Setsoafia *et al.*
Agricultural and Food Economics (2022) 10:9
https://doi.org/10.1186/s40100-022-00216-9

Agricultural and Food Economics

RESEARCH Open Access

Effects of sustainable agricultural practices on farm income and food security in northern Ghana

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Abstract

The adoption of sustainable agricultural practices (SAPs) has been recommended by many experts and international institutions to address food security and climate change problems. Global support for the Sustainable Development Goals has focused attention on efforts to up-scale the adoption of SAPs in developing countries where growth in populations and incomes compromises the resilience of natural resources. This study investigates the factors affecting smallholder farmers' decisions to adopt SAPs (improved seed, fertilizer, and soil and water conservation) and the impacts of the adoption on farm income and food security, using data collected from Ghana. Food security is captured by the reduced coping strategy index and household dietary diversity. The multinomial endogenous switching regression model is utilized to address selection bias issues. Results show that farmers' decisions to adopt SAPs are influenced by the social demographics of the households, plot-level characteristics, extension services and locations. Adopting all three SAPs has larger positive impacts on farm income and food security than adopting single or two SAPs. Our findings advocate for policies that enhance the quality of extension service and strengthen farmer-based organizations for the wider dissemination of adequate SAP information. Farmers should be encouraged to adopt SAPs as a comprehensive package for increasing farm income and ensuring food security.

Keywords: Sustainable agriculture practices, MESR model, Farm income, Food security, Ghana

JEL Classification: C34, O12, Q16, Q18

Introduction

There is considerable pressure on agriculture to meet the demands of a growing world population. This is heightened with rising demand for necessities such as food, raw materials for industries, and biofuels. However, growth in agricultural production globally does not match this demand well, especially in parts of Africa. Africa has been projected to be vulnerable to climate change because of its proximity to the equator (Ojo et al. 2021; Thinda et al. 2021; Sarr et al. 2021; Onyeneke 2021; Ahmed 2022). Some of the physical impacts of climate change in Africa are rising sea levels, temperature andchange, and rainfall change (World Bank 2010; Abdulai 2018), which will harm agricultural productivity, farm income, food security, and economic development. This will negatively affect the poor, whose livelihoods are tired of agriculture in Sub-Saharan Africa.

There has been a global discussion on overcoming the negative externalities of climate change. Most experts believe that sustainable agriculture management could be a solution to the challenge associated with climate change (Kassie et al. 2013; Ndiritu et al. 2014; Ogemah 2017; Zhou et al. 2018; Adenle et al. 2019; Rose et al. 2019; Zeweld et al. 2020; Ma and Wang 2020; Ehiakpor et al. 2021; Bekele et al. 2021). This approach is expected to improve agricultural production performance whilst reversing the negative degradation processes on the agroecosystem, particularly in smallholder farming systems. It is an upgrade of the green revolution, which led to a significant increase in agricultural productivity globally and is credited for jump-starting economies in Asia out of poverty but has left negative externalities such as deforestation, land degradation, salinization of water bodies, and loss of biodiversity in its wake.

To reverse the negative externalities from crop intensification, farmers have been advised to adopt sustainable agricultural practices (SAPs), which are made up of elements of the green revolution and an agronomic revolution. The literature is filled with studies on the adoption of specific or single elements of SAPs, such as improved seed, irrigation, drought-tolerant crop varieties, climate-resilient crop variety, organic soil amendments, and soil and water conservation practices, and their effects on crop yield and net farm income (Abdulai and Huffman 2014; Agula et al. 2018; Adenle et al. 2019; Adegbeye et al. 2020; Kimathi et al. 2021; Zheng et al. 2021; Ahmed 2022; Yang et al. 2022). Despite the potential complementarity or substitutability of specific elements of SAPs, the research on the adoption of multiple SAPs and their effects on outcome variables such as income, outputs, consumption expenditure and food security remains limited.

This paper seeks to investigate the determinants of multiple SAP adoption and the adoption effects on farm income and food security, using second-hand data collected from Ghana. This study contributes to the literature in twofold. First, it provides empirical insights into the importance of SAPs on welfare indicators, specifically food security. The use of food security as a proxy measure for welfare is particularly important in the Ghanaian context, where farming is done mostly on a subsistence level, and farmers sell crops as and when they need cash. Thus, farmers may be food secure but not have a high net farm income or high consumption expenditure. Our analysis extends previous studies that have focused on other proxies of household welfare such as net farm income, net crop income and consumption expenditure (Kassie et al. 2013; Teklewold et al. 2013a; Manda et al. 2016; Bopp et al. 2019; Oyetunde Usman et al. 2020; Ehiakpor et al. 2021). Secondly, we employ a multinomial endogenous switching regression model to mitigate selection bias. In particular, this model helps address the selection bias issues arising from observed factors (e.g., age, gender and education) and unobserved factors (farmers' innate ability in innovation adoption and motivations to address external shocks). Findings from the study will aid in formulating specific policies targeted at improving SAP adoption and enhancing the food security status of farm households in developing countries.

The remaining sections of the paper are as follows; "Literature review" section covers a review of relevant literature. The methodology is presented in "Methodology" section. The descriptive and empirical results are presented and discussed in "Results and discussions" section. The final section highlights the conclusions and policy implications of the findings.

Literature review

A growing number of studies have explored the factors that determine the adoption of SAPs in Africa. In the past, most of the works have focused on single components of SAPs (Abdulai and Huffman 2014; Carrión Yaguana et al. 2015; Fisher et al. 2015; Adenle et al. 2019; Manda et al. 2020a; Martey et al. 2020; Kimathi et al. 2021; Lampteym 2022). For example, Abdulai and Huffman (2014) reported that rice farmers' decisions to adopt soil and water conservation are influenced by their education, capital and labour constraints, social networks, extension contacts, and farm soil conditions. Manda et al. (2018) found that farmers' decisions to adopt improved maize varieties are mainly influenced by education, household size, livestock holdings, land per capita, market information, and locations in Zambia. The study by Martey et al. (2020) reveals that farmers' adoption of drought-tolerant maize varieties is mainly determined by access to seed, gender, access to extension, labour availability and location of the farmer in Ghana. Kimathi et al. (2021) investigated farmers' decisions to adopt climate-resilient potato varieties and found that the main factors affecting adoption were access to information, quality seeds, training, group membership and variations in agro-ecological zones.

Some studies have also explored the factors affecting smallholder farmers' decisions to adopt multiple SAPs. Most of the past works have been focused on Eastern and Southern Africa (Teklewold et al. 2013a; Kassie et al. 2015; Cecchini et al. 2016; Bese et al. 2021; Nonvide 2021), though a growing number of studies seek to bridge the research gap in the adoption of multiple SAPs in West Africa (Nkegbe and Shankar 2014; Struik et al. 2014; Ehiakpor et al. 2021; Faye et al. 2021). The multiple SAPs considered by Teklewold et al. (2013a) include maize–legume rotation, conservation tillage, animal manure use, improved seed, and inorganic fertiliser use. They showed that a household's trust in government support, credit constraints, spouse education, rainfall and plot-level disturbances, household wealth, social capital and networks, labour availability, plot and market access are the main factors determining both the probability and the extent of adoption of SAPs in rural Ethiopia. In their investigation for Ghana, the multiple SAPs considered by Ehiakpor et al. (2021) include improved maize seeds, maize-legume rotation, animal manure, legume intercropping, crop residue retention, zero/minimum tillage, integrated pest management, and chemical fertilizer. Non-farm income, livestock ownership, pest and disease prevalence, farmers' experience of erosion, farmers' perception of poor soil fertility, participation in field demonstration, membership of saving groups, access to agricultural credit, plot ownership, and distance to the agricultural input market are found to be important determinants of adoption of SAPs (Ehiakpor et al. 2021).

Studies estimating the impacts of SAP have utilized various outcome variables, such as household income, agrochemical use, demand for labour, crop yields, food security (Teklewold et al. 2013b; Abdulai and Huffman 2014; Gebremariam and Wünscher 2016;

Manda et al. 2016; Amondo et al. 2019; Marenya et al. 2020; Oduniyi and Chagwiza 2021). Gebremariam and Wünscher (2016) found that higher combinations of SAPs led to higher payoff measured by net crop income and consumption expenditure in Ghana. Khonje et al. (2018) showed that joint adoption of multiple SAPs had higher impacts on yields, household income and poverty than the adoption of components of the technology package in Zambia. Amondo et al. (2019) found that adopting drought-tolerant maize varieties increases maize yield by 15% in Zambia. Marenya et al. (2020) concluded that a higher number of SAPs adopted resulted in higher maize grain yield and maize income in Ethiopia. The adoption of elements of SAPs has been said to be context-specific because there are no blueprints of the various combination of SAPs that work in every environment. Therefore, this study explores how SAP adoption affects farm income and food security, using Ghana as a case.

Methodology

Smallholder farmers make decisions to adopt SAPs in response to external shocks such as drought, erosion, perceived decline in soil fertility, weeds, pests, and diseases. Both observed factors (e.g., age, gender, education and farm size) and unobserved factors (e.g., farmers' innate abilities and motivations) may affect their decisions when choosing to adopt a single SAP or a package (Kassie et al. 2013; Teklewold et al. 2013a; Manda et al. 2016; Ehiakpor et al. 2021). Due to the self-selection nature of technology adoption, farmers without adopting any SAPs and those adopting a single SAP or package may be systematically different. The fact results in a selection bias issue, which should be addressed for consistently estimating the effects of SAP adoption.

When technology adoption has more than two options, previous studies have used either the multi-valued treatment effects (MVT) model (Cattaneo 2010; Ma et al. 2021; Czyżewski et al. 2022) or the multinomial endogenous switching regression (MESR) model (Kassie et al. 2015; Oparinde 2021; Ahmed 2022) to address the selection bias issues. For example,Czyżewski et al. (2022) estimated the long-term impacts of political orientation (economic views and individual value systems) on the environment using the MVT model. They confirmed that local orientation is conducive to long-term environmental care. Using the MESR model, Ahmed (2022) evaluated the impact of improved maize varieties and inorganic fertilizer on productivity and wellbeing. He found that combining the two technologies significantly boosts maize yield and consumption expenditure than adopting the technologies in isolation. Because of the non-parametric nature, the MVT model can only address the observed selection bias and does not account for unobserved section bias. In comparison, the MESR model can help mitigate selection bias issues arising from both observed and unobserved factors, and thus, it is employed in this study.

Multinomial endogenous switching regression

The MESR model estimate three stages. The first stage models factors affecting smallholder farmers' decisions to adopt a specific SAP technology or a package. Following Teklewold et al. (2013a), this study focuses on three main SAP technologies, namely improved seeds (I), fertilizer (F), and soil and water conservation (cereal-legume rotation/cereal – legume intercropping, manure use, organic input use) (S). The three categories result in eight possible choices of SAPs. It bears an emphasis here that because of the small number of observations in the group that captures the combination of improved seed and fertilizer (26 samples) and the group that captures the combination of improved seed and soil and water conservation (9 samples), we combined them in empirical estimations. Also, it is worth noting here that no household has only adopted improved seed. These facts indicate that there are six mutually exclusive choices of SAP technology, including (1) non-adoption ($I_0F_0S_0$); (2) fertilizer only ($I_0F_1S_0$); (3) soil and water conservation only ($I_0F_0S_1$); (4) combination of improved seed and fertilizer and combination of improved seed and soil and water conservation ($I_1F_1S_0$); (5) combination of fertilizer and soil and water conservation ($I_0F_1S_1$); (6) combination of improved seed, fertilizer, and soil and water conservation ($I_1F_1S_1$). Farmers choose one of the six possible choices to maximize the expected benefit.

The study assumes that the error terms are identical and independently Gumbel distributed, the probability that farmer *i*, with *X* characteristics will choose package *j*, is specified using a multinomial logit model (McFadden 1973; Teklewold et al. 2013a; Zhou et al. 2020; Ma et al. 2022b). It is specified as follows:

$$P_{ij} = \Pr\left(\eta_{ij} < 0|X_i\right) = \frac{\exp\left(X_i\beta_j\right)}{\sum_{m=1}^{J} \exp\left(X_i\beta_m\right)} \tag{1}$$

where P_{ij} represents the probability that a farmer *i* chooses to adopt SAP technology *j*. X_i is a vector of observed exogenous variables that capture household, plot, and location-level characteristics. β_j is a vector of parameters to be estimated. The maximum likelihood estimation is used to estimate the parameters of the latent variable model.

In the second stage, the ordinary least square (OLS) model is used to establish the relationship between the outcome variables (farm income and food security) and a set of exogenous variables denoted by *Z* for the chosen SAP technology. Non-adoption of SAPs (i.e., base category, $I_0F_0S_0$) is denoted as $j=1$, with the other combinations denoted as ($j=2$ …, 6). The possible equations for each regime is specified as:

$$\begin{cases} \text{Regime } 1: Q_{i1} = Z_i\alpha_1 + u_{i1} \quad \text{if} \quad I = 1 & \text{(2a)} \\ \vdots \\ \text{Regime } J: Q_{iJ} = Z_i\alpha_J + u_{iJ} \quad \text{if} \quad I = J & \text{(2b)} \end{cases}$$

where *I* is an index that denotes farmer *i*'s choice of adopting a type of SAP technology; $Q_i$is the outcome variables for the *i*-th farmer; Z_i is a vector of exogenous variables; α_1 and α_J are parameters to be estimated; u_{i1} and u_{iJ} are the error terms.

Relying on a vector of observed covariates, captured by Z_i, Eqs. (2a) and (2b) can help address the observed selection bias issue. However, if the same unobserved factors (e.g., farmers' motivations to adopt SAPs) simultaneously influence farmers' decisions to adopt SAPs and outcome variables, the error terms in Eqs. (2a) and (2b) and the error term in Eq. (1) would be correlated. In this case, unobserved selection bias occurs. Failing to address such type of selection bias would generate biased estimates. Within the MESR framework, the selectivity correction terms are calculated after estimating Eq. (1) and then included into Eqs. (2a) and (2b) to mitigate unobserved selection bias. Formally, Eqs. (2a) and (2b) can be rewritten as follows:

$$\begin{cases} \text{Regime 1}: Q_{i1} = Z_i\alpha_1 + \lambda_1\sigma_1 + \omega_{i1} \quad \text{if} \quad I = 1 & \text{(3a)} \\ \vdots \\ \text{Regime } J: Q_{iJ} = Z_i\alpha_J + \lambda_J\sigma_J + \omega_{iJ} \quad \text{if} \quad I = J & \text{(3b)} \end{cases}$$

where Q_i and Z_i are defined earlier; λ_1 and λ_J are selectivity correction terms used to address unobserved selection bias issues; σ_1 and σ_J are covariance between error terms in Eqs. (1), (2a) and (2b). In the multinomial choice setting, there are $J-1$ selectivity-correction terms, one for each alternative SAP combination.

For consistently estimating the MESR model, at least one instrumental variable (IV) should be included in X_i in the MNL model but not in the Z_i in the outcome equations. In this study, two distance variables, distance to weekly market and minutes 30 to the plot, are employed as IVs for model identification purposes. Distance to the weekly market is measured as a continuous variable, measured in minutes. The variable representing minutes 30 to plot is a dummy variable, which equals 1 if the plot is within 30 min from the homestead and 0 otherwise. The two IVs are not expected to affect farm income and food security directly. We checked the validity of the IVs by running the Falsification test and conducting the correlation coefficient analysis (Pizer 2016; Liu et al. 2021; Ma et al. 2022a). For the sake of simplicity, we did not report the results.

The average treatment effect on the treated (ATT) is calculated at the third step. This involves comparing the expected outcomes (farm income and food security) of SAP adopters and non-adopters, with and without adoption. Using experimental data, it is easier to establish impacts; however, this study is based on observational cross-sectional data, thus making impact evaluation a bit challenging. The challenge is mainly estimating the counterfactual outcome, i.e. the outcome of SAP adopters if they had not adopted the SAP technology. Following previous studies (Kassie et al. 2015; Oparinde 2021; Ahmed 2022), the study estimates ATT in the actual and the counterfactual scenarios using the following equations:

The outcome variables for SAP adopters with adoption (observed):

$$\begin{cases} E(Q_{i2}|I = 2) = Z_i\alpha_2 + \sigma_2\lambda_2 & \text{(4a)} \\ \vdots \\ E\left(Q_{iJ}|I = J\right) = Z_i\alpha_J + \sigma_J\lambda_J & \text{(4b)} \end{cases}$$

The outcome variables for SAP adopters had they decided not to adopt (Counterfactual):

$$\begin{cases} E(Q_{i1}|I = 2) = Z_i\alpha_1 + \sigma_1\lambda_2 & \text{(5a)} \\ \vdots \\ E(Q_{i1}|I = J) = Z_i\alpha_1 + \sigma_1\lambda_J & \text{(5b)} \end{cases}$$

The difference between Eqs. (4a) and (5a) or Eqs. (4b) and (5b) is the ATT. For example, the difference between Eqs. (4a) and (5a) is given as:

$$\text{ATT} = E[Q_{i2}|I = 2] - E[Q_{i1}|I = 2] = Z_i(\alpha_2 - \alpha_1) + \lambda_2(\sigma_2 - \sigma_1) \tag{6}$$

Data and variables

The study used data collected by IITA for their Africa RISING project (https://africa-rising.net/) in the three northern regions, namely, Northern, Upper East, and Upper West regions. The data was collected in 2014 from 1284 households operating approximately 5500 plots in 50 rural communities in northern Ghana. The baseline survey used a stratified two-stage sampling technique, and data was collected using Computer Assisted Personal Interviewing (CAPI) supported by Survey CTO software on tablets (Tinonin et al. 2016). A structured questionnaire was used to conduct the household interviews. The data covers the various SAP technologies, demographic characteristics, agricultural land holdings, crop outputs and sales, livestock production, farmers' access to agricultural information and knowledge, access to credit and markets, household assets, and income.

The outcome variables for this study are farm income and food security. The farm income of crops cultivated is obtained by valuing the yield of crops at market price and deducting the costs of all variable inputs. Two variables capture food security, including reduced coping strategy index (rCSI) and household dietary diversity (HDD). Specifically, the rCSI is an index that is measured by scoring coping strategies households use (and frequency of use) when they experience food insecurity. rCSI is an index with five standardized questions on the coping strategies used when faced with food insecurity, the more strategies used, and food insecure the household is. The rCSI score ranges from 0 to 63. A higher level of rCSI score means a higher level of food insecurity. The HDD variable is based on the diverse food groups a household consumes. The higher the score, the more diverse the diet of a household, and the more food secure the household is. Drawing upon previous empirical studies on the adoption of SAPs and related agricultural innovations (Kassie et al. 2013; Teklewold et al. 2013a; Manda et al. 2016; Bopp et al. 2019; Oyetunde Usman et al. 2020; Ma and Wang 2020; Ehiakpor et al. 2021; Pham et al. 2021), we have identified and selected a range of control variables that may influence the adoption of SAPs. These include age, gender, education, marital status, household size, farm size, off-farm income, Africa RISING member, extension, extension satisfaction, number of crops, drought and floods, market access, sandy soil, clay soil, flat slope, moderate to steep, and location dummies.

Results and discussions

Descriptive results

Table 1 shows the frequency of respondents that used the different categories of SAPs. Of the eight possible categories of SAPs initially specified, 6.78% of farmers in our sample did not adopt any SAPs ($I_0F_0S_0$). No farmers adopted imported seed only ($I_1F_0S_0$), while only 9 farmers combined improved seed and soil and water conversation as SAPs ($I_1F_0S_1$). Only 26 farmers combined improved seed and soil and water conservation as SAPs ($I_1F_1S_0$). Therefore, as discussed earlier, we merged $I_1F_1S_0$ and $I_1F_0S_1$ into one group (coded as $I_1F_1S_0$), and the empirical analysis includes six groups in total. Table 1 also shows that more than half of the farmers in our sample (51.17%) combined fertilizer and soil and water conservation as SAPs. Around 7% of farmers adopted all the three identified SAPs.

Table 2 presents the variables and statistical descriptions. It shows that the average farm income is 2561 GHS (roughly 400 USD). The average means of rCSI and HDD, which capture food security, are 5.576 and 7.799, respectively. Table 2 also shows that the average age of respondents was about 48 years. Around 84% of respondents are male, and almost 90% of respondents got married. The surveyed households averagely have

Table 1 Different SAP categories

SAPs	Category details	Frequency	Percentage	Cumulative percentage
$I_0F_0S_0$	None of the SAPs (base category)	87	6.78	6.78
$I_1F_0S_0$	Improved seed only	0	0	6.78
$I_0F_1S_0$	Fertilizer only	215	16.74	23.52
$I_0F_0S_1$	Soil and water conservation only	198	15.42	38.94
$I_1F_1S_0$	Improved seed and fertilizer	26	2.02	40.96
$I_1F_0S_1$	Improved seed and soil and water conservation	9	0.70	41.66
$I_0F_1S_1$	Fertilizer and Soil and water conservation	657	51.17	92.83
$I_1F_1S_1$	All the SAPs categories (Improved seed, fertilizer, and soil and water conservation)	92	7.17	100
Total		1284	100	

We merged $I_1F_1S_0$ and $I_1F_0S_1$ into one group (coded as $I_1F_1S_0$) in the empirical analysis due to small sample sizes

Table 2 Variables and statistical descriptions

Variables	Description	Mean	SD
Dependent variables			
Farm income	Gross margin of farm production in Ghana Cedis (1000 GHS)	2.561	12.378
rCSI	Reduced Coping strategy index	5.576	10.516
HDD	Household dietary diversity	7.799	2.094
Control variables			
Age	Age of household head (HH) in years	47.759	14.493
Gender	1 if HH is male and 0 otherwise	0.842	0.365
Education	Number of years of education	2.178	4.429
Marital status	1 if HH is married and 0 otherwise	0.893	0.309
Household size	Number of people in a household	8.529	5.064
Farm size	Hectares of land that household cultivated	3.330	3.522
Off-farm income	Income acquired from off-farm work in Ghana Cedis (100 GHS)	1.103	2.266
Africa RISING member	1 if member in AfricaRISING farmer group and 0 otherwise	0.611	0.489
Extension	1 if a farmer receives advice from an extension officer and 0 otherwise	0.609	0.488
Extension satisfaction	1 if household is satisfied with the extension agent and 0 otherwise	0.456	0.498
Number of crops	Number of crops cultivated in the cropping season	4.040	1.871
Drought and floods	1 if household experienced drought in the previous season and 0 otherwise	0.621	0.485
Market access	1 if farmer has access to market and 0 otherwise	0.704	0.457
Sandy soil	1 if farmer perceives soil as sandy and 0 otherwise	0.137	0.344
Clay soil	1 if farmer perceives soil as clay and 0 otherwise	0.238	0.426
Flat slope	1 if farmer perceives plots as having a flat slope and 0 otherwise	0.910	0.286
Moderate to steep	1 if farmer perceives plot as having a moderate slope and 0 otherwise	0.077	0.267
Northern	1 if household is in the Northern region and 0 otherwise	0.478	0.500
Upper east	1 if household is in the Upper East region and 0 otherwise	0.173	0.378
Upper west	1 if household is in the Upper West region and 0 otherwise	0.349	0.480
Instrumental variables			
Distance to weekly market	Minutes	31.277	25.736
Minutes 30 to plot	1 if the distance between plot and homestead is within 30 min and 0 otherwise	0.547	0.498

around 9 persons. About 61% of respondents received advice from extension officers, and 45.6% were satisfied with the extension services. Approximately 70% of respondents had accessed the markets.

Empirical results

Determinants of adoption of SAP categories

Table 3 presents the results estimated by the MNL model, demonstrating the factors that influence smallholder farmers' decisions to adopt different SAPs categories. Farmers without adopting any type of SAPs (i.e. $I_0F_0S_0$) are used as the reference group in empirical estimations. Because the primary objective of the MNL model estimations is to calculate the selectivity correction terms rather than explain the determinants of SAP adoption perfectly, we explain the results of Table 3 briefly. The results show gender variable has significant coefficients in columns 2, 4 and 5. Our results appear to suggest that women are more likely to combine improved seeds and fertilizer ($I_1F_1S_0$) as SAPs to increase farm productivity. In comparison, men are more likely to rely on fertilizer ($I_0F_1S_0$) or combine fertilizer and soil and water conservation technology ($I_0F_1S_1$) as SAPs to improve farm performance. Our findings are largely supported by the previous studies (Smale et al. 2018; Paudel et al. 2020; Tambo et al. 2021), reporting gendered differences in agricultural technology adoption. For example, Smale et al. (2018) found that women are more likely to adopt improved seeds on the plots they manage in Sudan. Education has positive impacts in all estimated specifications but is only statistically significant in the specification of adopting improved seed and fertilizer ($I_1F_1S_0$). Better education enables farmers to be aware of the benefits of SAPs and motivate them to adopt them, especially productivity-enhancing technologies such as improved seed and fertilizer. This finding is consistent with the findings of Kassie et al. (2014) for Tanzania and Gebremariam and Wünscher (2016) for Ghana.

The significant coefficients of household size in columns 2 and 6 suggest that larger households are more likely to adopt multiple SAPs ($I_1F_1S_1$) but are less likely to adopt single SAP such as fertilizer ($I_0F_1S_0$). Larger households usually mean better labour endowments, allowing them to adopt multiple SAPs more easily than small ones. This is consistent with the findings of Kassie et al. (2014). Off-farm income has positive and significant coefficients in columns 3, 5 and 6. The findings suggest that farmers receiving a higher level of off-farm income are more likely to adopt fertilizer only ($I_0F_1S_0$), combine fertilizer and soil and water conservation as SAPs ($I_0F_1S_1$), and adopt all three SAPs ($I_1F_1S_1$). Additional income from off-farm activities can help release credit constraint issues, allowing farmers to invest in innovative technologies such as SAPs to improve farm performance. In their study for Pakistan, Kousar and Abdulai (2016) found that participation in off-farm work increases farmers' adoption of soil conservation measures.

The African RISING member variable has a positive and statistically significant impact on farmers' fertiliser adoption only ($I_0F_1S_0$), the combination of improved seed and fertilizer ($I_1F_1S_0$), and the combination of fertilizer and soil and water conservation ($I_0F_1S_1$). The importance of farmer-based organisations in promoting the adoption of innovative technologies has been widely discussed in the literature (Zhang et al. 2020; Manda et al. 2020b; Yu et al. 2021). For example, Manda et al. (2020a, b) reported that membership

Table 3 MNL estimates of SAP adoption

Variables	$I_0F_1S_0$	$I_0F_0S_1$	$I_1F_1S_0$	$I_0F_1S_1$	$I_1F_1S_1$
Age	0.004 (0.009)	0.012 (0.010)	0.011 (0.015)	0.010 (0.009)	0.005 (0.011)
Gender	0.174* (0.358)	0.601 (0.361)	− 0.541** (0.507)	0.804*** (0.338)	0.422 (0.456)
Education	0.239 (0.138)	0.127 (0.141)	0.567** (0.210)	0.153 (0.130)	0.200 (0.172)
Marital status	− 0.543 (0.454)	− 1.258*** (0.428)	− 0.722 (0.647)	− 0.661 (0.422)	− 0.705 (0.567)
Household size	− 0.019* (0.334)	0.323 (0.338)	0.227 (0.479)	0.381 (0.309)	0.919** (0.402)
Farm size	0.896 (0.391)	0.365 (0.407)	0.822 (0.505)	0.662 (0.374)	0.786 (0.460)
Off-farm income	0.101 (0.057)	0.053** (0.058)	0.057 (0.089)	0.143* (0.055)	0.240** (0.074)
Africa RISING member	0.816* (0.300)	0.748** (0.308)	0.656 (0.459)	1.443*** (0.284)	1.363 (0.400)
Extension	0.868* (0.289)	0.075*** (0.292)	1.057 (0.462)	0.664 (0.268)	1.237** (0.367)
Extension satisfaction	0.033 (0.299)	− 0.025 (0.299)	0.433 (0.442)	0.185 (0.282)	0.749*** (0.357)
Number of crops	− 0.488*** (0.461)	0.337 (0.454)	− 0.024 (0.732)	0.834*** (0.422)	1.576*** (0.564)
Drought and floods	0.326 (0.289)	0.078 (0.286)	0.933 (0.475)	0.368 (0.261)	0.247 (0.373)
Market access	0.661** (0.308)	− 0.244*** (0.292)	0.217 (0.480)	0.424 (0.274)	0.455 (0.378)
Sandy soil	0.206** (0.614)	1.082 (0.583)	0.158 (0.905)	1.191*** (0.572)	0.715 (0.659)
Clay soil	0.623 (0.415)	0.524 (0.408)	0.951 (0.542)	0.569 (0.389)	1.298*** (0.442)
Flat slope	0.159** (0.540)	− 0.441 (0.490)	− 0.629 (0.840)	− 0.711** (0.454)	− 0.599 (0.621)
Moderate to steep	− 0.989* (0.729)	0.009 (0.637)	− 0.451 (1.280)	− 0.034 (0.604)	0.090 (0.707)
Northern	0.124*** (0.382)	0.572 (0.360)	− 0.691*** (0.558)	1.235*** (0.345)	0.584 (0.447)
Upper East	0.805** (0.470)	1.494 (0.466)	− 0.647** (0.941)	1.722*** (0.431)	1.134 (0.590)
Distance to weekly market	0.149*** (0.143)	− 0.183* (0.140)	− 0.028 (0.195)	− 0.093 (0.132)	− 0.236** (0.152)
Minutes 30 to plot	0.146*** (0.268)	− 0.299 (0.267)	0.177 (0.451)	− 0.374** (0.247)	− 0.414 (0.320)
Constant	− 1.970 (1.234)	− 0.625 (1.207)	− 3.274* (1.812)	− 3.359*** (1.147)	− 7.725*** (1.435)

Robust standard errors in parentheses; ***$p<0.01$; **$p<0.05$; *$p<0.1$; Upper West is used as the reference region

We checked the Independence of Irrelevant Alternatives (IIA) assumption using the Stata command "*mlogtest, iia*" after estimating the MNL model. The results show that adding or deleting alternative outcome categories does not affect the odds among the remaining outcomes, confirming the validity of our MNL model estimates

in agricultural cooperatives increases the adoption speed of improved maize by 1.6–4.3 years. We show that farmers having access to extension services are more likely to adopt SAPs, including fertilizer only ($I_0F_1S_0$), soil and water conservation only ($I_0F_0S_1$), and all three SAps ($I_1F_1S_1$). In their studies for Nepal, Suvedi et al. (2017) found that farmers' participation in extension programs increases their adoption of improved crop varieties. This finding is further confirmed by Nakano et al. (2018), who found that farmer-to-farmer training through extension programs enhance farmers' adoption of technologies (e.g., fertilizer and improved bund) in Tanzania. The location dummies are statistically significant in columns 2, 4 and 5. Our findings suggest that relative to farmers living in Upper West (reference group), those residing in Northern and Upper East are more likely to adopt fertilizer only ($I_0F_1S_0$) and a combination of fertilizer and soil and water conservation ($I_0F_1S_1$), but less likely to adopt the combination of improved seeds and fertilizer ($I_1F_1S_0$). Our findings confirm spatial-fixed characteristics (e.g., social-economic conditions, resource endowments, climate conditions, and institutional arrangements) may also affect smallholder farmers' decisions to adopt SAPs and highlight the importance of including them in estimations.

Average treatment effects of SAPs

Table 4 presents the results estimating the treatment effects of SAP adoption on farm income and food security. For the sake of brevity, we do not present and discuss the results estimated by the OLS regression model but are available upon reasonable requests. Our ATT estimate results in Table 4 record differentiated findings regarding the impacts of adopting only one SAP technology on farm income and food security, measured by rCSI score and HDD score. Specifically, adopting only fertilizer ($I_0F_1S_0$) significantly reduces rCSI score and improves HDD score. The ATT estimates indicate that fertilizer adoption only ($I_0F_1S_0$) decreases rCSI score by 42% and increases the HDD score by 6.5%. We find that fertilizer adoption only ($I_0F_1S_0$) decreases farm income. A possible reason could be the improper use of fertilizer by smallholder farmers, such as using lower than recommended amounts of fertilizer; hence they do not achieve the maximum potential output expected.

Adoption of SAP package that combines improved seed and fertilizer ($I_1F_1S_0$) improves food security significantly. The ATT estimates show that $I_1F_1S_0$ adoption reduces rCSI score by 45% and increases HDD score by 4%. However, $I_1F_1S_0$ adoption decreases farm income, a finding that is largely consistent with the finding of Ma and Wang (2020), showing that SAP adoption significantly decreases farm income in China. Adoption of SAP package that combines fertilizer and soil and water conservation ($I_0F_1S_1$) increases farm income and improves food security. We show that $I_0F_1S_1$ adoption increases farm income by 12%, reduces rCSI score by 23%, and improves HDD score by 5%.

Table 4 Treatment effects of SAP adoption on farm income and food security

Outcome variables	SAP categories	Adopting (1)	Non-adopting (2)	ATT (3) = (1)–(2)
Farm income (ln)	$I_0F_1S_0$	4.015 (0.119)	4.760 (0.167)	− 0.744 (0.163)***
	$I_0F_0S_1$	4.672 (0.124)	4.611 (0.228)	0.613 (0.215)
	$I_1F_1S_0$	4.593 (0.531)	5.505 (0.367)	− 0.912 (0.504)*
	$I_0F_1S_1$	4.733 (0.062)	4.216 (0.114)	0.517 (0.108)***
	$I_1F_1S_1$	4.522 (0.227)	3.698 (0.351)	0.824 (0.386)**
rCSI	$I_0F_1S_0$	3.247(0.242)	5.604 (0.536)	− 2.357 (0.533)***
	$I_0F_0S_1$	8.984 (0.468)	9.331 (1.097)	− 0.346 (0.973)
	$I_1F_1S_0$	6.086 (2.267)	4.184 (1.301)	1.901 (2.632)
	$I_0F_1S_1$	5.247 (0.121)	6.859 (0.434)	− 1.596 (0.389)***
	$I_1F_1S_1$	4.217 (0.575)	8.891 (1.786)	− 4.674 (1.543)***
HDD	$I_0F_1S_0$	8.381 (0.065)	7.870 (0.086)	0.512 (0.109)***
	$I_0F_0S_1$	6.787 (0.087)	7.466 (0.113)	− 0.678 (0.121)***
	$I_1F_1S_0$	8.200 (0.284)	7.893 (0.211)	0.307 (0.316)
	$I_0F_1S_1$	7.885 (0.035)	7.477 (0.062)	0.408 (0.074)***
	$I_1F_1S_1$	7.804 (0.130)	6.871 (0.231)	0.933 (0.219)***

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

The ATT estimates show that adopting all the three SAPs ($I_1F_1S_1$) positively and statistically impacts farm income and food security. The impact magnitudes of adopting all the three SAPs are larger than that of adopting single or two SAPs. Specifically, the $I_1F_1S_1$ adoption increases farm income by 23%, reduces rCSI score by 53%, and improves HDD score by 14%. Our results are largely supported by the previous studies (Teklewold et al. 2013a; Manda et al. 2016; Oduniyi and Chagwiza 2021), pointing out that adopting multiple SAPs has larger impacts on welfare measures than adopting only one or two SAPs. For example, Teklewold et al. (2013b) showed that multiple SAP adoption significantly increases household income in Ethiopia. Oduniyi and Chagwiza (2021) found that adopting sustainable land management practices increases the food security of smallholder farmers in South Africa.

Conclusions and policy implications

Many institutions have credited sustainable agricultural practices (SAPs) as a viable solution that helps tackle the worlds' feeding problems and worsening environmental issues. This study used a multinomial endogenous switching regression (MESR) to investigate factors that affect smallholder farmers' decisions to adopt different categories of SAPs and estimate the effects of the adoption on farm income and food security. In particular, we used two measures, including rCSI score and HDD score, to capture food security. We estimated the data collected by IITA for their Africa RISING project in Ghana.

The MNL results showed that farmers' decisions to adopt SAPs are influenced by the social demographics of the households (e.g., gender, education, marital status, and household size), plot-level characteristics (e.g., number of crops, soil types, and topography), extension services, and locations. The study also recorded differentiated findings regarding the impacts of adopting only one or two SAPs on farm income and food security. For example, adopting only fertilizer significantly reduces rCSI score and improves HDD score, but it unexpectedly decreases farm income. Adoption of SAP package that combines improved seed and fertilizer significantly improves food security measures, but it also decreases farm income. Nevertheless, we found that adopting all the three SAPs positively and statistically impacts farm income and food security. The impact magnitudes of adopting all the three SAPs are larger than that of adopting single or two SAPs.

The study highlights that policies that improve the extension agents to farmer ratio should be pursued since access to extension positively influenced the adoption of SAPs. The satisfaction with the extension agent variable positively influenced the adoption of all the SAPs. This highlights the need to improve the quality of extension service to minimize the risk of adoption due to inadequate information transfer. Membership in farmer-based organizations (FBOs) such as Africa RISING positively influenced the adoption of different packages of SAPs. Therefore farmers should be encouraged to join FBOs, and similar organizations should be established or strengthened to enhance the dissemination of information regarding SAPs. Policies to improve farmer income and food security should advocate for the comprehensive adoption of all the SAPs packages and provide incentives to motivate the adoption of all SAPs packages.

Acknowledgements
The authors gratefully acknowledge the financial support from NZAID scholarship from MFAT and Lincoln university research fund. We want to thank IITA and IFPRI for making the data from the Africa RISING Project readily accessible. We also want to thank Dr. Gideon Danso-Abbeam for his helpful comments and suggestions.

Authors' contributions
All authors read and approved the final manuscript.

Funding
No funding was received in the carrying out of this research.

Availability of data and materials
Data is available from the leading author upon the reasonable request.

Declarations

Competing interests
The authors declare there is no conflict of interest.

Received: 7 September 2021 Revised: 5 February 2022 Accepted: 4 March 2022
Published online: 15 March 2022

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