



Received: 04 February 2021
Accepted: 07 August 2021

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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

The complementarity and substitutability of sustainable agricultural practices among maize farm households under AFRINT regions in Ghana: Do the socioeconomic determinants confirm these?

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Abstract: Sustainable Agricultural Practices (SAPs) have been promoted over the years as a means of ensuring sustainable development in the agricultural sector. However, adoption has generally been low across countries. This paper explores the linkages among SAPs and adoption decisions of SAPs among smallholder maize farm households in Ghana. The study used a household-level data on 394 farmers collected by the second round of the intensification of food crops agriculture in sub-Saharan Africa (AFRINT II) in Ghana. We employed a multivariate regression model to investigate the complementarity and the substitutability among the selected elements of SAPs as well as the simultaneous determinants of the SAPs components. We found out that some elements of the SAPs are complementary, while others are substitutes. The results also suggest that access to input credit,



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PUBLIC INTEREST STATEMENT

Over the years, the adoption of sustainable agricultural practices (SAPs) has been pushed as a method of guaranteeing long-term growth in the agricultural sector. However, this has been poor across countries, including Ghana. The objectives of this study were to investigate the levels and interrelationships among SAPs and the factors influencing their adoption among maize farmers in Ghana. The AFRINT II data set was used for the study. The sample involved 369 maize farm households in Ghana.

The results indicate that the probability of adoption is greater for the following: educated farmers, access to extension services, input credit, FBO membership, and farmers who intercrop. The study, therefore, recommends that the Ministry of Food and Agriculture (MoFA) as well as other Non-governmental Organizations (NGOs) support agricultural extension provision and uptake as well as the establishment of and support for the growth of Farmer Based Organizations (FBOs).

membership of farmer-based organizations, extension contact, and formal education, as well as intercropping, lead to the adoption of SAPs. The study recommends that SAP programmes that support the application of one technology (e.g., inorganic fertilizer) must provide simultaneous support for intercropping with nitrogen-fixing plants. Also, investment in public education is crucial in boosting farmers' knowledge of agricultural practices. Lastly, the positive and significant policy variables such as FBO suggest that focusing on strengthening community social network institutions is one other way of improving adoption decisions of SAPs.

Subjects: Agriculture & Environmental Sciences; Agricultural Economics; Agriculture and Food; Sustainable Development; RuralDevelopment

Keywords: adoption; complementarity; substitutability; AFRINT II; sustainable agricultural practices; multivariate probit; Ghana

1. Background

Agriculture plays a vital role in economic growth and development. It contributes enormously to the economy of Ghana and employs more than half of its population. This shows the immense impact of the agricultural sector as far as the Ghanaian economy is concerned (World Bank Group, 2018). Most of the farmers engaged in agriculture are smallholders and dwell in rural areas. Maize is known to be one of the highest sources of carbohydrates in Ghana, and it is cultivated across all regions in the country (Darfour & Rosentrater, 2016; Meherunnahar et al., 2018). It is a staple food for most ethnic groups in the country. Improvement in productivity of the crop would improve farmers' income and reduce poverty (Gassner et al., 2019). However, yields of maize are low because of poor soil fertility and agronomic practices (Yeboah et al., 2014). Thus, achieving higher and sustained yields remains the most significant challenge facing the agricultural sector, including the maize sub-sector. Though the usual farming practices are crucial to food security, some of these practices are considered unsustainable (Agula et al., 2018; The Montpellier Panel, 2013). For example, mono cropping is an efficient practice of growing a single crop on the same piece of land over time (Magdoff & Van Es, 2000). This practice damages soil quality (implying depletion of soil nutrients, reduction in organic matter and microbial activities in the soil and can cause significant erosion making the soil less productive over time) and increases crop exposure to pest attack (Magdoff & Van Es, 2000; Rosa-Schleich et al., 2019). In this regard, mono-cropping may be beneficial in the short run. However, the long-term effect is a dependency on the use of inorganic fertilizer to increase nutrients available for the crop and pesticides to control the pests. The excessive use of chemicals has adverse effects on biodiversity, the environment and the health of the farmer, as well as consumers (Mabe et al., 2017; Sud, 2020). These adverse effects call for the adoption of agricultural practices that ensure sustainable agricultural development with minimal environmental and health challenges.

Sustainable agricultural development is the management and conservation of a natural resource base and the orientation of technological and institutional change in such a way as to ensure the attainment and continued satisfaction of human needs for the present and future generations (FAO, 1995). The FAO (1995) stressed that sustainable agricultural practices (SAPs) are environmentally friendly, non-degrading, resource-conserving, socially acceptable, technically appropriate, and involve the use of economically viable practices in the production of food. Some of these practices include crop rotation, intercropping, fallowing, and integrated pest management. Ensuring sustainability in agriculture requires the integration of SAPs. Sustainable agriculture adopts productive, competitive, and efficient practices while protecting and improving the environment, the global ecosystem as well as the socioeconomic conditions of local communities. The principle of SAPs adoption does not exclude the adoption of external inputs but encourages their incorporation to complement domestic resources (Zaharia, 2010). SAPs help to maintain water retention, increase carbon sequestration, improve soil fertility, and protect the land from

erosion (Arslan et al., 2020; Rajendran et al., 2016; Teklewold et al., 2013). Thus, the use of SAPs helps to achieve the twin goals of achieving higher productivity and positive environmental outcomes (Pretty et al., 2018; The Montpellier Panel, 2013).

The use of SAPs will also improve farmers' ability to respond to climate change and variability and bring about positive environmental outcomes such as increased soil fertility and soil conservation and reduce deforestation that may emanate from the reduction in the agricultural land expansion (Makate et al., 2017; Pretty et al., 2018; Snapp et al., 2005). Unfortunately, adoption of SAPs has been low in both developed and developing countries of which Ghana is no exception. Despite the benefits associated with SAPs for the farmer and the positive environmental impacts, the factors influencing SAP adoption and the linkages that exist among these SAPs have not been adequately explored, hence the motivation of this paper. Ghanaian farmers are practising about 10 SAPs. These include crop rotation, intercropping with nitrogen-fixing crops, intercropping with non-nitrogen fixing plants, fallowing, animal manure, and zero or minimum tillage. Others include soil and water conservation, minimum use of pesticides and herbicides, improved planting practices, and the use of green manure.

Economic studies on agricultural technology adoption, including SAPs, have focused on the adoption of a single technology or few of the SAPs (Improved seeds, fertiliser application, etc.). However, farmers adopt a wide array of agricultural technologies either as complements or substitutes to increase their crop productivity. By focusing on a single technology, we tend to ignore the possibility that farmers have a choice of adopting many agrarian technologies at the same time and that the adoption of one technology may be partially dependent on the earlier technology choice (Teklewold et al., 2013). Analysis of farm technology adoption without accounting for technology inter-dependency may under- or over-estimate the magnitude of the determinants of farmers' decision to adopt and the impacts of such adoption (Arslan et al., 2020; Azumah et al., 2018; Donkoh, 2019). This study, therefore, helps to fill this gap in knowledge by identifying the factors influencing the simultaneous adoption of multiple farm practices. Thus, ten different SAPs commonly adopted by Ghanaian maize farmers have been included to understand the linkages and determinants of their use.

The specific objectives of the study are as follows: identify the adoption levels of SAPs in the study area; analyse the complementarity or substitutability of SAPs; and determine the factors influencing the adoption of SAPs in the study area.

The following hypotheses underscore the study:

(1) H0: The adoption levels of SAPs in the study area are generally low:

HA: The adoption levels of SAPs in the study are high

(1) H0: There are interrelationships among the SAPs; while some of the practices are complementary, others are substitutes.

HA: There are no interrelationships among the SAPs.

(1) H0: Farmers' demographic, farm-specific, institutional, and technological factors influence the adoption of SAPs.

HA: Farmers' demographic, farm-specific, institutional, and technological factors do not influence the adoption of SAPs.

In specific terms, the probability of adoption of SAPs is high because of the following reasons:

- Male farm managers, as opposed to female farmers, because the male farmers are generally more resourceful than the female farmers.
- The young farm managers, as opposed to the relatively old managers, because the younger managers are more adventurous.
- Farm managers with formal education, as opposed those with no formal education, because education helps farmers to read about and better understand the effectiveness/potency of sustainable practices
- Owners of small farms as compared to owners of large farms because of the labor-intensive nature of most SAPs.
- Mono-croppers than inter-croppers because mono cropping requires much more fertilizers than intercropping
- Farmers with no access to input credit as opposed to those with access to input credit, because some of the input credits are part of SAPs and so once a farmer has the former, he/she may not need the latter.
- A greater amount of hired labour paid as opposed to low amount because SAPs are laborious so that the greater amount spent on hired labour means enough manpower to work on SAPs.
- Farmers' access to extension as opposed to no access, because extension officers introduce technologies to farmers and guide them in their use.
- FBO membership as opposed to non-membership because, like extension officers, FBO members can introduce technologies to themselves and guide them in their use.

2. Methodology

2.1. Sustainable agricultural practices in Ghana

These SAP elements commonly practised by farmers in Northern Ghana are presented in [Table 1](#). *Crop rotation* is a farming practice where a farmer plants different crops on the same piece of land in a sequence. The rotation may differ from farmer to farmer based on the strengths and weaknesses of the natural environment (Chongtham et al., 2017). Intercropping, which is sometimes referred to as mixed cropping can be done with different plants; with leguminous crops which are known to fix nitrogen into the soil as well as non-nitrogen fixing crops. It is usually practised among smallholder farmers to improve soil fertility (Akter et al., 2004). *Fallowing* occurs when a piece of land generally used for farming is left with no crop on it for a season to allow it to recover its fertility (Donkoh, 2019; Smalley, 2013). *Animal manure* is a form of organic manure used as fertilizer for crops. It improves the richness of the soil by adding organic matter and lots of nutrients, such as nitrogen trapped by bacteria in the soil (Donkoh, 2019; Kostic et al., 2020). It is gotten from the droppings (faeces) of animals. On the other hand, *green manuring or compost* is an organic production method that involves the ploughing of plant tissues into the soil (Toungos & Bulus, 2019). Green manure or compost is created by leaving uprooted or sown crop parts to wither on a field so that they serve as mulch and soil amendment, thereby decreasing erosion and increasing fertility (Toungos & Bulus, 2019). *Zero or minimum tillage* is a soil conservation system with the aim of minimum soil manipulation necessary for successful crop production (Busari et al., 2015). This method does not turn the soil over, and it is in contrast to intensive tillage, which turns over the soil and changes the soil structure using ploughs.

2.2. Theoretical and estimation technique

The theoretical model employed is based on an approach developed by Chib and Greenberg (1998) known as the Multivariate Probit Model (MVP). The MVP is an extension of the probit model and is used to estimate adoption decisions in the presence of interdependency. In MVP, we recognize the correlations in the error terms among the adoption equations (in our case 10 equations) and jointly estimate the set of the ten probit models. In this case, the use of the univariate probit or logit model becomes inappropriate due to the inter-relationship among SAPs' technologies since probit or logit ignores such correlation in the error terms (Abukari et al., 2021; Ehiakpor et al., 2021). This

Table 1. Definition of variables and a priori expectations

Variable	Definitions	Measurement	A priori expectation
<i>Household-specific factors</i>			
Sex of farm manager	Sex of farm manager	Dummy(1 = male)	+
Age of farm manager	Age of farm manager	number of years	+
Education of farm manager	Total number of years in formal education	number of years	+
<i>Farm-specific factors</i>			
Farm size	Agricultural land holdings	Hectares	-
Cropping system (Pure stand or intercropped)	Whether crop was grown in pure stand or intercropped	Dummy (1 = Pure stand, 0 = Intercropped)	+
Receive agric input credit	Whether respondent received input credit	Dummy (1 = yes, 0 = no)	-
Payment of Hired Labour	Amount paid	Ghana cedi	+
<i>Institutional-specific factors</i>			
Governmental extension advice	Whether respondent receive advice from government extension	Dummy (1 = yes, 0 = no)	+
FBO membership	Whether respondent is a member of any FBO	Dummy (1 = yes, 0 = no)	+

correlation may emanate from the fact that the same latent variables could influence the adoption of different SAPs. Thus, univariate models do not account for the fact that the decision to adopt a particular SAP (e.g., crop rotation) may be dependent on the adoption of a complementary SAP (e.g., application of herbicides and pesticides) or influence by an available set of substitutes (e.g., application of inorganic fertilizer). Failure to capture such interdependency among the different components of the SAP may lead to inefficient estimates and misplaced policy implications (Onyeiwu et al., 2011). Hence, the most appropriate econometric model to be applied in analysing such interdependent decision-making, where farmers may choose to adopt a mix of the SAPs to optimize their utility rather than relying on a single farm technology is the MVP.

We follow studies such as Ehiakpor et al. (2021) and Abukari et al. (2021) to formulate the multivariate model which has 10 dependent variables,

$$Y_1 = 1 \text{ if } \beta_1 X + \varepsilon_1 > 0 \text{ such that;} \tag{1}$$

and

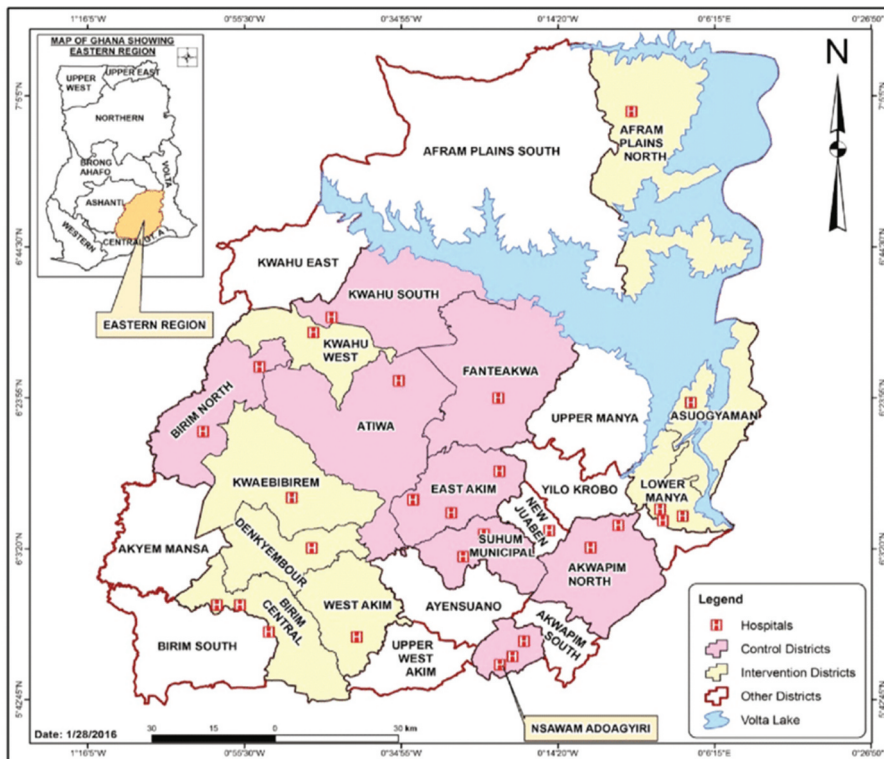
$$Y_i = 0 \text{ if } \beta_i X + \varepsilon_i \leq 0 \quad i = 1, 2, 3, \dots, 10 \tag{2}$$

where X is the set of variables hypothesized to explain the adoption decisions, $\beta_1, \beta_2, \beta_3, \dots, \beta_{10}$ are parameter vectors and $\varepsilon_1, \varepsilon_2, \varepsilon_3, \dots, \varepsilon_{10}$ are random errors distributed as a multivariate normal distribution with zero mean, unitary variance, and a $n \times n$ correlation matrix specified as;

$$\Sigma = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} & \dots & \rho_{1m} \\ \rho_{12} & 1 & \rho_{23} & \rho_{24} & \dots & \rho_{2m} \\ \rho_{13} & \rho_{23} & 1 & \rho_{34} & \dots & \rho_{3m} \\ \rho_{14} & \rho_{24} & \rho_{34} & 1 & \dots & \rho_{4m} \\ \vdots & \vdots & \vdots & \vdots & 1 & \vdots \\ \rho_{1m} & \rho_{2m} & \rho_{3m} & \rho_{4m} & \dots & 1 \end{bmatrix} \tag{3}$$

Figure 1. Map of the Eastern and Upper East region of Ghana.

Source: Eastern regional map adopted from Amoakoh et al. (2017). Upper East regional map adopted from Owusu et al. (2013).



where $\rho(\rho)$ represents the pairwise correlation coefficient of the error terms corresponding to the adoption of any two SAP components to be estimated in the model. A non-zero off-diagonal between two technologies (e.g., 12) implies correlation between the two technologies in question implying the use of MVP model or specifically a bivariate model. Note that the bivariate model is a special case of an MVP where only two technologies are involved. In this model, ρ is more than just a correlation coefficient. A positive correlation coefficient indicates a complementary relationship, while a negative correlation denotes the two elements are substitutes. The parameters of the MVP model are estimated using the maximum likelihood procedures.

2.3. Study area

Ghana is a coastal country in western Africa with latitude and longitude of 8°00'N and 2°00'W, respectively. It stretches to an area of 239,460 square kilometers (Ziggah et al., 2019) and is rich in natural resources. Ghana has a large proportion of its population that is urban and youthful. Ghana's capital is Accra, which is located at 50 33'N latitude and 0015'W longitude. Ghana's geographical location assures a unique climatic mix across the area. Ghana used to be divided into 10 regions, notably: Ashanti Region, Eastern Region, Northern Region, Western Region, Upper West Region, Upper East Region, Brong Ahafo Region, Central Region, Volta Region, and the Greater Accra Region but now sixteen with the six new regions being North East Region, Savannah Region, Bono East Region, Oti Region, Western North Region, and the Ahafo Region. This data was taken at a time the old regions were in existence; hence, the same applies to this study. Ghana has a population currently estimated at 30 million people (Cooke et al., 2016). Ghana shares border with Togo to the east, Burkina Faso to the north, Cote d'Ivoire to the west, and the Atlantic Ocean Gulf of Guinea to the south.

Agriculture is still mostly a traditional industry, but it employs over 70% of the country's entire population, making it a significant contributor to Ghana's economy. Ghana's food consists primarily of starchy roots (cassava, yam), fruit (plantain), and grains (maize, rice) (FAO, 2010) Figure 1.

2.4. Data source and sampling procedure

The intensification of food crops agriculture in sub-Saharan Africa (Afrint II) dataset was used for this study. The Afrint II data were taken from the years 2007 and 2010. The data was taken in nine (9) African countries, namely, Ghana, Kenya, Malawi, Nigeria, Tanzania, Ethiopia, Mozambique, Uganda, and Zambia. These countries were chosen because they had achieved success in agricultural intensification caused by farmers or the state, such as the Asian Green Revolution. These countries were also less limited in their access to agricultural capital. Therefore, the countries were purposively selected. The purposive sampling techniques were not only employed in the first stage of the sampling procedure, both the second and third also followed the same technique of sampling. Thus, after the countries were selected, the regions in the various countries as well as the villages in the regions (Upper East and Eastern regions) were also purposively selected based on their agricultural potentials. The last stage, which was the selection of the households involved simple random sampling based on the listing of all households in the village and the random selection of some. In addition to household questionnaire, some key informant interviews (involving community leaders and extension agents) and focus group discussions (also involving women) were also held at the community level. A total of 3810 respondents were interviewed across the nine countries considered. There was a total sample size of about 569 farmers from Ghana (from two regions; Upper East and Eastern regions) out of which 369 of them were maize farmers, after cleaning, we settled on 369; hence, the sample size of this study. A total number of 18 technologies of SAPs were identified out of which 10 of the commonly used ones in maize production in Ghana were used. Moreover, a few were dropped because they were very much skewed towards non-adopters, hence dropped because they were not allowing for convergence. The ten technologies adopted are as follows: Crop rotation (P1), Intercropping with other crops (P2), Intercropping with nitrogen fixing crops (P3), Fallowing (P4), Animal manure (P5), Zero or minimum tillage (P6), Green manure/compost/residue incorporation (P7), Soil and water conservation (level bunds, grass strips, terracing, etc.) (P8), Improved seeds (P9), and Pesticides/herbicides (P10) (minimum use).

2.5. Empirical model

The model that identifies the factors determining adoption of sustainable agricultural practices (SAPs) is the multivariate probit model. Let Y_i be the sustainable agricultural practices and X_i the explanatory variables that determine the adoption of any of these practices. In this model, a number of explanatory variables are considered, and these include sex of farm manager, age of farm manager, educational level of farm manager, extension access, cropping system, agricultural input credit access, FBO membership, and payment of hired labour.

The empirical specification of the multivariate probit model is given as:

$$Y_{ik} = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \beta_7 X_{7i} + \beta_8 X_{8i} + \varepsilon_i$$

Where Y_{ik} defines a set of dependent variables (adoption of crop rotation, intercropping, intercropping with nitrogen fixing crops, fallowing, animal manure, zero or minimum tillage, green manure or compost, soil and water conservation, improved planting practices, and pesticides or herbicide use) as binary outcome; 1 if adopted and 0 otherwise; X_i 's are a set of independent variables for each outcome equation (sex of farm manager, age of farm manager, educational level of farm manager, extension advice, maize grown in pure stand only or intercropped, whether you receive any agricultural input credit, membership of local group or organization and payment of hired labour); β_0 define the constant term for each outcome equation. $\beta_1, \beta_2, \beta_3, \dots, \beta_8$ are the parameters of the explanatory variables in the model. Where the ε_1 's are the joint normal with means zero, variances one, and correlation ρ .

2.6. Definition of variables and a priori expectations

The factors that are believed to determine the adoption of sustainable agricultural practices are divided into two parts, the first part looks at measurement of adoption of SAP by maize farmers and the second part looks at the linkages that exist between these practices. The analysis of factors that influence the adoption of SAP will be done using multivariate probit model.

3. Results and discussions

3.1. Descriptive statistics

The dependent variables for this study are the components of SAP practised by the farm households. Though the practice has a lot of advantages in soil fertility management, it is practised by only 23% of the sample farmers, probably due to the scarcity of land. *Intercropping* is the practice of growing multiple crops at the same time on the same piece of land. As reported in [Table 1](#), intercropping with other crops is the most practised SAP (about 80%) by maize farmers in Ghana. Farmers sow maize together with other non-nitrogen fixing crops like yam, cocoyam, and millet. On the contrary, only about 17% of the farmers intercrop their maize plants with nitrogen-fixing plants like beans and soya. While a significant proportion (63.69) of farmers do practice land fallowing or allow their land to regain nutrient, only about 25% and 22% of them add animal and compost, respectively, to the soil for fertility management. Minimum tillage is increasingly becoming one of the famous SAPs in the country, as about 76% of the farmers adopted this technique. *Soil and water conservation* are practices aimed at maintaining soil quality by avoiding soil erosion while providing the plant with the essential nutrients to support growth.

As indicated in [Table 2](#), only 10% of the sampled farmers practice the soil and water conservation technique, probably due to the drudgery nature of the technology. *Improved planting practices* such as the use of improved seeds are good farming practices that integrate biodiversity and ecosystem management for sustainable crop production. Due to its significance in maize production, 76% of the interviewed farmers used improved seeds. These practices are used to produce high yields of crops without destroying the soil structure (Ehiakpor et al., 2021; The Montpellier Panel, 2013). *Pesticide or herbicide* are agricultural chemicals that are used to protect crops against pests and weeds. They include herbicides to kill weeds, fungicides to get rid of diseases, and

Table 2. Adoption of the elements of the SAP

SAP	Freq.	Percent	Freq.	Percent
	Yes	%	No	%
Crop rotation (P ₁)	85	23.04	284	76.96
Intercropping with other crops (P ₂)	296	80.22	73	19.78
Intercropping with nitrogen fixing crops (P ₃)	62	16.80	307	83.20
Fallowing (P ₄)	235	63.69	134	36.31
Animal manure (P ₅)	93	25.20	276	74.80
Zero or minimum tillage (P ₆)	282	76.42	87	23.58
Green manure/ compost/ residue incorporation (P ₇)	83	22.49	286	77.51
Soil and water conservation (level bunds, grass strips, terracing, etc.) (P ₈)	37	10.03	332	89.97
Improved seeds (P ₉)	281	76.15	88	23.85
Pesticides/ herbicides (P ₁₀)	155	42.10	214	57.99

Table 3. Percentage distribution of SAP adoption levels of maize farmers in Ghana

SAP adoption levels	Frequency	Percent (%)
1	4	1.08
2	29	7.86
3	61	16.53
4	118	31.98
5	84	22.76
6	46	12.47
7	22	5.96
8	3	0.81
9	2	0.54
10	0	0
Total	369	100

insecticides to kill insects. Aside from the adverse effects of pesticides on the soil, research has shown that it still plays a significant role in increasing crop yield.

Furthermore, [Table 3](#) reports the intensity of adoption regarding the percentage of adopters. We observe that the highest percentage of adopters (31.98%) adopted 4 of the SAP followed by 22.76% who adopted 5 of the practices. The third-highest percentage of adopters (16.53%) adopted three methods, while the fourth and fifth-highest percentages adopted 6 and 2 practices, respectively, with none of the farmers adopting all the 10 SAPs. The rest are as indicated in the Table.

Summary statistics of the independent variables used in the study are presented in [Table 4](#). About 80% of the sampled respondents are male-headed households. The mean age of maize farmers was 48.8 years. This suggests that majority of farmers in the study area are primarily young adults and are in the economically active age group, which could be an advantage to the adoption of SAPs in the study area. This result is consistent with that of Ministry of Food and agriculture (MoFA) (2013), who reported the average age of farmers in Ghana to be 55 years. The average number of years spent in formal education was 6.16 years; this implies that broadly, maize farmers had at least

primary education. This could potentially influence the rate of adoption of SAPs as most of the farmers could read and write to some extent (Usman et al., 2020). The results also show that the average total farm size of a maize farmer in Ghana is 2 acres (0.81 hectares). Furthermore, 27.6% of maize farmers cultivate in pure stand; that is to say that they do not intercrop. It is important to note that, on average, the number of adults engaged in non-farm activities per household is low (less than 1). While 64.5% of maize farmers have an informal control over the land they use and can use it anytime without seeking permission from anyone, 9.2% of the respondents had formal land titles to their farm plots. While the average amount spent on hired labour was GH¢ 18.95, the average number of active household members was 4. Extension service is known to be an essential and critical source through which many farmers acquire knowledge on SAPs (Anang et al., 2020). This can be done directly through contact with extension agents, which can be private (NGO) or government (MoFA) or indirectly through colleague farmers. On average, 59.3% of maize farmers received extension advice in a season, with 18.9% belonging to FBOs. According to the UDS plug-in principle (SCI-SLM 2009), the extension agents should act as bettering agents rather than change agents for farmers to accept technologies introduced to them to bring about behavioural change. Also, 9.8% of the farmers, had access to agricultural input credit.

3.2. The complementarity and substitutability of SAPs

The likelihood ratio test for the overall correlation of the error terms [$Chi^2(8) = 234; p = 0.000$] is significant and different from zero suggesting the appropriateness of the MVP model. The significant coefficients of some of the pairwise correlation error terms indicated in Table 5 also support the rejection of the null hypothesis that the error terms of the adoption equations are not correlated (Donkoh et al., 2019).

The results show some degree of complementarity and substitutability of some SAPs (Arslan et al., 2020; Rajendran et al., 2016; Teklewold et al., 2013; Usman et al., 2020). Thus, the correlation coefficient of the error terms reveals that there is positive (complementarity) and negative (competitiveness) correlation between different components of the SAPs. The highest positive and significant correlation (80%) was found between animal manure and green manure, indicating the complementarity between them. The strong positive correlation between animal manure and green manure demonstrates the declining rate of soil fertility of most farmlands in Ghana. Given the poor nature of the soil in the study area, farmers prefer to use more organic, cost-effective, and environmentally friendly ways of improving the potency of their soil to using inorganic fertilizers. The use of multiple SAPs also indicates that for many farmers, different constraints are associated with different practices. There is also a strong negative and significant correlation between animal manure and fallowing, suggesting that farmers do not apply animal manure on land that has been left to fallow for a season or two. The competitive nature of animal manure and fallowing could partly be attributed to farmers' perception that applying manure on a fallowed land is a waste of resources. It is clear in Table 5 that the decision of farmers to adopt the different SAPs differs quite marginally based on the factors that influence their adoption of each of the technologies.

3.3. The factors influencing the adoption of SAP

The maximum likelihood estimates of the determinants of adoption decisions of SAPs from the MVP are reported in Table 6. The results show the significance of farmers' demographic, farm-specific, institutional, and technological factors in explaining the probability of maize farmers' decision to adopt SAPs. Sex was found to have a positive and significant effect on the adoption of animal manure but negative and significant effect on fallowing. This can be attributed to the fact that females do not engage fully in farming but trade and other non-farm activities to support their homes hence they are more likely to leave the land to fallow for a season or more. Males, on the other hand, are more likely to apply animal manure to their fields as it is a labour-intensive activity. Moreover, contrary to the findings of many studies (e.g., Assan et al., 2018), sex of the farm manager has a negative sign, indicating that farms whose managers were female had a high probability of adopting the SAPs than their male counterparts. The results from the table also show

Table 4. Descriptive statistics of variables

Variable	Mean	Std. Dev.	Min	Max
<i>Household-specific factors</i>				
Sex of farm manager	0.797	0.479	0	1
Age of farm manager	48.837	14.711	19	99
Education of farm manager	6.162	5.229	0	19
<i>Farm-specific factors</i>				
Total farm size	0.88	0.722	0.03	5.06
Cropping system (Pure stand or Intercropped)	0.276	0.447	0	1
Payment of Hired Labour	18.949	39.835	10	300
<i>Institutional-specific factors</i>				
Governmental extension advice access	0.593	.492	0	1
FBO membership	0.189	.392	0	1
Agricultural input credit access	0.098	.297	0	1

Table 5. Pairwise correlation from multivariate probit analyses

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1	1									
P2	-0.103 (0.123)	1								
P3	0.035 (0.101)	-0.010 (0.111)	1							
P4	-0.024 (0.087)	0.446 ^a (0.091)	-0.043 (0.093)	1						
P5	0.112 (0.097)	-0.323 ^a (0.099)	0.187 ^b (0.091)	-0.617 ^a (0.068)	1					
P6	0.163 ^c (0.097)	-0.051 (0.107)	-0.048 (0.093)	0.049 (0.091)	0.152 (0.096)	1				
P7	-0.088 (0.096)	-0.281 ^a (0.096)	0.295 ^a (0.086)	-0.392 ^a (0.081)	0.799 ^a (0.045)	0.123 (0.104)	1			
P8	0.201 ^b (0.103)	-0.395 ^a (0.106)	0.024 (0.104)	-0.539 ^a (0.086)	0.610 ^a (0.091)	0.405 ^a (.1052)	0.493 ^a (.0971)	1		
P9	0.197 ^b (0.099)	-0.001 (0.115)	-0.028 (0.098)	0.249 ^a (0.087)	0.048 (0.101)	0.609 ^a (.0700)	.0690 (.1121)	.1655 (.1143)	1	
P10	-0.046 (0.089)	-0.129 (0.097)	0.036 (0.083)	0.047 (0.085)	-0.314 ^a (0.092)	-0.256 ^a (0.084)	-0.260 (0.084)	-0.008 (0.112)	-0.168 ^c (.0886)	1

Likelihood ratio test [$Chi^2(8) = 234; p = 0.000$]

a, b, and c indicate significance at 10% and 1% levels respectively. Standard errors are in the parentheses. Crop rotation (P1), Intercropping with other crops (P2), Intercropping with nitrogen fixing crops (P3), Fallowing (P4), Animal manure (P5), Zero or minimum tillage (P6), Green manure/ compost/ residue incorporation (P7), Soil and water conservation (level bunds, grass strips, terracing, etc.) (P8), Improved seeds (P9), and Pesticides/ herbicides (P10).

that age is significant and has a negative effect on the adoption of zero or minimum tillage and improved planting practices. This suggests that the probability of adoption is higher for relatively young farmers. The finding contradicts Donkoh (2019) and Idrisa et al. (2010), where adoption of technologies was found to be higher among older farmers but consistent with Doss and Doss (2006) who found adoption to be high among younger farmers, mainly due to innovativeness and risk-taking ability.

Table 6. Determinants of sustainable agricultural practices in Ghana from the MVP

Variable	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Sex of farmer	0.039 (0.208)	0.024 (0.299)	0.3267 (0.229)	-0.387 ^b (0.191)	0.499 ^b (0.216)	-0.263 (0.200)	0.061 (0.197)	0.097 (0.263)	0.011 (0.188)	0.032 (0.181)
Age of the farmer	0.003 (0.006)	0.000 (0.007)	-0.009 (0.006)	0.000 (0.005)	0.006 (0.006)	-0.010 ^b (0.005)	0.001 (0.005)	-0.005 (0.006)	-0.013 ^a (0.005)	-0.008 (0.005)
Educational attainment of the farmers	0.028 ^c (0.015)	0.013 (0.021)	-0.008 (0.017)	0.060 ^a (0.015)	-0.020 (0.016)	-0.002 (0.016)	-0.027 ^c (0.015)	-0.045 ^b (0.020)	0.015 (0.016)	0.0310 ^b (0.014)
Extension contact	-0.102 (0.159)	0.214 (0.210)	-0.011 (0.166)	0.083 (0.148)	-0.165 (0.160)	0.410 ^a (0.154)	-0.137 (0.148)	-0.008 (0.186)	0.309b (0.155)	0.115 (0.143)
Cropping system	0.200 (0.174)	-2.278 ^a (0.224)	0.1743 (0.179)	-0.837 ^a (0.162)	1.127 ^a (0.166)	0.587 ^a (0.195)	0.684 ^a (0.157)	0.800 ^a (0.1915)	0.569 ^a (0.197)	-0.6642 ^a (0.165)
Agric. Input credit	0.543 (0.245)	0.137 (0.360)	0.339 (0.254)	0.296 (0.267)	-0.074 (0.279)	-0.006 (0.262)	0.134 (0.247)	-0.288 (0.351)	0.444 (0.311)	0.537 ^b 0.239
FBO Membership	0.721 ^a (0.186)	-0.511 ^c (0.266)	-0.044 (0.212)	-0.182 (0.194)	0.331 ^c (0.192)	0.219 (0.215)	0.145 (0.184)	0.247 (0.239)	0.644 ^a (0.243)	0.168 (0.183)
Payment of hired labour	-0.003 (0.003)	0.009 (0.007)	0.003 (0.002)	0.002 (0.002)	-0.002 (0.002)	0.001 (0.002)	-0.007 (0.004)	-0.000 (0.002)	0.568 (0.197)	-0.003 (0.002)
Constant	-1.265 ^a (0.362)	1.635 (0.492)	-0.881 ^b (0.381)	0.488 (0.337)	-1.616 ^a (0.366)	1.025 ^a (0.346)	-0.776 ^b (0.331)	-1.243 ^a (0.411)	0.846 ^a (0.337)	-0.014 (0.316)

a, b, and c denote significant levels at 1%, 5%, and 10%, respectively. Crop rotation (P1), Intercropping with other crops (P2), Intercropping with nitrogen fixing crops (P3), Following (P4), Animal manure (P5), Zero or minimum tillage (P6), Green manure/ compost/ residue incorporation (P7), Soil and water conservation (level bunds, grass strips, terracing, etc.) (P8), Improved seeds (P9), and Pesticides/ herbicides (P10).

The education of the farm manager was significant and positively related to the adoption of crop rotation, fallowing, and use of pesticides and herbicides, which is consistent with the findings of Doss and Doss (2006) and Akudugu et al. (2012). On the contrary, education was significant but negatively associated with the adoption of green manure/compost/residue incorporation, and soil and water conservation practices. However, being educated or not did not have any influence on the adoption of intercropping, intercropping with nitrogen-fixing crops, animal manure, zero or minimum tillage, and improved planting practices. The choice of cropping system generally dictates the extent to which farmers adopt several practices. Whether a farmer plants maize in a pure stand or mixes with other crops is significant and positively influences the adoption of animal manure, zero or minimum tillage, green manure, soil and water conservation, and improved planting practices. This is consistent with our *a priori* expectation since the kind of cropping system practised determined the SAPs to adopt.

Adoption of SAPs is largely influenced by farmers' contacts with agricultural extension agents. Thus, whether a maize farmer had access to extension services or not was statistically significant and positively impacted the adoption of zero or minimum tillage, and improved planting practices. This suggests that, as farmers have more contacts with extension agents, they become more informed about the various SAPs, which increases their probability of adoption.

FBO membership is significant and positively influences the adoption of crop rotation, animal manure, and improved planting practices. On the other hand, FBO membership negatively affects the adoption of intercropping. The role played by FBO membership is imperative as far as the adoption of SAPs is concerned since new practices are introduced to farmers by their colleagues in the association (i.e., there is learning from one another). The coefficient of the input credit variable is positive and significant, implying that farmers who accessed input credit during the farming season had a higher probability of adopting crop rotation, and pesticide and herbicide use.

4. Conclusions

The study sought to understand the complementarity and substitutability of SAPs as well as the determinants of SAPs adoption decisions among maize farm households in Ghana. This was achieved through the use of the estimation of a multivariate probit model using data set from AFRINT II. The results of the study revealed that both complementarity and substitutability exist among the elements of SAPs. The strongest complementarity existed between animal manure and green manure, whereas the most substantial substitutability was found between animal manure and fallowing. The empirical results further show that factors such as educational level, access to extension services, agricultural credit input access, FBO membership, and cropping system had positive and significant effects on the adoption of SAPs in Ghana. These interdependent farm technologies and the factors influencing their adoption have important policy implications. First, farm-level policies that influence the adoption decision of a particular technology could have a spillover effect on the adoption of other SAPs. Thus, the interrelations and potential synergies among the SAP components suggest to policymakers that SAP programmes that support the application of one technology (e.g., inorganic fertilizer) must provide simultaneous support for intercropping with nitrogen-fixing plants. Second, the positive influence of education on adoption of SAP underscores the significance of education in enhancing the understanding and consequently, the adoption of SAPs. Thus, investment in the public education sector is crucial in boosting farmers' knowledge of agricultural practices. Lastly, the positive and significant policy variables such as FBO suggest that focusing on strengthening community social network institution is one other way of improving adoption decisions of SAPs.

Abbreviations

AFRINT: Intensification of food crops agriculture in sub-Saharan Africa; FBO: Farmer based organisation; MoFA: Ministry of food and agriculture; SAPs: Sustainable agricultural practices; MVP: Multivariate probit; NGO: Non-governmental organisation; SCI-SLM: Stimulating

community initiatives in sustainable land management; UDS: University for Development Studies

Acknowledgements

We acknowledge the Lund University for taking and making the data available to the public.

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Disclosure statement

The author(s) declare that they have no competing interests.

Funding

The authors received no direct funding for this research.

Availability of data and materials

The raw data will be made available upon request.

Authors' contributions

MAD developed the concept and designed the study. EM did the data analysis using STATA software, and GDA technically supported the data analysis and the write up. DO interpreted the results, DSE wrote the conclusions and policy recommendations, SAD wrote the abstract and proofread the final manuscript.

Citation information

Cite this article as: The complementarity and substitutability of sustainable agricultural practices among maize farm households under AFRINT regions in Ghana: Do the socioeconomic determinants confirm these?, Emmanuel Marfo, Gideon Danso-Abbeam, Samuel A. Donkoh, Makafui Adzo Dikro, Dennis Sedem Ehiakpor & Daniel Ofori, *Cogent Food & Agriculture* (2021), 7: 1969736.

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