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Determinants of adoption of multiple sustainable agricultural practices among smallholder farmers in Nigeria

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A B S T R A C T

Despite the important roles of Sustainable Agricultural Practices (SAPs) in improving productivity, welfare, and food security of farming households, the adoption rates of SAPs have been perceived to be generally low, especially in developing countries. Using cross-sectional data collected from the 2015 Nigeria General Household Survey, this study examines the factors influencing the adoption of multiple SAPs, while also considering the drivers of the intensity of adoption of these practices. The methods of data analysis are based on the Multivariate probit and the Ordered probit models. The SAPs considered include improved seeds, inorganic fertilizer, mixed-cropping techniques, and organic manure. The empirical results show that farmers' adoption of different SAPs and their intensity of use depend significantly on factors such as the age of household head, gender, education, household size, access to extension services, and household wealth status. Our findings imply that policymakers and agricultural development agencies should seek to maintain or increase household asset bases, and encourage both formal and informal training programme among farming households to facilitate the adoption of SAPs.

1. Introduction

There is no doubt that the global agricultural food system is facing unprecedented shocks in recent times largely due to climate change that usually results in uncertainty in production and constitute threats to yield and welfare of farmers, especially smallholder farmers in Sub-Saharan Africa (SSA) whose livelihood strongly depends on agriculture. For example, the manifestation of midseason droughts in terms of low and inconsistent rainfall pattern can cause harm to maize at the productive and vegetative stages, resulting in complete harvest failure or yield loss (Daryanto et al., 2016) which may have a serious implication on food security and welfare of farmers. In response to these unprecedented shocks from climate change impacts, policymakers and development agencies have promoted interventions targeted at the development, dissemination, and adoption of sustainable agricultural practices (SAPs) across SSA. Examples of these practices include soil and water conservation practices in Zambia (Arslan et al., 2014) and improved seed varieties in Nigeria (Abdoulaye et al., 2018; Olagunju et al., 2019). The impacts of the adoption of SAPs have been widely linked to improved productivity, welfare, and food security across SSA (Bezu et al., 2014; Simtowe et al., 2019). However, to date, adoption rates are generally low in SSA despite its multiple benefits (Abebe et al., 2013; Kagoya et al., 2018).

In reality, agricultural production in SSA countries is driven by multiple idiosyncratic and covariate risks that drive farm households to adopt multiple SAPs to counter impending production risks. A typical farm household is however subjected to making rational choices among multiple SAPs amidst diversified risk-driven multiple cropping systems on the combination of choices to adopt dependent on his or her attributes. As such, the adoption of a particular SAP may be dependent on the use of another. For example, most improved seed varieties are promoted in packages including fertilizer, irrigation, and pesticides (Emmanuel et al., 2016; Adebayo et al., 2018). This makes it quite important to control for the interdependence of SAPs in multiple adoptions to avoid underestimation or overestimation of factors influencing the adoption of agricultural SAPs (Wu & Babcock, 1998). There are increasing empirical studies that focused on examining the factors

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influencing the adoption of SAPs across SSA using this approach, these include studies in Kenya (Ndiritu et al., 2014; Wainaina et al., 2016); Ethiopia (Gebremariam & Tesfaye, 2018; Bedeke et al., 2019); and Southern Africa (Kassie et al., 2015).

Considerably, these studies justified the need for a better understanding of farmers' adoption behaviour to aid in designing propoor policies that could whet their adoption behaviours. Across these studies, socioeconomic, institutional, environmental, and climatic attributes influencing the adoption of multiple SAPs across SSA have been explored in various contexts. One key finding from these studies is that there is heterogeneity in factors of adoption, implying that adoption factors differ in terms of attributes of households considered, technology and locations.

The present study aims at examining the factors influencing multiple adoptions of SAPs among farming households in Nigeria. Our study makes significant contributions to the literature. Firstly, this study provides the first attempt to explicitly assess the predictors of adoption of multiple SAPs in Nigeria in the case of interactions of several socioeconomic and farm factors in a complex and diverse national agricultural setting. Second, our study adopts a comprehensive household data of Nigeria General Household data which is inclusive of households' agricultural data from the World Bank Living Standard Measurement Survey. We identified various SAPs choices adopted by households while recognising the interdependence between various SAPs considered. This is important for promoting effective policies to redefine strategies for promoting the adoption of agricultural innovations. Thirdly, we further question the limitation of assessing the probability of adoption without considering the intensity of use. Given that not every farm households can adopt all available SAPs as a result of variations in farming and livelihood contexts and, in reality, farm households combine SAPs in different numbers. In particular, our study seeks to address the following research questions: (1) What are the factors influencing the adoption of multiple SAPs at the farm household level? (2) what are the factors influencing the intensity of adoption?

2. Review of empirical studies

The adoption of multiple SAPs is unavoidable where farm households are exposed to multiple climatic shocks that may impact the expected productivity level. There is however bound to be conflicting or complementary choices for farm households subject to their households' perceived utility. Decisions in joint adoption vary heterogeneously and are well noted across SSA (Abdulai et al., 2011; Teklewold et al., 2013). Past studies have highlighted varying conflicting results of factors driving adoption based on the innovative agricultural types and location (Teklewold et al., 2013; Wainaina et al., 2016; Makate & Makate, 2019), thereby confirming the heterogeneity that exists in households' adoption behaviours. We explain the interactions of these attributes below as stated in past literature as a background to their relevance in this study.

In terms of human attributes, gender is an exemplary factor driving or constraining the adoption of SAPs. Within conservation packages, gender differences can exist in adoption. Also, in the mix of SAPs, differences in adoption decisions can be skewed to a particular class of SAP, for example in Theriault et al. (2017), female plot managers were less likely to adopt yield-enhancing (Inorganic fertilizer and or improved seed variety) and soil-restoring strategies (fungicide, herbicide/pesticide) however no differences in yield protecting strategies (e.g manure, compost, planting pits, etc). In the literary context, the variations in results per the gender variable adopted can also relate to the women population considered. For example, differentials exist in decisions to adopt considering female plot managers who are household heads and wives in male households (Peterman et al., 2010). In a similar finding by Doss and Morris (2000), the adoption rate of maize varieties for female farmers living in male-headed households was significantly higher than the rate for female farmers living in female-headed households.

Educated farm households expectantly should be enlightened about the evolution in modern practices and should adopt easily. However, results from joint adoption studies revealed diverse effects on adoption decisions with differing perspectives (Ndiritu et al., 2014; Wainaina et al., 2016). Also, conservation practices have been noted to be labour intensive in adoption studies. Household size is a quite notable proxy of labour supply that can as well influence adoption decisions. Some studies have found that Larger farm households are more likely to invest in the adoption of labour-intensive sustainable practices (Ndiritu et al., 2014). Proxies of households' assets signify wealth status and ease in purchasing modern varieties and employing labour for production activities. The adoption of agricultural innovations has been found significant in impacting livelihood through asset measurement as a proxy (Awotide et al., 2015). However, inequality in the adoption of SAPs can as well be related to wealth disparities. In the context of this study, we considered household assets value as a proxy to assess its interaction with identified SAPs. In various contexts in adoption studies, the role of SAPs in ensuring food security is well established in the literature (Kassie et al., 2015; Jaleta et al., 2018). At the same time, households' use of production practices is defined by their food security status (Oyetunde-Usman and Olagunju 2019). The food security status of households may be influencing adoption decisions in that food-insecure households may be willing to adopt portfolios of SAPs to improve productivity. Besides, the use of food security indicator as a factor of adoption is not quite common, in the context of this study, we adopted a subjective measure of households' food security status based on their access to healthy and nutritious food to assess how households' food security status interacts in joint adoption of improved seeds and conservative practices.

Extension institutions are usually endogenous in interventions and are foremost in promoting the adoption of modern varieties and conservation practices. Heterogeneity, however, exists in extension proxies in driving or constraining adoption. For example, in Makate et al., 2019, access to extension services varied according to the agricultural practices, while it drives adoption of conservation agriculture and improved legumes, it did not drive adoption of drought-tolerant maize varieties. Physical factors such as land are a key asset in households' agriculture and it is central to development policies (Goldstein & Udry, 2014). It is a productive resource for agricultural development and poverty reduction measures (Khonje et al., 2015) and it is relevant in fostering investment in agricultural growth for development gains (Lawry et al., 2014). In long term investment innovations such as conservation practices, land ownership drives adoption decisions while lack of it can preclude farmers from investing in agricultural innovations due to the risk of eviction (Abdulai et al., 2011; and Zeng et al., 2018). Further, variation exists in the role of land ownership in driving adoption (Wainaina et al., 2016; and Bedeke et al., 2019). Production shocks are positively associated with the adoption of agricultural innovations and various types of shocks interact heterogeneously with varying SAPs. For example in Gebremariam & Tesfaye, 2018, production shock was positively associated with the adoption of organic fertilizers, it constrained the adoption of chemical fertilizer and irrigation practices. Also, climatic variables such as temperature and rainfall can be determinants of the adoption of SAPs (Arslan et al., 2014).

3. Data and econometric framework

3.1. Data source

This study employs a dataset obtained from the Nigeria General Household Survey that was conducted in 2015 as part of the World Bank Living Standard Measurement Survey-Integrated Surveys on Agriculture (LSMS-ISA) project. This project supports the redesign and implementation of the General Household Survey and serves as a larger part of the regional project in sub-Saharan Africa. For Nigeria, it was carried out in partnership between the Nigeria Bureau of Statistics, the Federal Ministry of Agriculture and Rural Development (FMA&RD), the National Food Reserve Agency (NFRA), the Bill and Melinda Gates Foundation (BMGF), and the World Bank (WB). The key objectives include (i) to improve the production of household-level agriculture statistics linked with non-agriculture dimensions of household welfare and behaviour and (ii) to foster the dissemination and use of these data. In particular, the dataset was collected through a nationally representative survey of 5000 agricultural households, which are representative of the geopolitical and agro-ecological zones of Nigeria. It contains a wide range of detailed information on agricultural household and plot characteristics, topographical and climatic factors, as well as different Sustainable Agricultural Practices (SAPs). Following our data cleaning process, a total of 2113 agricultural households were used for analysis.

In this study, we considered four main categories of SAPs which are common among agricultural households in Nigeria. These include the use of high yielding hybrid and improved seeds, the use of inorganic fertilizers, adoption of mixed cropping, and use of organic manure. We incorporated different determining factors that may influence the adoption of various SAPs including socioeconomic, institutional, demographic, topographical, and climatic factors. Specifically, the factors considered in this study include age of household head, gender of household head, household size, land ownership status, formal education of at least 6 years, asset value, production shocks, access to extension services, distance from a market in kilometers, food insecurity index, annual mean temperature, annual mean precipitation, mean temperature of the wettest period.

3.2. Econometric framework

3.2.1. The Multivariate Probit Model

To assess the factors influencing the adoption of multiple SAPs, we rely on the assumption of interdependence of different SAPs, suggesting that the decision to adopt SAPs is inherently multivariate. Following the study conducted by Teklewold et al. (2013), we employed a Multivariate Probit Model (MVP) approach to assess the factors influencing the adoption of multiple SAPs at the farm households' level. Unlike other dichotomous models, the MVP model can account for unobservable factors that affect farm households' adoption decisions by allowing for correlation across error terms of latent equations (Belderbos et al., 2004). Such correlations allow error term for positive correlation (complementarity) and negative correlation (substitutability) between the various SAPs (Ndiritu et al., 2014; Bedeke et al., 2019).

In modelling this, we considered a random utility framework of a *jth* farm household $(j = 1.....,K)$ facing a decision to adopt or not adopt a set of interdependent SAPs $q(q = 1......Q)$. The utility U_a represents benefits derived by households from adopting traditional agricultural practices and U_b represents the benefits of adopting SAPs which in the context of this study include the adoption of improved seed (S), Organic manure (O), Inorganic fertilizer (I), and Mixed cropping practices (M). We further hypothesize that a *jth* household only chooses to adopt SAPs *b* on plot *q*, if the net benefit Y^*_{jqb}, a latent variable is greater than zero. This is illustrated thus:

$$Y^*_{jqb} = U^*_b - U_a > 0 \tag{1}$$

As such, the net benefit Y^*_{jqb} is determined by the households observed socioeconomic, plot, location, and climatic characteristics (X_{jq}) and the error term (ε_{jq}):

$$Y^*_{jqb} = X_{jq}\beta_b + \varepsilon_{jq} \tag{2}$$

where b = S, O, I, M.

The observed dichotomous outcome equation for each choice of SAPs adopted by households is given as:

$$Y_{jqb} = \begin{cases} 1 \text{ if } Y^*_{jqb} > 0 \\ 0 \text{ otherwise} \end{cases} \quad Where\ \ b = S, O, I, M \tag{3}$$

If the adoption of *b* types of SAPs are assumed to be interdependent or occur at the same time, the error term is assumed to jointly follow a multivariate normal distribution pattern with zero conditional mean and a unitary variance. The symmetric covariance matrix π is illustrated as follows:

$$\pi = \begin{Bmatrix} 1 & \delta SO & \delta SI & \delta SM \\ \delta OS & 1 & \delta OI & \delta OM \\ \delta IS & \delta IO & 1 & \delta IM \\ \delta MS & \delta MO & \delta MI & 1 \end{Bmatrix} \tag{4}$$

The off-diagonal elements in the covariance matrix represent the unobserved correlation between the error components of the different types of SAPs.

3.2.2. The ordered probit model

From our MVP model above, we conceptualised that before the adoption of one or more SAPs, a farm household compares the net benefit of adopting and not adopting and only chooses to adopt the new SAPs if the net benefit is greater than non-adoption. Farm households tend to adopt more SAPs if the household derives higher utility from the previous adoption. However, the MVP model is limited to estimating the intensity of adoption of SAPs. We considered assessing the extent of adoption by the numbers of SAPs adopted at the household levels. This concept is related to a Poisson count distribution model, however, a Poisson distribution contradicts our assumption of the interdependence of SAPs which renders it inappropriate.

Usually, a common analytical process of assessing the intensity of adoption is considering the proportion of land area as stipulated by some adoption studies (Arslan et al., 2014). As a result of data limitation on variables related to this, we, therefore, treated our dependent variable as an ordinal variable that follows categories of ordered outcomes, for example, households that adopt one, two, or more SAPs. Following Cameron and Trivedi (2010), our ordered outcomes are modelled sequentially as a latent variable y^*, where y^* is an underlying unobserved measure of households' adoption of SAPs in numbers and it is specified as follows:

$$y^*_i = X'_i B + u_i \tag{5}$$

For a *jth* farm household where normalization is that the regressors *x* do not include an intercept, for a low y^*, adoption of SAPs is low, for $y^* > 1$ number of SAPs increases, for $y^* > 2$, adoption increases further and this continues further. For *m* categories following a standard ordered probability model, the probability of observing outcome i corresponds to the following:

$$\Pr(outcome_j = i) = \Pr(K_{i-1} < X_i'\beta + u_i \leq \alpha_i) \quad (6)$$

where u_i is assumed to be normally distributed with a standard normal cumulative distribution function. The coefficients $\beta_1 \ldots\ldots \beta_k$ is jointly estimated with the cutpoints $\alpha_1, \alpha_2, \ldots, \alpha_{K-1},$ where k is the number of possible outcomes.

4. Results and discussions

4.1. Descriptive statistics

The description and summary statistics of these variables employed in this study are presented in Table 1. In many adoption studies, age is an important determinant of households' decisions to adopt agricultural innovations as this could indicate the level of experience in farming practices and use. From our findings, the average age of the household head is about 52 years signifying that, on average, farm households are still in their active farming years. However, age status has been reported to have a mixed effect on SAPs adoption (Nigussie et al., 2017). Further to this, very few (10%) of the households are headed by females. While this may suggest fewer female roles in the farming population, it does not cover the role of spouses of male-headed households who could be plot managers and can influence adoption decisions. On the other hand, the average household size is approximately 8 indicating a typical large family setting. Large family sizes are a feature of most agricultural settings in developing countries and signify possibilities of family labour use. In addition, depending on the type of SAPs, household size has been reported as a factor that is considered in households' decisions to adopt. By way of example, soil and water-conserving technologies require more labour needs and have been found positive in driving adoption (Gebremariam & Tesfaye, 2018), on the other hand, it can be negative in the adoption of similar practices (Amsalu & de Graaff, 2007). Households' statistics further revealed that 82% of households' heads had at least 6 years of formal education, however suggesting that majority of households' heads are educated and could have easy knowledge of farm practices and technological information uptake.

Also, 88% of households' heads are tenure secured, this may be as a result of ease of transfer rights similar to most countries in West Africa (Bambio and Bouayad Agha 2018). From our descriptive analysis, asset cost represents non-farm assets, in this context, households with higher asset cost is indicative of better welfare status and ability to purchase costlier agricultural technologies, similar proxies of wealth have been found positive in driving adoption of agricultural innovations (Teklewold et al., 2013; Arslan et al., 2014).

Incidentally, the adoption of SAPs is partly defined by impending idiosyncratic and covariant risk as expressed in various studies (Dercon & Christiaensen, 2011). In this study, we considered production shock which is a cogent factor of adoption and determines the mix of practices a farm household chooses to adopt. From our descriptive analysis, in a typical farming season, about 40% of farm households experienced one form of production shocks or the other. This significantly showed that households agriculture is risk-driven and suggests the possibilities of a higher mix of different agricultural innovative practices. Access to extension services plays significant roles in increasing awareness, demonstrating on-farm trials and practices, and influencing continued adoption. In this study, only 19% of farm households had access to this. It is apparent that access to extension services is still at its low peak and suggests a high perceived risk of adopting SAPs among farm households. Nonetheless, studies have reported a positive impact of access to extension services in driving the adoption of agricultural innovative practices (Wossen et al., 2017; Yigezu et al., 2018). From the result table, on average, the nearest major market is 62.98 km. Distance to the nearest major market can indicate households' ease of access to grain traders and other market networking relations. At the same time, increased distance from market centres could signify poor market information access, poor access to seeds supply, and local weather information as well (Kaliba et al., 2000). As reported by Wainaina et al., 2016, farm households living far away from the nearest market considered agricultural practices that require low transaction cost to implement.

The food insecurity status indicator illustrated in Table 1 constitutes binary responses from ten subjective measures of food security covering availability, accessibility, nutrition, and stability. A higher index as illustrated in Table 1 indicates that households are prone to being food insecure. The indicators of climatic factors of agricultural households revealed that, on average, the annual mean temperature is 26.3 °C, the annual mean precipitation is 1187.84 mm and the mean temperature of the wettest quarter is

Table 1
Description and summary statistics of variables.

Variable	Description	Expected sign	Mean	Std. dev
Category 1	**Households and plot factors**			
Age	Age of Household Head (Years)	Positive/Negative	52.14	13.96
Gender	Gender of household head (Dummy, female = 1, male = 0)	Positive/Negative	0.10	0.30
Household Size	Number of family members (Count)	Positive/Negative	8.22	3.64
Owned land	Land ownership status (Dummy, owned land = 1, otherwise = 0)	Positive	0.88	1.06
Education	Had at least six years of formal Education (Dummy, yes = 1, no = 0)	Positive	0.82	0.38
Asset value	Value of asset in Nigerian Naira (NGN)	Positive	84048.55	435155.5
Production shock	Experience production shock (Dummy, yes = 1, no = 0)	Positive/Negative	0.40	0.49
Extension service	Access to extension Service (Dummy, yes = 1, no = 0)	Positive	0.19	0.39
Market distance	Distance from farm household to major markets (in kilometers)	Negative	62.98	33.73
Food insecurity status	Household's food insecurity status (ranges from score 0 to10, with 0 being lowest and 10 highest)	Positive	6.86	2.78
Category 2	**Topographical and climatic factors**			
Temperature	Annual mean temperature (0 °C)	Positive/Negative	26.30	11.64
Precipitation	Annual mean precipitation (mm)	Positive/Negative	1187.84	530.37
Wettest period temp	Mean Temp. of the Wettest period (0 °C)	Positive/Negative	25.23	12.90
	Sustainable Agricultural Practices (SAPs)			
Improved seeds	Adoption of improved seeds (Dummy, adopter = 1, non-adopter = 0)		0.14	0.34
Inorganic fertilizer	Adoption of inorganic fertilizer (Dummy, adopter = 1, non-adopter = 0)		0.80	0.40
Mixed cropping	Adoption of mixed cropping techniques (Dummy, adopter = 1, non-adopter = 0)		0.77	0.42
Organic manure	Adoption of organic manure (Dummy, adopter = 1, non-adopter = 0)		0.49	0.50

25.2 °C. The second section of Table 1 describes the agricultural SAPs adopted in these studies. From the descriptive statistics, inorganic fertilizer and mixed cropping techniques are the most adopted practices in the range of 80% and 77% respectively, while only 14% of farm households adopted improved seed varieties. Seemingly, the adoption of improved seed varieties is still low among agricultural farm households (14%).

4.2. Complements and substitutes of sustainable agricultural practices

Table 2 reports the correlation coefficient of error terms extracted from the multivariate probit estimation. Correlation of error terms of SAPs indicates interdependence among the four SAPs considered, including the adoption of improved seeds, inorganic fertilizer, mixed cropping, and organic manure. This arises because similar unobserved households' characteristics can influence the adoption of different SAPs. Our results indicate conditional adoption of SAPs is evident in a pair of SAPs that are positively correlated between pairs of mixed cropping and organic manure. This is similar to the complementarity effect among SAPs in Muriithi et al., 2018. Likewise, farm household joint adoption of SAPs may be due to the low cost of adopting such conservation practices to reduce the use of chemical fertilizer and save cost.

Further to this, the propensity of households to adopt improved seed increases with the use of inorganic fertilizers. Consequently, combining improved seed varieties along with inorganic fertilizer is likely to increase productivity and maximize income. At the same time, the decision to adopt may be affected by the availability of substitutes as indicated in negatively correlated SAPs pairs; Inorganic fertilizer, and organic manure. This shows that the probability of adopting inorganic fertilizer is highly negatively correlated with organic manure, suggesting that farm households to a large extent either adopt more inorganic fertilizer and less organic manure or substitute one for the other.

4.3. Multivariate Probit Model estimates of the factors influencing adoption of multiple SAPs among agricultural households

To answer the first main research question which is to examine the factors influencing the adoption of multiple SAPs at the farm household level, we employed the Multivariate probit model. The results from the model are reported in Table 3. The results reveal that the log-likelihood ratio (LR) of the model is −3706.055 and Wald $\mathcal{X}^2$ (52) = 747.99 significant at ($p < 0.01$), suggesting that the model is of a good fit. The significance of the LR test also suggests that the decisions to adopt multiple SAPs are interdependent.

The results presented in Table 3 also show that the probability of adopting mixed cropping techniques and organic manure increases among older farmers while the probability of adoption of improved seed and inorganic fertilizer increases among younger farmers, this was significant at $p < 0.01$. The differentials in these preferences may be due to the ability of younger farmers to understand the use of modern innovative practices such as improved seeds and fertilizers. This was partly in relation to Bedeke et al. 2019, where younger farmers were more likely to use improved seeds varieties. This may, however, differ as older farmers were found willing to adopt improved maize varieties in Tanzania (Beyene & Kassie, 2015). In the case of gender, female household heads were less likely to adopt improved seeds and mixed cropping practices. In a way, this is suggestive of female farmers lagging roles in the adoption of modern innovative SAPs. In past studies, low adoption of modern SAPs has been related to differentials in technology preferences, cultural acceptability, and suitability of a particular technology for women agricultural tasks (Doss & Morris, 2000; Peterman et al., 2010; Quisumbing & Pandolfelli, 2010).

The coefficient of household size variable is significant ($p < 0.05$) in driving the adoption of only inorganic fertilizer. Household size can be a proxy to labour supply that could have an impact on driving or constraining adoption. Application of inorganic fertilizer can be labour intensive and as indicated in Table 1, is the most adopted SAPs among agricultural households in this study. As such, there is a possibility of consideration of family size in the adoption of such practice. Tenure security can as well be peculiar to the decision to adopt long-term technologies such as soil and water conservation technologies. From our result, ownership of land was significant ($p < 0.01$) in driving the adoption of both organic manure and inorganic fertilizer. This form of the relationship suggests that land ownership promotes both soil-conserving and yield-enhancing practices.

Also, a unit increase in the log of asset value significantly increases the decision to adopt improved seeds by 6.4%, implying the role of wealth status in driving adoption of SAPs. From past studies, proxies of farm households' wealth status have been found positive and significant in driving the adoption of improved seed varieties (Arslan et al., 2014; Nigussie et al., 2017). The coefficient of production shocks positively and significantly impacts the adoption of mixed cropping practices and organic manure. This shows that households consider sustainable land practices to protect against common production shocks such as flooding, pest, and disease attack. Surprisingly, the coefficients of production shocks suggest that farm households are less likely to adopt improved seeds and inorganic fertilizer. The explanation to this may be subject to households' consideration of improved seed and inorganic fertilizer for immediate high yield impact and not for a long-term effect. Also, households with access to extension services influenced the adoption of inorganic fertilizer and organic manure, this was significant at $p < 0.05$ and $p < 0.01$ respectively. This may be because extension access is endogenous to the adoption of agricultural technologies, most especially in the awareness and demonstration of improved production practices. For example, the use of inorganic fertilizer requires information on usage and application which may

Table 2
Correlation coefficient of error terms obtained from the MVP estimates.

Sustainable Agricultural Practices (SAPs)	Correlation coefficients	Standard error	Z statistics
Mixed cropping and organic manure (rho21)	0.160***	0.037	4.330
Inorganic fertilizer and Mixed cropping (rho31)	−0.058	0.043	−1.350
Improved seeds and mixed cropping (rho41)	−0.033	0.045	−0.720
Inorganic fertilizer and Organic manure (rho32)	−0.843***	0.022	−38.30
Improved seeds and organic fertilizer (rho42)	−0.086**	0.044	−1.980
Improved seeds and inorganic fertilizer (rho43)	0.119***	0.046	2.600
Likelihood ratio test for rho21 = rho31 = rho41 = rho 32 = rho 42 = rho 43= 0.00 chi2(6)= 517.499*			

*, **, and *** indicate statistical significance at $p < 0.1$, $p < 0.05$ and $p < 0.001$ respectively. rho signifies correlation between SAPs. 1 = organic manure; 2 = mixed cropping 3 = Inorganic fertilizer; 4 = Improved seeds.

Table 3
Multivariate probit model of factors driving adoption of SAPs.

Variables	Improved Seeds		Inorganic Fertilizer		Mixed Cropping		Organic manure	
	Coeff. (Std. error)	Z. stat.	Coeff. (Std. error)	Z. stat.	Coeff. (Std. error)	Z. stat.	Coeff. (Std. error)	Z. stat.
Age	−0.005* (0.003)	−1.69	−0.008*** (0.002)	−3.53	0.015*** (0.003)	5.96	0.011*** (0.002)	5.04
Gender	−0.325** (0.134)	−2.43	−0.119 (0.103)	−1.15	−0.283*** (0.106)	−2.68	0.015 (0.102)	0.15
Household size	0.014 (0.011)	1.32	0.021** (0.010)	2.14	0.002 (0.010)	0.22	0.004 (0.009)	0.46
Land ownership	−0.068 (0.033)	−2.02	−0.100*** (0.033)	−3.01	0.003 (0.032)	0.11	0.125*** (0.029)	4.24
Education	−0.023 (0.110)	−0.21	0.275*** (0.087)	3.17	−0.657*** (0.114)	−5.77	−0.239** (0.084)	−2.84
Asset value (log)	0.064* (0.033)	1.93	0.000 (0.031)	−0.01	0.023 (0.030)	0.77	−0.003 (0.028)	−0.09
Production shock	−0.276*** (0.0790	−3.5	−0.223*** (0.067)	−3.32	0.137** (0.070)	1.97	0.396*** (0.062)	6.39
Extension service	0.186 (0.099)	1.89	0.225** (0.094)	2.4	0.146 (0.094)	1.56	0.223*** (0.081)	2.75
Market distance	−0.007*** (0.001)	−6.23	0.002** (0.001)	2.14	−0.003*** (0.001)	−3.46	−0.003*** (0.001)	−2.8
Food Insecurity index	−0.032** (0.014	−2.24	0.023* (0.013)	1.84	0.061*** (0.013)	4.68	0.001 (0.011)	0.07
Mean Temperature	0.022** (0.010)	2.06	0.032*** (0.009)	3.71	−0.047*** (0.009)	−5.34	−0.098*** (0.008)<	−11.62
Mean precipitation	9.0E-4* (8.0E-4)	1.71	4.2E-4*** (9.0E-5)	−4.83	(6.0E-5) (8.0E-5)	−0.66	(9.0E-5) (8.0E-5)	1.11
Wettest period temp	−0.031*** (0.010)	−3.12	−0.049*** (0.008)	−6.14	0.055*** (0.008)	6.55	0.090*** (0.008)	11.55
Constant	1.119 (0.933)	1.2	5.790*** (1.015)	5.7	−0.952 (0.826)	−1.15	1.953** (0.795)	2.46
Number of observations: 2113 Log likelihood = -3706.055 Wald $\mathcal{X}^2$(52) = 747.99 Prob > $\mathcal{X}^2$ = 0.0000								
Joint significance of mean of household's varying covariates $\mathcal{X}^2$(6) = 517.499 Prob > $\mathcal{X}^2$ = 0.0000								

*, **, and *** indicate statistical significance at $p < 0.1$, $p < 0.05$ and $p < 0.01$ respectively.

be complex and may not yield the needed result if not followed appropriately, this was evident in Duflo et al., 2008, assessment of fertilizer use in Kenya. As such, access to extension services on the right use of fertilizers can be significant in households' decisions to adopt. Further, the results of distance to market were quite mixed, it was only positive and significant for inorganic fertilizer and negative for other SAPs types.

Food insecurity status of households is relevant in SAPs' adoption. From our result, farm households who are prone to being food-insecure have a higher probability of adopting mixed cropping activities and inorganic fertilizer, however, may not likely adopt improved seeds varieties. Food-insecure households are about increasing yield using basic land practices and common high yield SAPs such as fertilizer. The likelihood of adopting improved seed and inorganic fertilizer significantly increased with an increase in annual mean temperature and precipitation. Climatic variation in temperature and rainfall is one of the key driving factors of modern agricultural innovative practices as illustrated in several adoption studies (Arslan et al., 2014; Beyene & Kassie, 2015; Gebremariam & Tesfaye, 2018). Also, the probability to adopt however decreases with an increase in mean of the temperature of the wettest period for improved seed and inorganic fertilizer, except for mixed cropping practices and organic manure.

4.4. Ordered probit estimates of the factors influencing the number of SAPs adopted among agricultural households

In Table 4, we present the results of the ordered probit estimates of the factors affecting the number of SAPs adopted among agricultural households. The chi-squared statistics from the orders probit model is statistically significant ($p < 0.001$) ($\mathcal{X}^2(13) = 276.75$ Prob > chi-square = 0.000), suggesting that the model is of good fit.

The result also shows that the number of SAPs adopted increases with the age of household head and household size. This may be due to the experience accumulated over the farming years especially with SAPs. The results also show that households that are food-insecure explore multiple agricultural modern practices to increase households' food needs. In terms of gender of household head, female-headed households are less likely to adopt more SAPs, as such similar reasons persist as those explained in the MVP model (Table 3). This can also be attributed to the fact that poor access to complementary inputs can be a limiting factor in adopting more SAPs for female household heads. Surprisingly, the result of the annual mean temperature and mean temperature of the wettest period contradicts the result in the MVP model in Table 3. One can say that variation exists within each SAPs type and the households' reason for adoption. The increasing annual mean temperature may not necessarily improve households' decisions to adopt more SAPs but may imply their decision to go for substitute incorporating broader features of previously adopted SAPs. In contrast to this, the probability of adopting more agricultural SAPs increases with increasing mean temperature of the wettest period. Access to extension services was as well important in driving farm households' adoption of more SAPs at $p < 0.01$.

Our result further underscores the importance of production shocks in driving the adoption of modern agricultural innovations. The propensity of adopting more SAPs increases as farm households' experience more production shocks. As illustrated in Dercon and Christiaensen (2011), for every standard deviation increase in predicted consumption in the case of rainfall failure, there is a 16% increase in fertilizer technology use in Ethiopia. Interestingly, the number of SAPs adoption increases with households with less than six years of formal education. Households' decision to adopt may weigh higher on the network of information on SAPs use. The log of assets variable was positively significant at $p < 0.05$. This further confirmed the role of wealth on SAPs' adoption. Incidentally, households that live far away from major market have a higher probability of adopting more SAPs. While this is in contrast with the common notion, access to notable market information that drives adoption may not be dependent on distance and probably available local information networks within.

5. Conclusion and policy implications

The important roles of modern SAPs in bolstering productivity as well as ensuring food security and reducing poverty are well established in the literature. Despite these benefits, coupled with concerted efforts at creating awareness on the adoption of these innovations in developing countries, adoption rates among farmers have been perceived to be generally low, especially in SSA. Using cross-sectional data collected from the 2015 Nigeria General Household Survey, our study assessed the factors influencing the adoption of multiple SAPs in Nigeria, while also considering the drivers of adoption intensity of these SAPs at farm household level. The SAPs considered include improved seeds, inorganic fertilizer, mixed cropping techniques, and organic manure.

Table 4
Ordered probit estimates of the factors influencing the number of SAPs adopted.

Variables	Coefficient	Robust Std. Error.	Z. Statistics
Age of Household Head	0.008***	0.002	4.16
Female Household Head	−0.308***	0.085	−3.63
Household Size	0.016**	0.007	2.21
Land Ownership (yes=1, no=0)	0.004	0.025	0.18
Education(yes=1, no=0)	−0.273***	0.065	−4.22
Asset Cost (log)	0.047**	0.023	2.01
Experience Shock (yes=1, no=0)	0.094*	0.052	1.8
Extension Service (yes=1, no=0)	0.348***	0.073	4.78
Distance from Market (km)	−0.004***	0.001	−5.67
Food Insecurity index	0.022***	0.009	2.33
Annual mean temperature (0^0C)	−0.053***	0.007	−7.93
Annual Mean Precipitation (mm)	4.0E-4	2.0E-4	−1.45
Mean Temp. of the Wettest period (0^0C)	0.042*	0.006	6.86
/cut1	−3.715	0.738	
/cut2	−2.163	0.733	
/cut3	−0.672	0.732	
Number of observations =2113 Wald chi2(13)=276.75 Prob > chi2 = 0.000			
Log pseudolikelihood = -2213.7361 Pseudo R2 =0.0627			

*, **, and *** indicate statistical significance at $p < 0.1$, $p < 0.05$ and $p < 0.01$ respectively.

The results from the study showed that farmers' adoption of different SAPs and their intensity of use depends on the age of household head, gender, education, household size, access to extension services, and household's wealth status. In particular, the study found that the probability of adoption of improved seeds and inorganic fertilizer increases only among younger farmers. The study also revealed that female-headed households were lagging in the adoption of improved seeds and mixed cropping technologies. Besides, adoption of all SAPs considered was also influenced by distance from major markets, with farmers living farther away from the market being less probably to adopt improved seed, mixed cropping production techniques, and organic manure. Our analysis also suggests that production shocks play a significant role in the adoption decision of all SAPs by farmers. Finally, farmer decisions to adopt multiple SAPs were found to be affected by climatic factors, such as temperature and precipitation.

Our results offer a number of vital implications for policy. As evidenced in our results, it can be concluded that agricultural innovations are interdependent. This suggests that the interdependence nature of agricultural innovations should be considered in designing effective strategies for the development and dissemination of agricultural SAPs in Nigeria, as well as in other developing countries. Giving that diverse factors influence the different combination of SAPs, it is important that in designing incentives for smallholder farmers to adopt multiple SAPs, policymakers should take into consideration several farm managerial, socio-economic and plot-specific factors to ensure that farmers can maximise the benefits of SAPs. Examples include provision of training programme designed to enlightening farmers on the benefits of SAPs, as well as on first-hand information on weather conditions. Also, shock management strength of farmers should be well examined and considered when designing and executing dissemination schemes for different SAPs.

Declaration of competing interest

The authors of this paper declare no conflict of interest.

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