Drivers of adoption of crop protection and soil fertility management practices among smallholder soybean farmers in Tolon district of Ghana

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ARTICLE INFO

Keywords: Adoption Crop protection Soil fertility management Count data model Smallholder farmers Ghana

ABSTRACT

Among the critical challenges affecting crop production and agricultural productivity in most developing countries are declining soil fertility and the incidence of crop pests and diseases. Hence, there have been efforts by scientists and policy-makers especially in sub-Saharan Africa to promote the uptake of agronomic and production practices that address these challenges. This study, therefore, aimed at investigating the drivers of adoption of crop protection and soil fertility (CPSF) management practices among soybean farmers in rural Ghana. The management practices investigated included application of chemical fertilizers, biofertilizers (inoculants) and herbicides. The study was motivated by the critical roles that adoption of CPSF management practices play in promoting agricultural productivity. Multivariate probit (MVP) and censored Tobit modelling were used to estimate adoption and intensity of adoption, respectively. Adoption of rhizobium inoculant and chemical fertilizer, as well as adoption of rhizobium inoculant and herbicide application, were mutually exclusive, while adoption of chemical fertilizer and herbicide were found to be complementary. Adoption intensity was higher for female farmers and increased with age, herd size, farm capital and farm size. Furthermore, institutional factors were more influential in the case of inoculant and herbicide adoption while for fertilizer adoption, farmer characteristics were the influential factors. The study recommends that policies to promote adoption should take into account the interdependence among the technologies. Also, there is the need to target farmers who cannot afford the cost of inputs with support in the form of input subsidies to reduce partial adoption.

1. Introduction

Agriculture plays a very critical role in economic growth, food security and poverty alleviation in most developing countries, particularly in sub-Saharan Africa (Danso-Abbeam and Baiyegunhi, 2018). Smallholder farmers in developing countries, however, face a myriad of production challenges, which are compounded by the effect of climate change. Among these challenges are the incidence of crop pests and diseases, as well as the decline in soil fertility status of crop lands (Darge et al., 2018; Horna et al., 2008), resulting in low agricultural productivity (Bateman, 2015). Efforts aimed at addressing these challenges have included the application of crop protection and soil fertility management practices such as the use of biological, organic and inorganic fertilizers to improve soil fertility as well as the application of herbicides, fungicides and pesticides to control crop pests and diseases (Danso-Abbeam and Baiyegunhi, 2017, 2018).

Among the emerging crops grown by smallholder farmers in developing countries for cash and food is soybean (*Glycine max*). Globally, the area cultivated to soybean in the last two decades has outstripped that of rice and maize, by one-third (Tamimie and Goldsmith, 2019). According to Lybbert and Sumner (2010), variability in climatic conditions have led to shorter planting seasons, erratic rainfall regimes, increase in temperatures and long drought periods which have made it imperative to adopt technologies in soybean production. In recent times, these technologies include the use of inoculants to enhance soil fertility status, planting of improved varieties and application of agrochemicals to control crop pests and diseases. The use of agro-inputs such as chemical fertilizer, inoculant, herbicide and pesticide by smallholder soybean farmers is, however, considered to be little compared to application rates on larger farms (Mbanya, 2011).

Soybean is among the important cash crops grown by small-scale farmers in the northern savanna of Ghana where agriculture is the major occupation. The history of soybean cultivation in Ghana is more recent, with the cultivation of the crop gaining prominence in recent times due to its economic benefits (Hartman et al., 2011; Sinclair et al., 2014). In Ghana, the cultivating of soybean is being promoted by the

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https://doi.org/10.1016/j.heliyon.2021.e06900
Received 2 January 2021; Received in revised form 29 March 2021; Accepted 20 April 2021
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country’s research institutions and the Ministry of Food and Agriculture for income generation, improvement in household dietary status and creation of jobs especially in rural areas of the country (Mbanya, 2011).

Despite the economic importance of soybean, production of the crop is faced with several challenges including declining soil fertility, pest and diseases, low crop yields and low output price. According to MoFA (2016), soybean yield in Ghana averages 1.65 metric tons against an achievable yield of 3.5 metric tons. Hence, a wide yield gap exists in soybean production in Ghana, as pertains in other developing countries that produce the crop. Yield of soybean is affected by several factors including declining soil fertility, pest infestation and low adoption of soil fertility and productivity-enhancing factors of production.

Traditionally, farmers rely on chemical fertilizers to enhance the fertility of their soils. Kombi et al. (2012) noted that due to financial constraints, farmers in northern Ghana are unable to purchase and apply the recommended rates of chemical fertilizer needed to achieve optimum yield. The use of manure, an alternative to inorganic fertilizer, has been negligible among smallholder farmers, although many farmers still use some minimal amount of manure in production. Although most smallholders typically apply chemical fertilizers to cereals and vegetables, legume producers including soybean farmers also use mineral fertilizers, particularly phosphorus-based fertilizers, to enhance production. More recently, inoculant-based technologies that enhance the productivity of soybean and other leguminous crops has been introduced to farmers. Inoculating soybean varieties with rhizobia strains enhances soil fertility by incorporating atmospheric nitrogen into soils through the process of nodule formation on the roots of crops (Tefera et al., 2010). The introduction of inoculant technology is particularly important to smallholder farmers who often cannot pay for the high cost of chemical fertilizers (Gyoglu et al., 2016).

Herbicide application is another important agronomic practice that helps in the control of weeds to improve crop yield. Weediness is a critical factor that contributes to low crop yields and lower net returns from farming (Locke et al., 2002). This is because weeds compete with cultivated crops for available soil nutrients and moisture, leading to low yields. Chemical control of weeds has therefore become an important practice among Ghanaian smallholders due to its effectiveness in controlling noxious weeds and the ease of application compared to manual weeding which is tedious and time-consuming.

Insecticide is another typical input used by soybean farmers due to insect pest damage, which is a common problem in crop production in most tropical environments. However, for this study, insecticide adoption was excluded from the multivariate probit analysis because of its low adoption among the sampled farmers. Very few farmers (16.5%) were in the adopter category implying that the binary choice insecticide adoption variable is skewed towards non-adopters, hence the decision to exclude insecticide application from the analysis. However, in estimating the adoption intensity, which examined the total expenditure on all inputs for pest control and soil fertility management, the expenditure on insecticides was included in the analysis.

Studies on the determinants of farmers’ decisions on simultaneous adoption of biofertilizer (inoculants), chemical fertilizer, insecticide and herbicides as well as the intensity of adoption in Ghana and other developing countries are hard to find, hence the motivation for the study. This is against the backdrop that soil fertility management and pest control are among the most important constraints facing farmers in northern Ghana (Wood, 2013). Adoption of these agro-inputs is essential to promote farm productivity (Danso-Abbeam and Baiyegunhi, 2017). In addition, little is known about the relationship between socioeconomic, institutional and farm-level factors and adoption of crop protection and soil fertility (CPSF) management practices by soybean and other crop farmers in Ghana. This study thus fills this important research gap.

Studies relating to the simultaneous adoption of CPSF management practices in Ghana include Danso-Abbeam and Baiyegunhi (2017). According to the authors, adoption of agrochemical inputs (chemical fertilizer, insecticide and fungicide) by smallholders is complementary, implying that the choice to adopt an agrochemical is dependent on the choice to adopt other agrochemicals. Also, the decision to adopt agrochemical inputs was determined by factors such as educational level, farm size, asset ownership, soil fertility status, extension access, and pests and disease incidence, while the intensity of adoption was influenced by farm size, assets ownership, contact with extension agents, income from off-farm work, and perceptions of soil fertility status as well as pest and disease incidence. In another study by Danso-Abbeam and Baiyegunhi (2018), the authors applied multinomial logit model to evaluate the welfare effect of pesticide adoption among Ghanaian cocoa producers. The results showed that pesticide adoption enhanced farmers’ welfare. Also, Anang and Amikuzumo (2015) assessed the determinants of pesticide adoption in northern Ghana and noted that the decision to apply pesticides in rice cultivation was affected by farm size, level of income, market distance and agricultural extension contact.

Knowledge of smallholders’ adoption intensity of CPSF management practices is important because the right application rates of these inputs will enable farmers to derive the optimum benefit from their adoption. Studies by Denkyira et al. (2016) and Diiró et al. (2015) in Ghana and Uganda, respectively, indicate that farmers do not derive the maximum productivity gains from agrochemical inputs because of sub-optimal application rates.

Knowledge of the extent of adoption of CPSF management practices is essential in designing policies to promote good agricultural practices to protect the environment while promoting crop yields and farm profits at the same time. The study therefore evaluated the factors affecting adoption of CPSF management practices as well as the adoption intensity, using a sample of peasant soybean producers in Ghana. Specifically, the paper aimed at (1) determining the factors driving simultaneous adoption of CPSF management practices by small-scale soybean producers, and (2) estimating the factors affecting the adoption intensity of CPSF management practices.

The rest of the paper is as follows. Section 2 presents the methodology which includes the type and source of data, sampling technique, data collection and method of data analysis. Next, the study’s key results are presented and discussed. The final section is devoted to concluding remarks alongside policy recommendations arising from the study’s findings.

2. Methodology

2.1. Study area and sampling approach

The study was carried out in the Tolon district, located in the Guinea Savanna zone of Ghana. The area receives a single rainfall between May and October. The district is a major agricultural producing area where crops like rice, maize, yam, soybean, groundnuts, and pepper are grown. Soybean production is an important economic activity in the area for income and food security. The district has a population of 72,990 according to the national population census data of 2010 conducted by the Ghana Statistical Service (GSS, 2014). The area is prone to persistent erosion that has contributed to removal of the fertile top soil resulting in soils with low fertility for agricultural production. Soybean cultivation is known to enhance soil fertility by fixing atmospheric nitrogen into the soil, hence its popularity and acceptability by farmers in the district. Soybean is also resistant to weeds and provides a good source of income to many farm households.

The choice of the study area was informed by the fact that the district is well-known for the cultivation of soybean as a source of livelihood. Five communities were randomly selected followed by the random selection of 40 farmers from each community providing a sample size of 200 soybean producers. Each farmer was interviewed face-to-face using pre-tested questionnaires. The enumerators explained the purpose of the study to the participants and obtained informed consent from those who took part in the survey. Since most of the respondents were unable to
read or write, the enumerators interpreted the questions to them in the local dialect.

The information collected covered the 2018/2019 farming season and was collected between January and March 2019. The information solicited from farmers included individual and household characteristics, farm-specific factors, input-output data as well as institutional factors. The data analysis was carried out using Stata version 15 software.

2.2. Modeling adoption of multiple practices: the multivariate probit (MVP) model

The estimation of adoption of multiple technologies or practices involves the simultaneous estimation of a number of probit (or logit) models. Each of the technologies or practices represents a binary choice, and a joint estimation under the assumptions of a joint correlation between the errors of the individual equations is required. The multivariate probit (logit) model has typically been used in such situations to estimate the influence of socioeconomic variables on farmers’ joint adoption decisions. Thus, this study employs multivariate probit (MVP) regression to analyze farmers’ joint adoption decisions in line with Danso-Abbeam and Baiyegunhi (2017), Mulwa et al. (2017) and Kassie et al. (2013).

For each of the adoption decisions, the following probit model can be formulated.

\[ Y_i^* = \beta X_i + \epsilon_i \]  

(1)

\[ Y_i = \begin{cases} 1 \text{ if } Y_i^* > 0 \\ 0 \text{ if } Y_i^* \leq 0 \end{cases} \]  

(2)

where \( Y_i^* \) is an index function measuring the probability of adoption of a management practice, \( Y_i \) is the observed adoption value, which takes a value of 1 for adopters and 0 if otherwise. \( \beta \) represents unknown coefficients, and \( X_i \) denotes the independent variables explaining adoption.

The probability of adoption is obtained by the following expression.

\[ Pr(Y_i = 1) = Pr(u_i > -\beta X_i) = 1 - F(-\beta X_i) \]  

(3)

where \( F(.) \) signifies the cumulative distributive function of \( u_i \).

The empirical MVP model is presented as

\[ Y_{ik} = \beta_0 + \sum_{j=1}^{3} \beta_j X_{ikj} + u_{ik} \quad (k = \text{fertilizer, inoculant, herbicide}) \]  

(4)

where \( X_{1i} \) = age, \( X_{2i} \) = sex, \( X_{3i} \) = educational status, \( X_{4i} \) = herd size, \( X_{5i} \) = farm size, \( X_{6i} \) = cost of ploughing, \( X_{7i} \) = farm capital, \( X_{8i} \) = off-farm work, \( X_{9i} \) = farmer-group membership, \( X_{10i} \) = extension contact, and \( X_{11i} \) = access to credit.

2.3. Estimating the intensity of adoption: the Tobit model

In the existing literature, there are different approaches for measuring the intensity of adoption. One approach commonly used is to count the number of technologies adopted using count data modeling which includes Poisson regression (standard or generalized), negative binomial regression, zero-inflated Poisson, or zero-inflated binomial regression. These models are based on the assumption of a count dependent variable, hence a summation of the different technologies adopted by farmers is computed as the response variable. The models accommodate values for non-adoption (dependent variable taking value of zero) and any positive value for the number of technologies or practices adopted. Recent applications of count data models to evaluate intensity of adoption include Azumah et al. (2020), Mahama et al. (2020), and Mensah-Bonsu et al. (2017).

Another measure of adoption intensity in the literature is the share of land allocated to the technology. For example, in estimating intensity of adoption of improved varieties, the area planted to the improved variety is measured as the intensity of adoption. This approach has been used by authors such as Jaleta et al. (2013), Kaguongo et al. (2012), Mugisha and Diiro (2010) and Alene et al. (2000). Due to the likelihood of non-adoption, the Tobit model is often used in the analysis (Alene et al., 2000), with other authors using a double-hurdle estimation (Ghimire and Huang, 2015).

An alternate approach for estimating the intensity of adoption in the literature is where the response variable is measured as expenditure on the technologies or practices adopted. As a result of the likelihood of non-adoption by some farmers, the Tobit model may be used as in Danso-Abbeam and Baiyegunhi (2017), or a double-hurdle model may be used (Ghimire and Huang, 2015). This approach is plausible intuitively, in that the use of expenditure values provides a measure of producers’ farm investment decisions directly, unlike the situation where intensity is proxied by the number of practices adopted. Recent application of this procedure includes Danso-Abbeam and Baiyegunhi (2017) who used the Tobit model to assess the intensity of agrochemical adoption, measured as the expenditure on agrochemical inputs. Martey et al. (2012) also used the Tobit model to assess the intensity of commercialization by small-scale farmers in Ghana.

The study used expenditure on chemical fertilizer, biofertilizer (rhizobium inoculant), herbicide and insecticide as appropriate representation of the intensity of adoption as it accounts directly for the cost of production which plays a major role in decision-making at the farm-level. The Tobit model suits this analysis because the response variable is censored above zero while the independent variables are completely observed. The factors affecting the intensity of adoption of CPSF management practices were thus estimated using a censored Tobit model (Tobin 1958). Following Awotide et al. (2016), the tobit model was specified as follows:

\[ Z_{ik} = w_{ik} z_{ik} + \epsilon_i \]  

(5)

where \( Z_{ik} = \begin{cases} Z_{ik} \quad \text{if } Z_{ik} > 0 \\ 0 \quad \text{if } Z_{ik} \leq 0 \end{cases} \]  

(6)

where \( Z_{ik} \) is an unobservable index variable measuring the probability of a farmer to adopt management practice \( k \), and \( Z_{ik} \) is the observed adoption intensity; \( w_{ik} \) represents the explanatory variables explaining adoption intensity, and \( \epsilon_i \approx N(0, \sigma) \) such that \( i = 1, \ldots, n \).

The empirical Tobit model is expressed as follows:

\[ Z_{ik} = a_0 + \sum_{k=1}^{11} a_k w_{ik} + \epsilon_i \]  

where \( w_1 = \text{age}, w_2 = \text{sex}, w_3 = \text{educational status}, w_4 = \text{herd size}, w_5 = \text{farm size}, w_6 = \text{cost of ploughing}, w_7 = \text{farm capital}, w_8 = \text{off-farm work}, w_9 = \text{farmer-group membership}, w_{10} = \text{extension contact}, w_{11} = \text{access to credit}. \]

3. Results and discussion

3.1. Description of the sample

The descriptive statistics of the respondents are presented in Table 1. Farmer characteristics are important determinants of adoption decisions. On average, the sampled farmers were aged 38 years, which is within the active age group for agricultural production. Mahama et al. (2020) reported a mean age of 35 years for soybean farmers in Ghana. Adoption is expected to increase with age in line with Danso-Abbeam and Baiyegunhi (2017) and Anang (2018). This is because as farmers get older, they gain...
experience and acquire knowledge of productivity-enhancing technologies. Also, most of the respondents are male farmers, and lacked formal education. The finding resonates with that of Mahama et al. (2020) who observed that soybean producers in Ghana had less than two years of formal education. The lack of formal education is a likely drawback to adoption because education has been shown to increase awareness and knowledge of modern technologies leading to higher adoption (Anang et al., 2020). The respondents had on average four cattle, which is a measure of wealth in rural communities of Ghana. Herd size is expected to enhance technology adoption in line with Anang (2019).

Farm-specific factors play a vital role in adoption of technologies. The data shows that the respondents had a mean farm size of 0.64 acres and average farm capital of GH¢ 68. This confirms that the farmers are smallholders who also use very little capital in production. The respondents spent on average GH¢108 as cost of ploughing, which is an important component of production cost, and expected to influence technology adoption.

With regards to the institutional factors, the data shows that 30% of the respondents were engaged in off-farm work as an income diversification strategy, while 51% and 20% had access to extension service and agricultural credit, respectively. In addition, 35% belonged to a farmer group. The role of extension in promoting technology adoption has been highlighted by Danso-Abbeam and Baiyegunhi (2017) and Anang et al. (2020). Danso-Abbeam and Baiyegunhi (2017) also reported a positive association between credit and technology adoption by farmers in Ghana. The authors also observed that off-farm employment increased adoption of agrochemicals by farmers in Ghana.

Respondents spent an average of GH¢148 on CPSF management while 55%, 49% and 70% adopt fertilizer, inoculant and herbicide, respectively. Hence, herbicide application is the most commonly adopted practice by the sampled smallholder soybean cultivators. The result shows that weed control is of prime concern to the farmers. Weeds compete with field crops for soil nutrients and stunt the growth of plants leading to low yield. Chemical fertilizer application has increased recently in response to government initiatives such as the introduction of input subsidy to farmers. Despite the introduction of subsidies on inorganic fertilizer, adoption of the input is still below the expected level, which may be attributed partly to financial constraints of farm households. Inoculant adoption was lower than that of herbicide and chemical fertilizer, which can be attributed to the fact that inoculant technology is relatively new to farmers in the area. Biofertilizers such as inoculants are newly introduced technologies and farmers’ awareness of their benefits and methods of application is beginning to increase which is expected to lead to higher adoption.

3.2. Correlation estimates of the CPSF management practices

Table 2 shows the correlation estimates between the three management practices. When the correlation coefficient exceeds 0.5 it is regarded as high, while those in the range 0.25–0.5 are deemed medium (Sharma et al., 2011; Mensah-Bonsu et al., 2017). Furthermore, when the correlation is positive, it implies the technologies are adopted jointly (Sharma et al., 2011). In other words, such technologies are complementary. Conversely, a negative correlation points to technologies that are mutually exclusive. Such inputs or technologies are substitutes.

The results indicate that the correlation between chemical fertilizer and inoculant technology is medium, while the two technologies are mutually exclusive. The negative correlation between inoculant and chemical fertilizer adoption could be explained on the basis that farmers may perceive both inputs to enhance crop yield, and may consider them as inputs that could substitute for each other while others may be unable to adopt both inputs for financial reasons and therefore opt for either of them. Similarly, the results indicate medium correlation between inoculant technology and herbicide adoption, which are mutually exclusive. Inoculant technology suppresses the growth of weeds such as striga and this could account for its negative correlation with herbicide application. On the other hand, the correlation between chemical fertilizer and herbicide is high, with the two technologies having joint adoption.

3.3. Adoption of CPSF management practices: multivariate probit model

The results of the joint adoption of CPSF management practices by smallholder soybean farmers are depicted in Table 3. The log-likelihood ratio test measuring the correlation between the errors of the joint equations is significant at 1%, thus the three equations are correlated. Thus, the application of the MVP model is appropriate for this analysis, rather than the estimation of three separate probit equations.

Fertilizer adoption increased with the farmer’s age and significant at 1%. This indicates that older farmers have higher likelihood to adopt chemical fertilizer in soybean production. The result aligns with that of
Danso-Abbeam and Baiyegunhi (2017) which indicated that older Ghanaian cocoa producers had a higher likelihood to adopt fungicides in farming. Fertilizer adoption also increased with herd size at 10% and farm capital at 1%. This suggests that the propensity to adopt chemical fertilizer increases with herd size and farm capital endowment. The implication is that wealth factors are important in fertilizer adoption decisions of farmers. Furthermore, adoption of chemical fertilizer was higher for female soybean farmers at 1%. Danso-Abbeam and Baiyegunhi (2018) observe that adoption of pesticide management practices was higher for female cocoa producers in Ghana, which buttresses the findings of this study.

Adoption of inoculants (biofertilizer) increased with extension contact and farmer group membership, but decreased with educational status and participation in off-farm work. The findings imply that institutional factors play a role in inoculant adoption by smallholder soybean farmers. Extension agents and farmer groups are important channels through which farmers receive information on productivity-enhancing technologies such as inoculant application, hence their positive influence on biofertilizer adoption. A study in Ghana by Danso-Abbeam and Baiyegunhi (2018) showed that adoption of pesticide management practices increased with extension contact, lending credence to the findings of this study. Radeny et al. (2018) on their part observed that farmer group membership increased adoption of climate-smart agricultural (CSA) technologies by farmers in East Africa. Singh et al. (2008) also observed that adoption of integrated pest management (IPM) practices by farmers in India increased with farmer self-help group membership.

The empirical findings further reveal that adoption of herbicides increased with farm size, herd size, farm credit and engagement in off-farm employment but decreased with extension contact. The results suggest that farmers with larger farms have a higher likelihood to adopt herbicides in soybean production. As farms get larger, weeding cost is anticipated to rise. Farmers are thus more likely to apply chemical weed control with an increase in farm size, which agrees with Singh et al. (2008) in their analysis of IPM adoption by cotton farmers in India. Herd size is a proxy for wealth, while credit access indicates improved liquidity, which are expected to enhance chemical weed control (herbicide application) by farmers. The implications of the findings are that wealth indicators and factors which improve liquidity of the household tend to increase the propensity to adopt chemical weed control. These findings are supported by Danso-Abbeam and Baiyegunhi (2018) who showed that off-farm employment and credit access both increased adoption of pest management packages in Ghana.

The findings further reveal that institutional factors are more important with regard to inoculant and herbicide adoption while farmer characteristics are more important with regard to fertilizer adoption decision of smallholder soybean farmers. Hence, these factors should be considered carefully when designing strategies to promote technology adoption among smallholders. The direction of influence of agricultural extension on inoculant and herbicide adoption is revealing. Whereas extension access was associated with higher adoption of inoculant technology, the reverse was observed for herbicide adoption. Inoculant technology is environmentally-friendly, and hence, more likely to be recommended by extension workers compared to herbicide application which is less environmentally-friendly. A study by Anang and Amikuzuno (2015), which supports the finding of this study, reported a negative influence of extension contact on pesticide adoption by smallholder rice farmers in northern Ghana.

### 3.4. Adoption intensity of CPSF management practices

| Variable | Fertilizer model | Inoculant model | Herbicide model |
|----------|------------------|-----------------|----------------|
|          | Coef.            | S. E.           | Coef.          | S. E.       | Coef.          | S. E.       |
| Constant | -4.684**         | 2.775           | 7.110          | 5.811       | 2.057          | 2.321       |
| Age      | 1.117***         | 0.415           | -0.191         | 0.405       | -0.059         | 0.466       |
| Sex      | -0.709***        | 0.261           | 0.065          | 0.258       | -0.437         | 0.289       |
| Educational status | 0.376 | 0.309 | -0.526* | 0.290 | 0.240 | 0.349 |
| Herd size | 0.041*          | 0.023           | 0.004          | 0.020       | 0.080**        | 0.033       |
| Farm size | 0.444            | 0.277           | -0.257         | 0.263       | 1.075***       | 0.365       |
| Cost of ploughing | -0.272 | 0.616 | -2.209 | 1.563 | -0.100 | 0.360 |
| Farm capital | 0.523***        | 0.196           | 0.126          | 0.199       | 0.005          | 0.227       |
| Off-farm work | 0.342 | 0.222 | -0.367* | 0.220 | 0.650** | 0.278 |
| Extension visits | 0.147 | 0.219 | 0.803*** | 0.220 | -0.526* | 0.263 |
| Farmer group | -0.302         | 0.232           | 0.774***       | 0.228       | -0.029         | 0.256       |
| Credit   | 0.379            | 0.263           | 0.049          | 0.264       | 0.605*         | 0.337       |

***, ** and * denote statistical significance at 1%, 5% and 10% respectively. S.E denotes standard error. Likelihood ratio test of rho 21 = rho 31 = rho 32 = 0: chi 2(3) = 36.468, Prob > chi2 = 0.000.
Adoption intensity was higher for female soybean farmers with statistical significance at 1%. The result of the MVP model buttresses this finding; adoption of chemical fertilizer was higher among female farmers, even though gender had no effect on adoption of the other inputs. The result is revealing because women are often perceived to have lower adoption compared to men, which is blamed on their lower economic status within the household in many developing countries. Women’s higher adoption relative to men has however been reported by other authors such as Aryal et al. (2018) who studied adoption of multiple CSA practices in India.

The study further revealed that adoption of chemical fertilizer, biofertilizer (inoculant) and herbicide is interdependent. Hence, policies to enhance biofertilizer and agrochemical input adoption by soybean producers must take this interdependence into consideration. For instance, while there is a fertilizer subsidy policy in Ghana, there is no subsidy on herbicides; hence the need for similar subsidy on herbicides to enhance adoption. Also, inoculant is a relatively new technology, the adoption of which will largely depend on education and awareness creation by extension agents. Furthermore, farmer groups should be strengthened and used as channels for extension delivery and communication to farmers to promote adoption.

### Table 4. Adoption intensity of CPSF management practices.

| Expenditure level (GH¢) | Frequency | Percent |
|-------------------------|-----------|---------|
| GH¢ 4.5 in 2018.       | 148.4     | 0       |
| Minimum                 | 876       | 100     |
| Maximum                 | 0         | 0       |

1.0 US$ = GH¢ 4.5 in 2018.

The intensity of adoption increased with age of the respondents at 5% level indicating that older farmers adopt CPSF management practices more than younger farmers. Older farmers have been involved in farming for several years and have acquired knowledge of productivity-enhancing technologies which is expected to increase adoption of CPSF management practices. The result is supported by Mahama et al. (2020) in an investigation of soybean production technology adoption in Ghana.

The study also indicate that the intensity of adoption increased with herd size. The result is expected because of the role of herd ownership in smallholder production systems. Cattle ownership is a proxy for wealth (Anang et al., 2020) and wealth is expected to correlate positively with adoption of productivity-enhancing technologies; hence herd size is projected to influence intensity of adoption. Wealthier farm families can afford the cost of inputs and are expected to invest more in CPSF management practices.

The intensity of adoption of CPSF management practices increased with farm size, with a statistical significance at 1%. The result is consistent with the finding of Danso-Abbeam and Baiyegunhi (2017) who observed that an increase in farmers’ acreage enhanced agrochemical adoption intensity among cocoa farmers in Ghana. Similar result was obtained by Nkamleu et al. (2007) and Danso-Abbeam et al. (2014). Soybean production is considered as a viable economic venture in the study area hence farmers with larger farms are expected to intensify their investments in inputs that enhance crop protection and soil fertility management.

Finally, farm capital is positively related to adoption intensity at 1% significance level. This means that producers endowed with farm assets intensify their investment in inputs that promote crop protection and soil fertility management. The result aligns with a priori expectation because farm capital is expected to enhance agricultural intensification and hence the intensity of agrochemical input adoption. The result is supported by the finding of Danso-Abbeam and Baiyegunhi (2017) which showed that possession of motor-powered and manual spraying machines enhanced agrochemical input adoption by Ghanaian cocoa farmers. Motorized mechanized.

### Table 5. Factors influencing adoption intensity of CPSF management practices.

| Variable                        | Coefficient | Std. error | P > |z| |
|---------------------------------|-------------|------------|-----|--|--|
| Constant                        | 0.225       | 1.615      | 0.889| |
| Age                             | 0.885***    | 0.378      | 0.020| |
| Sex                             | -0.662***   | 0.238      | 0.005| |
| Educational status              | -0.026      | 0.274      | 0.925| |
| Herd size                       | 0.042***    | 0.020      | 0.035| |
| Farm size                       | 0.992***    | 0.249      | 0.000| |
| Cost of ploughing               | -0.126      | 0.117      | 0.284| |
| Farm capital                    | 0.484***    | 0.184      | 0.009| |
| Off-farm employment             | 0.267       | 0.207      | 0.198| |
| Extension visits                | 0.121       | 0.205      | 0.558| |
| Farmer group membership         | 0.111       | 0.214      | 0.606| |
| Access to credit                | 0.267       | 0.245      | 0.277| |

*** and ** imply significance at 1% and 5% respectively.
The results from the tobit model revealed that wealth factors – herd size, farm capital and farm size – are important determinants of intensity of adoption. To promote biofertilizer and agrochemical adoption in soybean production, the study recommends targeting the farmers who cannot afford the cost of inputs with support in the form of input subsidies. This will reduce partial adoption, which does not produce the desired output effect.

**Declarations**

**Author contribution statement**

Benjamin Tetteh Anang: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Jennifer Asemimewu: Conceived and designed the experiments; Wrote the paper.

James Fearon: Analyzed and interpreted the data; Wrote the paper.

**Funding statement**

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Data availability statement**

Data will be made available on request.

**Declaration of interests statement**

The authors declare no conflict of interest.

**Additional information**

No additional information is available for this paper.

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