Anang *et al. Agriculture & Food Security* (2023) 12:29
https://doi.org/10.1186/s40066-023-00435-3

Agriculture & Food Security

RESEARCH

Open Access

Predictors of inoculant-based technology adoption by smallholder soybean farmers in northern Ghana: implications for soil fertility management

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Abstract

Inoculant-based technologies are environmentally friendly and economic ways to improve soil fertility status by incorporating atmospheric nitrogen into root nodules of leguminous crops to increase crop yield. The uptake of inoculant-based technologies by smallholder farmers in Ghana is not well documented despite measures by research institutions to introduce these technologies to farmers. This study therefore sought to investigate the farmer characteristics, farm-level, input and institutional-level determinants of inoculant-based technology adoption by small-scale soybean producers in Northern Ghana, relying on cross-sectional data and double-hurdle modelling. This study identified the main drivers of inoculant adoption as farmers' age, sex, educational status, household size, agrochemicals adoption, soil fertility status, extension contact, farmer group membership and participation in off-farm work. Intensity of adoption, expressed as expenditure per hectare on inoculants was significantly influenced by household size, degree of specialization in soybean production, agrochemicals adoption, cost of ploughing, cattle ownership and participation in off-farm work. The results showed that the decision to adopt inoculant technology and the intensity of adoption are influenced by different sets of variables. Improving smallholders' access to agricultural extension and promoting participation in farmer groups are expected to enhance inoculant technology adoption to promote grain legume production.

Keywords Adoption, Inoculant technology, Soybean, Double-hurdle model, Northern Ghana

Introduction

Adoption of improved technologies has been widely documented as an essential path towards the transformation of the agricultural sectors of most Africa economies including Ghana [9, 10, 29]. Several technologies have been introduced to farmers targeted at improving food security and employment creation in Sub-Saharan Africa aimed at achieving the zero hunger global agenda.

One critical area of concern is the production-side technologies. A number of empirical studies have looked into improved varieties, while others have focused on soil fertility management technologies such as manure and fertilizer application, *zai* technology, among others [7, 9, 18]. While these are important for improved production, there have been increasing concerns about the cost of adopting these technologies. For instance, Danso-Abbeam et al. [9] indicated that, although zai technology

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has the potency to double farm yield, it is labour intensive and the cost of digging the pits are also high.

Also, the yield of most grain legumes in Ghana is below achievable levels [19] and low soil fertility especially in the savanna ecological zones is a known contributing factor [2]. This is compounded by the fact that many smallholder farmers find it difficult to afford the cost of inorganic fertilizers to improve soil fertility [17]. Not every famer is able to access government's subsidized fertilizer under the Planting for Food and Jobs (PFJs) initiative. To address the problem of declining soil fertility and its effect on farm yields, farmers in the country have been introduced to inoculant-based technology that uses nitrogen-fixing bacteria to fix atmospheric nitrogen into root nodules of crops, especially grain legumes. Leguminous crops form a symbiotic relationship with a group of bacteria referred to as rhizobia to fix atmospheric nitrogen which is converted to usable form for the host crop [12, 14]. The application of inoculants in crop production is environmentally friendly and an economic way to improve farm yields.

Many of the empirical studies on rhizobium inoculant use in developing countries have focused on soybean relative to other legumes such as groundnuts and cowpea [1, 21, 22]. One major reason for the trend is that soybean is a cash crop with several nutritional benefits. It is used to produce several consumables including soymilk, cakes and condiments. In Ghana, one product from soybean which is of high demand is known as "soymeat" with varying names like "wagashie" and "soya", depending on the location. Abdullahi et al. [1] revealed that over 90% of the research conducted on inoculants have been on soybean because it responds more effectively to inoculation compared to other legumes like groundnut and cowpea. Soybean has also become a preferred crop in Sub-Saharan Africa because of its high potential to produce cheaper protein to meet the protein needs of households, thereby helping eradicate malnutrition especially among children Abdullahi et al. [1].

Some of the recent studies on inoculant technology adoption include Mutuma et al. [21] who investigated the uptake and profitability of inoculants use by small-scale farmers in Kenya and noticed a significant difference in both the yield and profitability of farmers who used inoculants against those who did not. Ulzen et al. [26] reported 11–38% increase in cowpea grain yield and 1.5-fold increase in soybean grain yield as a result of inoculation in northern Ghana. In terms of economic benefit, they recorded a value cost ratio of 8.7, which is a measure of returns on investment. Asei et al. [6] also recorded a 67% increase in soybean grain yield in a study in northern Ghana, while Kiwia et al. [16] reported that combining phosphorus fertilizer with inoculants increased soybean yield over phosphorus fertilizer alone by 25.7%. In another study, Nabintu et al. [22] examined farmer' perceptions about rhizobium inoculants in the Democratic Republic of Congo and found that farmers generally perceive higher productivity and cost efficiency of rhizobium but were challenged with its consistent unavailability at the market. Abdullahi et al. [1] recommended the use of inoculants since it is relatively cheaper, safer and easier to use in order to improve the nitrogen content utilized by leguminous crops to boost production. In other studies, Mohammed and Abdulai [20] observed that ICT-based extension services enhanced farm performance as well as knowledge scores of inoculant adopters relative to non-adopters in Ghana. Dzanku et al. [11] on the other hand investigated the appropriate extension mechanisms to boost inoculant technology adoption to enhance crop yield in Ghana and found that television was the best channel for communication.

In spite of the beneficial effects of rhizobium inoculation, adoption of the technology remains low among farmers in Ghana [5]. There are several efforts by governmental and non-governmental organizations to promote inoculant use among farmers as a soil fertility management strategy to enhance crop yields. Farmers are therefore becoming increasingly aware of the benefits of inoculation which is anticipated to increase adoption. While inoculants are less costly compared to chemical fertilizers, there is no subsidy on inoculants and smallholders with low household income are less likely to adopt. The Savanna Agricultural Research Institute (SARI) is responsible for inoculant production for farmers in the study area. SARI's inoculant production is supplemented by imports by private organizations with inoculants made available to farmers chiefly through local input dealers. Agricultural extension agents also facilitate farmers' access to inoculants.

This study therefore explores the factors (the farmer characteristics, farm level, input and institutional levels) influencing inoculant technology adoption as a soil fertility management practice among soybean farmers in northern Ghana, precisely the Tolon district. Specifically, this study identifies the factors influencing inoculant technology adoption and the extent of adoption. This study is important for a number of reasons. First, there is the need to popularize the use of rhizobium inoculants among smallholder farmers in order to create market for the product. Even though rhizobium inoculants have been shown to enhance yields, there is not a well-known market for these biofertilizers in Ghana, compared to what pertains to other farm inputs like seeds, chemical fertilizers, pesticides and herbicides. Second, popularizing rhizobium inoculants will enhance adoption, thereby improving soil fertility levels and farm yields. In addition, this study examines the intensity of adoption which is lacking in most studies in the context of Ghana, thus shedding light on the factors affecting the degree of adoption. This study differs from previous studies on the topic in the context of Ghana in that it employs a two-stage analysis that addresses self-selection and determines farmers' propensity to adopt inoculant technology and the determinants of adoption intensity measured as expenditure per hectare on inoculants while controlling for other key variables that influence these decisions.

The rest of the paper is structured according to the following format. The next section deals with the methodological approach encompassing the sampling, data collection and analysis, and empirical model specification. The results and discussion follow in Sect. "Results and discussion" and the conclusion in Sect. "Conclusion".

Methodology

Study area and sampling

The research was carried out in the Tolon district of Ghana, where soybean cultivation is a vital economic activity among smallholders because of its economic value. The district, which is largely agrarian, is situated in the Guinea savanna of Ghana. The soils in the district are generally low in fertility due to soil erosion, bush burning and low application of chemical fertilizers [2]. The Savanna Agricultural Research Institute (SARI), which is involved in inoculant production and dissemination of research findings to farmers, is located in the district. This influenced the choice of the study area because inoculant technology is relatively new to smallholder farmers in Ghana and farmers in the district are expected to have some knowledge of the technology. Extension agents working with farmers in the district help promote the technology and therefore facilitate adoption of the technology. Just as pertains in other parts of the country, access to agricultural extension is still limited, but every district and operational area in the country is served by an extension agent. Also, there are input dealers who facilitate farmers' access to inputs such as inoculants at the community level.

Using Green [13] sample size determination, a sample size of 200 was found to be adequate for the analysis. Green's sample size approach calculates the sample size (N) based on the number of explanatory variables (m) in the model, that is, $N = 50 + 8(m)$. With 16 explanatory variables, we obtain $N = 50 + 8(16) = 178 \approx 200$. Multistage random sampling was used which involved the selection of the Northern Region, followed by the selection of Tolon district as a soybean producing area. Northern Region was chosen for this study because most of the soybean production in the country is carried out in this region. Tolon district was selected because it is a major producer of soybean and also because it is the district where SARI, which is involved in inoculant production and dissemination to farmers, is located. The presence of SARI means that farmers in the district are anticipated to be more exposed to inoculant technology. Next, five communities were selected based on soybean production potential, followed by the random sampling of 40 respondents from each community. Overall, a total of 200 soybean producers were randomly selected for this study. The respondents were interviewed using pretested questionnaire. Information on production practices, household and farm data, access to services and inputs, and socio-economic variables were collected. The data covered production activities for the 2018/2019 farming season and were collected between January and March 2019.

Method of data analysis

Following empirical studies by Danso-Abbeam et al. [9] and Anang and Dagunga [3], a likelihood ratio test was first performed to determine whether the discrete decision to adopt inoculant-based technology and the intensity of adoption were joint or separate. The significance of the test, as shown in Table 5 of the appendix, justifies that a two-stage model was better fit for the data as compared to a Tobit model. A double-hurdle model was then used to analyse the data since the adoption decision comprised the first and the second hurdle. The first model is the choice to adopt inoculant technology which is estimated using probit regression. The second hurdle involves the intensity of adoption, or the expenditure on inoculant adoption, where some values of the dependent variable are truncated at zero. The econometric problem can be solved by applying a double-hurdle model that jointly estimates the decision to adopt and the adoption intensity to yield consistent parameter estimates.

Following empirical studies by Wiredu et al. [28] and Danso-Abbeam et al. [9], the first hurdle involves the estimation of a probit model to evaluate the decision to adopt inoculants. The probit model, specified as an index function, can be expressed as follows:

$$L_i^* = \beta x_i + \varepsilon_i, \quad (1)$$

$$\text{where } L_i = \begin{cases} 1, & L_i^* > 0 \\ 0, & L_i^* \leq 0 \end{cases}, \quad (2)$$

where L_i^* is the latent continuous variable which measures the probability of adoption; L_i is binary and assumes a value of 1 if the farmer is an adopter and 0 if non-adopter. ε_i is the error term.

The second hurdle involves estimation of the intensity of adoption (measured as expenditure per hectare on rhizobium inoculants) using truncated regression and expressed as follows:

$$y_i^* = \beta x_i + v_{i,} \tag{3}$$

$$y_i = \begin{cases} y_i^*, \ y_i^* > 0 \\ 0, \ y_i^* \leq 0 \end{cases}, \tag{4}$$

where y_i^* is the latent continuous variable measuring the intensity of adoption, y_i is the observed expenditure per hectare on inoculant technology and v_i is a random error term.

Empirical models

Empirically, the probit model for inoculant adoption is expressed as follows:

$$\begin{aligned} L_i^* = & \beta_0 + \beta_1 SEX_i + \beta_2 AGE_i \\ & + \beta_3 AGESQ_i + \beta_4 EDUC_i \\ & + \beta_5 HHS_i + \beta_6 DIST_i \\ & + \beta_7 FERT_i + \beta_8 PEST_i \\ & + \beta_9 CRE_i + \beta_{10} HERD_i \\ & + \beta_{11} SF_i + \beta_{12} EXT_i \\ & + \beta_{13} FBO_i + \beta_{14} DSP_i \\ & + \beta_{15} OFW_i + \beta_{16} PCOST_i + \varepsilon_i. \end{aligned} \tag{5}$$

Furthermore, the empirical truncated regression model for estimating the intensity of adoption is as follows:

$$\begin{aligned} y_i^* = & \beta_0 + \beta_1 SEX_i + \beta_2 AGE_i \\ & + \beta_3 AGESQ_i + \beta_4 EDUC_i + \beta_5 HHS_i \\ & + \beta_6 DIST_i + \beta_7 FERT_i + \beta_8 PEST_i \\ & + \beta_9 CRE_i + \beta_{10} HERD_i + \beta_{11} SF_i \\ & + \beta_{12} EXT_i + \beta_{13} FBO_i + \beta_{14} DSP_i \\ & + \beta_{15} OFW_i + \beta_{16} PCOST_i + \varepsilon_i. \end{aligned} \tag{6}$$

Choice of variables for the study

The choice of variables for the study was based on the extant literature as well as the study's a priori expectations. The factors hypothesized to influence inoculant adoption are divided into farmer/household factors, farm-level characteristics, input variables and institutional factors.

Farmer/household factors: Sex is an important farmer characteristic and a determinant of adoption decision [21] with males hypothesized to have higher adoption than females [23]. The reason is that among smallholder farmers, men control most of the household resources and also are more likely to participate in training programmes than females. Age is another important adoption determinant in the literature [4, 8]. Younger farmers are expected to be more industrious and likely to take risks than older farmers who are more risk averse. Thus, age could have a negative sign with adoption. Educational status of the household head is hypothesized to enhance the likelihood and intensity of adoption of inoculants since education enhances learning and acquisition of information and knowledge of technologies. This is in line with Donkoh et al. [10], Olatunde et al. [23] and Mahama et al. [18]. Household size determines the labour supply of the household and influences technology adoption [15]. Larger households with limited resources may be find it difficult to purchase and adopt inoculants; hence, household size may be inversely related to inoculant adoption decision. Kimaro et al. [15] alluded that households with many members are more disposed to adopt technologies that enhance farm profitability such as inoculants and improved varieties. Herd ownership is another important variable anticipated to positively influence adoption. This is because ownership of cattle is used as proxy for wealth. Anang and Zakariah [4] reported that herd ownership had a significant effect on joint adoption of inoculants and inorganic fertilizer in Ghana.

Farm-level characteristics: Perceived soil fertility status may influence inoculant adoption with higher soil fertility correlating with lower adoption. This is because farmers are anticipated to spend less on inoculants if their soils are fertile. Farmers with fertile soils are expected to channel their resources to other pressing needs besides inoculants. The degree of specialization in soybean production, which relates to the proportion of total land allocated to soybean cultivation, is anticipated to increase the probability and intensity of inoculant adoption.

Input variables: Adoption of chemical fertilizer is expected to have an inverse influence on inoculant adoption [21]. This is because both inputs enhance soil fertility; hence, farmers with limited resource who are able to acquire fertilizer may be limited in their ability to acquire and use inoculants. Sammauria et al. [24] have indicated that the use of inoculants is a substitute for chemical fertilizers. On the other hand, pesticide and herbicide use may have an indeterminate effect on adoption. This is because, just like fertilizer, the cost of these inputs may reduce the ability to purchase inoculants. However, if farmers perceive the complementarity between these inputs, it may promote adoption. Furthermore, the cost of ploughing is anticipated to reduce adoption of inoculants for resource-poor households. Cost of ploughing is a key component of farmers' production cost and as this cost increases, it is likely to have a negative consequence on adoption of inoculants.

Institutional factors: Access to agricultural extension is expected to enhance adoption since extension agents are instrumental in technology dissemination to farmers.

This is in line with Danso-Abbeam and Baiyegunhi [8]. Belonging to a farmer group is a key institutional factor which is associated with technology adoption Olatunde et al. [23]. Group membership is expected to increase inoculant adoption in line with Wafullah [27] because farmer groups are channels through which innovations and modern technologies are transmitted to farmers. Access to credit is another key determinant of technology adoption. Access to credit is anticipated to lead to higher adoption of inoculants. With regard to participation in off-farm work, the effect on adoption is expected to be positive if the income from off-farm work is channelled to on-farm investment. The opposite effect is expected if farmers spend the income from off-farm work on other household needs [4]. Meanwhile, market distance is hypothesized to have a negative effect on adoption since it increases transaction cost.

Results and discussion

Description and summary statistics of the variables

The description and summary statistics of the variables included in the analysis are provided in Table 1.

Most of the respondents were males, in their youthful ages, and possessed very little formal education. Soybean production is therefore an economic activity dominated by young farmers. Olatunde et al. [23] found that most soybean farmers in Nigeria were males as compared to females and in their youthful and prime ages for farming. Promotion of soybean farming can therefore empower the youth to venture into farming to reduce rural unemployment. The respondents had average household and farm size of 13 members and 0.6 hectares, respectively. Farmers perceived their soils to be infertile, while 54.5% applied chemical fertilizer. Also, 50.5% of the respondents had access to agricultural extension, 34.5% were members of a farmer association, while 30% participated in off-farm work as a source of extra income for the household.

Characteristics of the sample according to adoption status

Table 2 presents the results of the farmer-specific factors, input and institutional factors hypothesized to influence farmers' adoption decisions.

The results showed that there was no significant difference between the mean age of adopters and non-adopters. In the adopter category, males constituted about 66% while in the non-adopter category, males made up 58.9% of the respondents. Mutuma et al. [21] found about 70% of soybean farmers in Kenya to be female farmers. The relatively higher proportion of male soybean

Table 1 Description and summary statistics of variables used in this study

Variable	Description/measurement	Mean	S. D	Freq	%
Dependent variables					
Inoculant adoption (*L*)	Equals 1 for adopters, 0 otherwise	–	–	86	0.43
Intensity of adoption (*y*)	Expenditure per hectare on inoculants in Ghana cedi	19.87	24.91	–	–
Farmer/household factors					
Sex (SEX)	1 if male, 0 otherwise	–	–	124	62.0
Age (AGE)	Age of farmer in years	38.13	10.63	–	–
Educational status (EDUC)	1 if formally educated, 0 otherwise	–	–	29	14.5
Household size (HHS)	Number of household members	12.68	6.118	–	–
Herd ownership (HERD)	Equals 1 if yes, 0 otherwise	–	–	97	48.5
Farm-level characteristics					
Degree of specialization (DSP)	Proportion of land allocated to soybean	0.383	0.240	–	–
Soil fertility status (SF)	Equals 1 if fertile, 0 otherwise	–	–	58	29.0
Input variables					
Cost of ploughing (PCOST)	Cost of tractor ploughing in Ghana cedi	107.6	55.60	–	–
Fertilizer dummy (FERT)	1 for fertilizer adoption, 0 otherwise	–	–	109	54.5
Pesticide and herbicide (PEST)	Quantity of pesticides and herbicides in litres	1.675	0.789	–	–
Institutional factors					
Off-farm employment (OFW)	Equals 1 for participants, 0 otherwise	–	–	60	30.0
Extension visits (EXT)	Equals 1 if farmer was visited, 0 otherwise	–	–	101	50.5
Farmer group member (FBO)	Equals 1 if member, 0 otherwise	–	–	69	34.5
Access to credit (CRE)	1 for access, 0 otherwise	–	–	40	20
Distance to market (DIST)	Distance to market in kilometres	2.916	1.386	–	–

Frequencies if dummy variable is 1. GH¢ means Ghana cedi; GH¢ 5.4 is approximately US$ 1.0. S.D

Table 2 Characteristics of the sample according to adoption status

Variable	Adopters $n=86$				Non-adopters $n=114$				Mean difference/ chi-square
	Mean	S. D	Freq	%	Mean	S. D	Freq	%	
Farmer/household factors									
Sex	–	–	57	66.28	–	–	67	58.77	1.17a
Age	38.81	11.14	–	–	37.61	10.24	–	–	1.209
Educational status	–	–	12	13.95	–	–	17	14.91	0.04a
Household size	13.22	6.338	–	–	12.27	5.941	–	–	0.949
Herd ownership			44	51.16			59	51.75	0.007
Farm-level factors									
Degree of specialization	0.356	0.228	–	–	0.403	0.249	–	–	−0.047
Soil fertility status	–	–	27	31.40	–	–	31	27.19	0.42a
Input variables									
Cost of ploughing	103.8	56.76	–	–	110.5	54.79	–	–	6.747
Fertilizer dummy	–	–	38	44.19	–	–	71	62.28	6.47a**
Pesticides & herbicides	2.012	0.804			1.421	0.677			0.590
Institutional factors									
Off-farm employment	–	–	25	29.07	–	–	35	30.70	0.06a
Extension visits	–	–	60	69.77	–	–	41	35.96	22.41a***
Member of farmer group	–	–	45	52.33	–	–	24	21.05	21.22a***
Access to credit			22	25.58			18	15.79	2.938*
Distance to market	2.575	1.246	–	–	3.174	1.435	–	–	0.598***

**$p < 0.05$, ***$p < 0.001$; a = chi-square value. Frequencies if dummy variable is 1 as in Table 1

farmers agrees with the finding of Olatunde et al. [23] which showed that most soybean farmers in Nigeria were males. Educational status, as well as household size, did not differ statistically between the adopters and non–adopters of rhizobium inoculants in the study area. Also, three farm-level characteristics, namely farm size, degree of specialization and soil fertility status, did not differ statistically between inoculum adopters and non-adopters.

With the input variables considered, the results showed that there was no significant difference in the cost of ploughing for both groups, but there exists a significant mean difference in the usage of fertilizers between adopters and non-adopters. A smaller proportion of adopters applied chemical fertilizer compared to the proportion of non-adopters who applied fertilizer. This means that adoption of inoculants is expected to decrease with chemical fertilizer application. Hence, farmers' behaviour suggests a possible substitution between rhizobium inoculant and chemical fertilizers in soybean production. Mutuma et al. [21] found a similar result in Kenya where users of rhizobium inoculants applied lower quantities of chemical fertilizers as compared to non-users.

Finally, there was significant difference in access to extension, membership of farmer groups and distance to market between adopters and non-adopters. A greater percentage of adopters had contact with extension agents (i.e. 69.8% as compared to 36.0% for non-adopters), which is expected to enhance adoption of inoculants. Extension agents are important source of information to farmers and, through educational programmes and trainings, help farmers embrace new ideas and technologies that enhance their production activities. A greater percentage of adopters belonged to a farmer group. About 52.3% of respondents belonged to farmer groups relative to 21.1% of non-adopters. This finding also agrees with Olatunde et al. [23] who found that about 96% of soybean farmers using rhizobium inoculants in Kenya belonged to farmer groups. Membership in a farmer group is therefore expected to increase the decision to adopt inoculants. This is expected because farmer associations are fora for exchanging ideas, acquiring and disseminating information relevant to the welfare of members such as modern production methods and access to production factors. Adopters had shorter distance to the local market suggesting greater market access as compared to non-adopters. The market distance variable is therefore expected to influence the decision to adopt inoculant technology.

Expenditure on inoculant technology

Table 3 presents the distribution of farmers' expenditure per hectare on inoculant technology.

Table 3 Expenditure on rhizobium inoculants

Expenditure per hectare (GH¢)	Frequency	Per cent
0	114	57
1–25	14	7
26–50	66	33
51–75	3	1.5
Above 75	3	1.5
Total	200	100

GH¢ denotes Ghana Cedi. GH¢ 5.4 is approximately US$ 1.

The results indicate that more than half of the respondents (57%) did not use inoculants in production, while 7% applied the equivalent of 1 packet of inoculant. Also, 33% spent between GH¢ 26 and GH¢ 50 per hectare on inoculants (i.e. US$ 6.10 and US$ 9.30, respectively), while 3% of the respondents spent between GH¢ 51 and GH¢ 99 per hectare on inoculants (i.e. US$9.44 and US$18.33, respectively). Santos et al. [25] indicated that rhizobium inoculants are cheaper and environmentally friendlier compared to other agrochemicals like inorganic fertilizers. A pack of 0.1 kg (i.e. 100 g) of inoculant costs between GH¢ 20 and GH¢ 30 (US$ 3.70 and US$ 5.56) in the study area and is recommended for inoculating 20 kg of soybean seeds to an acre of land.

Double-hurdle estimates of factors influencing inoculant technology adoption and intensity of adoption

The determinants of inoculant technology adoption are presented in Table 4. The table presents the results for the probit model (first hurdle) explaining farmers' discrete adoption decision as well as the truncated regression (second hurdle) showing the intensity of adoption. The results show that both farmer characteristics and farm-level factors, as well as input variables and institutional factors influence farmers' adoption decision and the intensity of inoculant adoption in northern Ghana.

The farmer-specific factors showed that sex of the farmer influenced the decision to adopt inoculant-based technology adoption but not the intensity of adoption. The results indicate that female farmers have a higher likelihood to adopt inoculant technology compared to male farmers. The result agrees with Nabintu et al. [22] who found female farmers to have higher adoption of

Table 4 Double-hurdle estimates of factors influencing inoculant technology adoption

Variable	Adoption decision		Intensity of adoption	
	Coefficient	Std. error	Coefficient	Std. error
Farmer/household factors				
Sex	3.326**	1.637	3.184	6.423
Age	1.157***	0.422	0.646	1.355
Age squared	0.012***	0.004	0.009	0.015
Educational status	1.154***	0.406	1.556	1.005
Household size	0.151*	0.079	1.179***	0.382
Cattle ownership	0.106	1.098	14.10**	5.542
Farm-level characteristics				
Degree of specialization	3.658	2.657	21.38*	12.201
Soil fertility status	2.249*	1.215	1.661	5.343
Input variables				
Cost of ploughing	0.015	0.012	0.166***	0.048
Fertilizer dummy	14.82***	4.773	32.21***	6.978
Pesticides and herbicides	12.19***	3.901	16.60***	4.645
Institutional factors				
Off-farm employment	4.014**	1.613	8.815*	5.048
Extension visits	12.94***	4.054	4.398	5.793
Member of farmer group	7.409***	2.515	2.190	4.779
Access to credit	1.988	1.745	1.549	6.220
Distance to market		0.293	0.824	2.067
Constant	15.07**	7.550	17.89	32.999
Sigma			21.54***	1.787

***, ** and * indicate statistical significance at 1%, 5% and 10% respectively inoculants compared to male farmers in Democratic Republic of Congo.

The results also show that the age of the farmer influenced the decision to adopt inoculant-based technology adoption but not the intensity of adoption. The results show that adoption initially decreases with age of the farmer. However, as the farmer increases in age, the probability of adoption increases. Hence, adoption of inoculant technology follows a non-linear pattern among the smallholder farmers in the study area.

Also, educational status of the farmer was significant in explaining the decision to adopt inoculant-based technology. The results showed that farmers with formal education were less likely to adopt the inoculant-based technology. This contradicts the a priori expectation because one would expect that formally educated farmers would have had more knowledge about the benefits of the technology, but the results showed otherwise. Mahama et al. [18] found that the education of a farmer had a positive influence on the intensity of adopting soybean technologies in Ghana. Their measure of education was, however, continuous as opposed to the discrete scale employed in this study. Even though Donkoh et al. [10] and Olatunde et al. [23] highlighted that educated farmers are more risk averse and have a higher probability to adopt agricultural technology, the justification for the finding in this study could be explained by two reasons. First, most of the farmers in the study did not have access to formal education. About 85% of them did not have formal education but adopted the technology probably because they were exposed to it. Secondly, it could be that, the farmers who were formally educated were involved in other off-farm activities with less commitment to soybean farming activities, hence their lower probability of adoption.

Additionally, household size explained both the decision to adopt and the intensity of adoption. While adoption of inoculants decreased with household size, intensity of adoption on the other hand increased. Kimaro et al. [15] alluded that households with many members are more disposed to adopt technologies that enhance farm profitability such as inoculants and improved varieties.

The results also indicate that cattle ownership was associated with higher adoption intensity but did not significantly influence the decision to adopt inoculant technology. Herd owners could benefit from availability of manure from the cattle they rear, which could be used to improve soil fertility, thus reducing their dependence on fertility-enhancing inputs. On the other hand, cattle owners may be classified as "better-off" compared to non-cattle owners, hence may be able to intensify input use such as inoculants. Anang and Zakariah [4] reported that herd ownership had a significant effect on joint adoption of inoculants and inorganic fertilizer in Ghana.

Results from the farm-level factors showed that the degree of specialization measured as the proportion of the total land area allocated to soybean production was found to positively influence the intensity of adoption. This implies that farmers who allocated a larger proportion of their total land to soybean cultivation were more likely to spend more on inoculants.

This study further revealed that adoption of inoculants decreased with fertility of farmers' field. In other words, the more fertile the soil, the lower the likelihood to adopt inoculants, which is consistent with a priori expectation. Farmers are rational, hence will allocate resources in the way that meets their needs. As a result of resource constraints, smallholder farmers with relatively fertile soils are expected to channel their limited resources into other limiting factors of production, thus reducing the adoption of fertility-improving inputs such as inoculants. Perception of soil fertility status, however, had no influence on the intensity of adoption.

With the input factors, the cost of ploughing had a negative influence on the intensity of adoption of inoculants. This meets the study's a priori expectation because as the cost of ploughing increases, smallholder farmers who typically have low level of incomes are less likely to intensify adoption. The cost of ploughing is an important part of the cost structure of most smallholder farmers and therefore plays a critical role in farm investment decisions.

Also, chemical fertilizer adoption was found to reduce the probability and intensity of inoculant adoption implying that farmers generally consider rhizobium inoculant and chemical fertilizer as substitutes. Sammauria et al. [24] indicated that, the use of inoculants as a substitute for chemical fertilizers is not only efficient but also sustainable and that continuous use of chemical fertilizers has a deterioration effect on soil health and pollutes water bodies. It may also be argued that since farmers are generally resource poor, they are not able to afford both soil amendment factors at the same time. However, unlike chemical fertilizer, application of pesticides and herbicides increased the probability and intensity of inoculant adoption, implying that farmers generally perceive pesticides and herbicides to be complementary to rhizobium inoculant in soybean cultivation.

Institutional factors were very influential in farmers' decisions to adopt inoculant technology. For example, access to agricultural extension agents significantly influenced the decision to adopt inoculant-based technology. This was expected and makes economic sense because the technology was disseminated to farmers through agricultural extension agents. Hence, farmers who received extension visits are more likely to learn about the technology and subsequently adopt it. The results align with that of Danso-Abbeam and Baiyegunhi [8] who found extension visits to have a positive influence on adoption of agrochemical management practices in Ghana.

Participation in off-farm work had a negative influence on the probability and intensity of adoption of inoculant technology. The result implies that smallholder farmers who work outside the farm use less inoculants in production. This may indicate that majority of the farmers who engage in off-farm work may not be full-time farmers and do not give full attention to soybean cultivation. It may further suggest that these farmers may be worse-off economically, hence their participation in off-farm jobs in a rural setting to generate additional income. As indicated by Anang and Zakariah [4], for very low-income households, participation in off-farm work may not lead to higher farm investment, and may even result in a reduction in on-farm investment because such households may be driven by the need to survive. In other words, income from off-farm employment may be insufficient to finance farm operations and may be diverted to meet other pressing household needs, because for such households, survival is prioritized above other household decisions.

Membership of farmer groups was another significant institutional factor that explains producers' choice to adopt rhizobium inoculant technology. Farmer group membership enhanced inoculant technology adoption which aligns with the study's a priori expectation because membership of farmer groups helps in promoting smallholders' access to information, services and farm inputs. The result is consistent with Wafullah [27] who found that membership of farmer groups significantly influences the probability of adopting inoculant technology in Kenya.

Conclusion

This study evaluated the factors influencing inoculant technology adoption and the intensity of adoption using a sample of soybean producers in the Tolon district, Ghana. A double-hurdle model was used to assess the determinants of adoption. The results of this study show that the decision to adopt inoculant technology and the intensity of adoption are influenced by different sets of variables. Adoption increased with pesticide and herbicide use, extension contact and farmer group membership, but decreased with education of the farmer, household size, fertility of the soil, application of chemical fertilizer and participation in off-farm work. Intensity of adoption on the other hand increased with the household size, degree of specialization in soybean production, pesticide and herbicide use, and cattle ownership, but decreased with adoption of chemical fertilizer, cost of ploughing and participation in off-farm work.

This study therefore asserts that measures to promote inoculant adoption among smallholder grain legume producers for soil fertility and productivity improvements should focus on institutional factors such as access to agricultural extension and farmer group membership. This is because rhizobium inoculation is a relatively new technology in the study area, and its acceptance will depend on how well extension messages on its application and benefits are packaged and presented to farmers. Also, inoculants must be made readily available to farmers and if possible, the price of the input must be subsidized to encourage more farmers to adopt. In addition, farmer groups must be incentivized to increase their effectiveness as channels for exchanging and disseminating information about inoculants and other technologies among farmers.

Appendix

See Table 5

Table 5 Likelihood ratio test

Models	Likelihood ratio (LR) Test			
	Probit	Truncated	Tobit	LR Statistic (L)
Adoption and intensity of adoption	103.195	809.161	809.161	206.390***

*** The likelihood ratio test statistic, L is estimated as $L = 2(LR_{prob} + LR_{trun} - LR_{tob})$, where LR_{prob}, LR_{trun} and LR_{tob} signify the likelihood ratios of the probit, truncated and Tobit regression models, respectively

Acknowledgements
The authors are grateful to the participating farmers who sacrificed their time and voluntarily provided information for this study.

Author contributions
BTA performed the data analysis, wrote the initial draft and read the final draft. GD analysed the data, wrote the paper and read the final draft. MB wrote the paper, did the proof-reading and read the final draft.

Funding
Not applicable.

Availability of data and materials
Data relating to this research are available upon reasonable request from the first author.

Declarations

Ethics approval and consent to participate
The consent of participating farmers was sought before they responded to the instrument for the data collection. Participants were assured of their anonymity.

Competing interests
The authors declare that there are no competing interests with regard to this research work.

Received: 14 December 2022 Accepted: 6 August 2023
Published online: 02 October 2023

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