b]	0.151	0.082	0.153
Research	-0.927[c]	0.181	0.342[a]	0.180	-0.063	0.175	-0.139	0.164	-0.351[b]	0.173	-0.743[c]	0.171	-0.778[c]	0.165
Training	0.984[c]	0.200	-0.610[c]	0.216	1.190[c]	0.186	1.043[c]	0.180	0.803[c]	0.213	0.567[c]	0.187	0.766[c]	0.183
Credit access	-0.434[c]	0.204	0.457[b]	0.222	-0.294[a]	0.193	-0.275	0.188	0.308	0.205	-0.788[c]	0.213	-0.035	0.214
Farm size	-0.055[c]	0.024	-0.016	0.019	-0.071[c]	0.015	-0.058[c]	0.013	-0.048[b]	0.019	-0.165[c]	0.039	-0.063[c]	0.020
HH size	-0.004	0.128	-0.003	0.011	-0.003	0.012	-0.010	0.011	-0.003	0.013	0.004	0.013	0.031[b]	0.013
Sex	0.347[b]	0.183	-0.045	0.194	0.411[b]	0.170	0.710[c]	0.171	-0.034	0.179	0.015	0.176	0.003	0.169
Age	0.015[b]	0.008	0.002	0.008	0.026[c]	0.008	0.028[c]	0.007	0.017[b]	0.007	-0.001	0.008	-0.002	0.008
Const.	-1.133[c]	0.368	0.356	0.377	-1.824[c]	0.379	-2.204[c]	0.382	-2.261[c]	0.411	-0.336	0.367	-1.082[c]	0.380

[a], [b], and [c] represent 10%, 5%, and 1% level of significance respectively.
Source: Analysis of field data, 2017

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2   The technology transfer methods seek to achieve the same outcome, however, the process through which the result is achieved is different for the various methods

CONCLUSIONS AND POLICY IMPLICATIONS

The need to apply modern agricultural technologies in the rice sector of northern Ghana has become even more relevant as the possibility of expanding cultivable land is getting exhausted due to population growth and urbanisation. Yet, the agriculture sector in the northern part of the county is well known for its traditional nature and the use of poor production techniques. Therefore, research and the adoption of improved production technologies are crucial in increasing the productivity and lowering the poverty levels amongst rice farmers. In this study, we analysed the adoption of different improved technologies among rice farmers in northern Ghana using data from household survey of 543 rice farmers. There is complementarity among improved rice production technologies (nursery establishment, harrowing, line planting, spacing, urea briquette, irrigation, and bunding), meaning that the adoption of a given improved agricultural technology was conditional on the adoption of the others. This implies that farm-level policies that affect one improved agricultural technology for rice production can have spillover effects on the other technologies. The study concludes that variables affecting farmers' decisions to adopt a technology differ among technologies. Educational level of the farmer, household size, experience of the rice farmer, farm size, sex, age of the farmer, FBO membership, location, research access, training and access to credit play significant roles, partly with differing signs across technologies. Technology extension mechanisms such demonstration, TV, radio, video, mobile phones, and household extension methods have significant influence on the adoption of improved rice production technologies. It is therefore incumbent on stakeholders in the rice sector of Ghana, especially MoFA, to ensure that policies that support agricultural development consider promoting bunding, irrigation, line planting, spacing, harrowing, and the establishment of nurseries among rice farmers. There is significant justification for the review of the agricultural extension methods and approaches of MoFA to include ICT and mass media approaches that have proven to be effective. Government should continuously work with development partners and the NGO sector to develop the existing irrigation schemes in terms of irrigable land, and also construct bunds around the rice production valleys in the study area so that rice farmers could expand their farm sizes to increase production. To improve the output of rice, farmers are advised to jointly adopt the identified improved production technologies because they play a complementary role in increasing output. Farmers are advised to join or form groups to be able to learn new techniques of production from their colleague farmers, and to stand the chance of contracting group loans and technologies which could increase their output.

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