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Sustainable agricultural practices and household welfare among smallholder farmers in southwest, Nigeria

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Abstract

Sustainable agricultural practices (SAPs) are increasingly promoted as a pathway to improving agricultural productivity, enhancing climate resilience, and advancing the welfare of smallholder farming households. However, evidence on whether SAP adoption translates into measurable welfare gains remains inconclusive because adoption decisions are potentially endogenous and sustainable farming behaviour is inherently multidimensional. This study investigated the determinants of SAP adoption and its effect on household welfare among 211 smallholder farming households in Ogun State, Nigeria. Primary data were collected through a multistage sampling procedure. A Poisson regression model was employed to identify factors influencing SAP adoption intensity, while exploratory factor analysis was used to develop a composite SAP adoption index. The welfare effect of SAP adoption was subsequently estimated using an instrumental variable probit (IV-Probit) model with distance to the nearest extension service centre as an instrument to address potential endogeneity. The results showed that education, farming experience, membership of farmer associations, land ownership, and awareness of SAPs significantly increased adoption intensity, whereas age and access to credit reduced adoption. After correcting for endogeneity, greater adoption intensity significantly reduced the probability of household poverty, confirming that SAP adoption improves household welfare. Membership of farmer associations and access to credit further reduced the likelihood of poverty, whereas larger household size and marital status increased poverty risk. The findings demonstrate that promoting the adoption of multiple sustainable agricultural practices can simultaneously enhance rural livelihoods and support sustainable agricultural development. Strengthening extension services, improving farmers' awareness, securing land tenure, reinforcing farmer organizations, and aligning rural credit with sustainable agricultural investments are critical policy priorities for accelerating SAP adoption and improving household welfare among smallholder farmers.

Keywords: Sustainable agricultural practices, Household welfare, Poverty, IV-Probit; Smallholder farmers, Nigeria.

1 Introduction

Agriculture remains a critical sector in Nigeria's economy and in the livelihoods of rural households, particularly in areas where smallholder farming dominates local production systems. In much of sub-Saharan Africa (SSA), including Nigeria, the agricultural sector is largely controlled by smallholder farmers who often operate with limited access to innovative farming practices, improved technologies, and institutional support systems [29]. This situation has constrained the ability of the sector to attain its full productive potential despite its strategic importance for food production, employment generation, income creation, and rural development. Agriculture in SSA remains underutilized and falls far short of its productive potential, with the region recording slower progress in improving land, labour, and productivity than other parts of the world [18]. This challenge is particularly troubling in a context of rapid population growth, increasing pressure on land, and the growing need to strengthen food systems and household welfare in rural communities.

In Nigeria, the underperformance of agriculture has been linked to a range of structural and production-related constraints. The agricultural system is still characterized by peasant production, customary land tenure, low productive capacity, weak technology adoption, and crude farming methods that reduce efficiency and limit output growth [54]. Smallholder farmers often cultivate under rain-fed conditions, depend on family labour, and have limited access to improved inputs, mechanization, formal credit, and extension services. These conditions create a fragile production environment in which agricultural productivity remains low and farming households struggle to attain stable income and improved living conditions. Agricultural policies increasingly seek to promote behavioural change among farmers and agricultural integration through institutional innovations in order to support sustainable agricultural development and improve farm productivity [34]. This policy orientation reflects the understanding that the long-term growth of agriculture depends not only on increasing output but also on ensuring that farming practices remain environmentally sustainable and economically beneficial to households.

A major challenge confronting smallholder agriculture in Nigeria is the problem of land degradation and the continuous decline in farm productivity. Land degradation and declining productivity in rural agriculture have been linked to poor agronomic practices, age-long methods of soil amendment, and obsolete mechanical approaches to soil management [54]. These problems are particularly severe in smallholder production systems where repeated cultivation of the same land, inadequate nutrient replacement, and weak soil conservation practices gradually reduce soil fertility and compromise crop performance. The consequences of this decline are reflected in low yields, unstable farm returns, rising vulnerability to climatic shocks, and worsening welfare outcomes among rural households. Since many farming households rely heavily on agriculture for both subsistence and cash income, any sustained decline in agricultural productivity directly affects food availability, household earnings, asset accumulation, and general livelihood conditions.

The challenges associated with low productivity have been compounded by climate-related risks such as erratic rainfall, low rainfall conditions, rising temperatures, pest and disease outbreaks, and other environmental stresses that affect agricultural production across many rural parts of SSA. Sustainable agricultural practices (SAPs) are therefore increasingly viewed as one of the most viable responses to these intertwined problems of low productivity, environmental degradation, and climate stress. Sustainable agricultural practices remain one of the most effective approaches for addressing challenges related to climate change, low rainfall, and low agricultural productivity in many rural parts of SSA [66]. Such practices include crop rotation, intercropping,

cover cropping, and conservation tillage, all of which have been shown to improve crop productivity while safeguarding environmental resources [66]. This dual role of SAPs as both productivity-enhancing and resource-conserving practices has made them increasingly relevant in agricultural policy and rural development discourse.

Sustainable agricultural practices broadly refer to farm management approaches that improve agricultural production while conserving the natural resource base and reducing negative environmental externalities. The logic behind SAPs is that agricultural growth should not be pursued through practices that deplete soils, waste resources, and expose farmers to long-term production risks. Rather, farming systems should be organized in ways that improve soil health, promote efficient resource use, strengthen resilience to climatic and economic shocks, and enhance the sustainability of food production. The adoption of sustainable agricultural practices has the potential to improve agricultural sustainability through reduced agricultural input use and less waste generation from available resources [44]. In this sense, SAPs are not only technical options for raising output; they are also management strategies for promoting ecological balance, production efficiency, and long-term livelihood security.

The importance of SAPs has therefore become increasingly visible in both policy development and agricultural research across sub-Saharan Africa. The adoption of SAPs as an approach to improving food production cannot be overemphasized in the policy development and research agenda of many countries in SSA, including Nigeria [60]. The renewed attention to SAPs is tied to the recognition that the region's agricultural future depends on systems that can simultaneously support productivity, climate resilience, and natural resource conservation. This is especially important in Nigeria, where agriculture remains central to rural livelihoods but continues to face persistent problems of low productivity, soil fertility decline, weak innovation uptake, and growing production uncertainty. Under these conditions, SAPs provide a framework for improving output while also addressing the environmental and structural weaknesses of existing farming systems.

Examples of sustainable agricultural practices commonly discussed in the literature include crop rotation, intercropping, cover cropping, conservation tillage, mixed farming, integrated pest management, use of organic manure, irrigation, agroforestry, and improved seed varieties. These practices differ in their agronomic function, but they are united by a common goal of making agricultural production more sustainable, resilient, and efficient. Crop rotation, for example, can help break pest and disease cycles and restore soil fertility. Intercropping may improve land-use efficiency, diversify production, and reduce production risk. Cover cropping and conservation tillage contribute to soil protection, moisture retention, and organic matter build-up. Integrated pest management reduces excessive reliance on synthetic chemicals and promotes healthier crop management systems. Where these practices are used effectively, they can improve farm output, reduce production losses, and enhance the capacity of farming households to cope with climatic and economic stress. For smallholders who often operate under severe resource constraints, the potential of these practices to stabilize production and improve returns makes them highly relevant to welfare outcomes.

The welfare implications of SAP use are particularly important because smallholder agriculture is closely tied to household well-being in rural Nigeria. For most farming households, agriculture is not only a productive activity but also the foundation of household consumption, food security, education financing, health expenditure, and asset accumulation. Consequently, any innovation or practice that raises productivity, reduces risk, or improves efficiency may have important consequences for household welfare. In this context, household welfare can be

understood to include such outcomes as increased income, improved livelihood status, better food consumption possibilities, enhanced resilience, and greater capacity to meet basic needs. The relevance of SAPs therefore goes beyond agronomic performance alone. The key policy question is whether the use of sustainable agricultural practices actually translates into better welfare outcomes for farming households.

Notwithstanding the growing literature on SAPs in Nigeria, important knowledge gaps remain. Previous studies such as those by Ireti et al. (2021), Ogunkunle et al. [48], Oke et al. [51], and Arifalo and Afolabi [8] have largely focused on the significance of SAPs or the factors influencing their use in Nigeria, with less direct attention to how these practices improve farmers' household welfare. Much of the existing evidence concentrates on adoption determinants, productivity outcomes, efficiency effects, or the agronomic significance of sustainable practices. While these contributions are valuable, they do not fully answer the broader development question of whether SAP use improves the income and livelihood status of farming households. This is a crucial gap because the justification for promoting SAPs among smallholders ultimately rests not only on environmental sustainability or productivity enhancement, but also on the extent to which such practices improve the welfare of rural households.

The need to focus specifically on household welfare is even more compelling in Ogun State, where agriculture remains an important source of livelihood for many rural households. Smallholder farmers in the state face the same production constraints evident across much of rural Nigeria: declining soil fertility, small farm sizes, limited access to improved inputs, climate-related risks, and inadequate institutional support. At the same time, the state has a strong agricultural base and a significant presence of cassava and other crop-based production systems in which sustainable agricultural practices are increasingly relevant. Investigating whether the use of SAPs improves household welfare is therefore both timely and policy relevant. If SAP use is shown to improve household welfare, then policies that promote these practices can be justified not only as environmental interventions but also as poverty-reducing and livelihood-enhancing strategies. Conversely, if the welfare effects are weak or conditional, then policymakers will need to pay closer attention to complementary factors such as extension access, education, farmer organizations, and productive assets that shape whether adoption translates into meaningful household benefits.

Against this background, the present study is both relevant and necessary. It builds on the growing recognition that SAPs are central to sustainable agricultural development in SSA, while also addressing the important empirical gap regarding their welfare implications for smallholder households. By moving beyond the question of whether farmers adopt sustainable practices to ask whether such practices improve household welfare, the study contributes to a more policy-relevant understanding of agricultural sustainability in Ogun State and similar rural settings in Nigeria.

2 Literature review

2.1 Concept of sustainable agricultural practices (SAPs)

Agricultural development depends to a large extent on farmers' willingness and ability to make use of new technologies and innovations for the socioeconomic well-being of the people [59]. Sustainable agricultural practice (SAP) is "a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment" [16]. Sustainable agriculture is an important concept for alerting farmers and serves as an alternative farming system to traditional methods of farming. These methods are capable of achieving the profitability-maximization

objective of conventional agriculture while maintaining the ecological dynamics of agro-ecosystems and biodiversity. Consideration for sustainable agricultural practices is not only driven by the future need for increased production, but also by the need to maintain the quality of the environment, water, and soil [32]. Sustainable agricultural practices such as crop rotation, the use of cover crops, integrated pest management (IPM), agroforestry techniques, and reduced tillage systems improve the ability to adapt to climate change and variability, reduce the environmental effects of agriculture, and allow for a more efficient use of natural resources [61].

2.2 Empirical review on sustainable agricultural practices (SAPs)

Studies suggest that the relationship between SAP adoption and welfare is increasingly receiving scholarly attention, although the evidence remains context-specific. A study on eco-friendly agricultural practices among smallholder farmers in South-West Nigeria found that adoption had a welfare-increasing impact and that years of formal education, social capital indicators, collective action, and extension delivery significantly predicted adoption [55]. The study also revealed that adoption was still largely partial, implying that many farmers do not adopt the full package of environmentally friendly practices. This is important because partial adoption may influence the scale and consistency of welfare outcomes. It was further concluded that farmers with a higher propensity to adopt these practices were likely those with better access to productive resources such as land, labour, capital, social networks, and institutional support [55]. This suggests that welfare gains associated with adoption may be shaped not only by the practices themselves but also by the resource conditions under which farmers adopt them.

Related evidence from outside Nigeria also reinforces the importance of examining SAPs through a welfare lens. Using data from Burkina Faso, a study investigated both the determinants of SAP adoption and the impacts of single and multiple SAP adoption on household food security [31]. The study found that age, education, cooperative membership, farm size, and access to climate and technology information significantly influenced farmers' decisions to adopt SAPs. More importantly, it showed that the adoption of single or joint SAPs does not automatically lead to positive impacts on crop yield, income, or food security unless the practices are implemented under suitable conditions [31]. This finding is especially relevant because it highlights the fact that the welfare benefits of SAPs are conditional rather than automatic. It also indicates that the effect of SAP use on welfare depends on the interaction between the practices adopted and the broader socioeconomic, institutional, and production environment of the household.

Studies on the determinants of multiple SAP adoption also help explain why some households are more likely than others to benefit from sustainable farming practices. A study among smallholder farmers in South Africa reported that the use of improved crop varieties, organic manure, integrated pest management, irrigation, and intercropping was influenced by factors such as age, education, household labour, farm size, income level, and membership of farm organizations [39]. The study concluded that the combination of multiple SAPs had a positive impact on farming and that adoption was shaped by socioeconomic, institutional, and cultural factors [39]. This reinforces the argument that SAP use is not simply a technical choice but a behavioural and institutional outcome that reflects access to information, labour, assets, and support systems. It also suggests that welfare improvements associated with SAPs may be stronger when farmers are able to adopt multiple complementary practices rather than isolated technologies.

Evidence from cassava farming in Ogun State also points to the relevance of SAPs for economic outcomes. A study on the effect of SAP adoption on profit efficiency among cassava farmers in Ogun State identified several sustainable agricultural practices adopted by farmers,

including soil enrichment, integrated pest management, intercropping, crop rotation, mixed farming, agroforestry, and cover cropping [51]. The findings indicated that SAP adoption could enhance profit efficiency and that extension contact was an important factor associated with efficiency outcomes [51]. This study is particularly relevant because it provides evidence from the same state as the present research and shows that SAP use can be linked to measurable economic performance among smallholder cassava farmers. Although profit efficiency is not identical to household welfare, it is closely related because improved efficiency can increase farm income and strengthen the household's economic position.

A study in Ilorin East Local Government Area of Kwara State, Nigeria examined smallholder farmers' perceptions of sustainable agricultural practices [12]. The majority of the farmers were male, married, within active and productive age brackets, and had formal education. They also had access to extension agents, which served as the most common source of information on sustainable agricultural practices. Farmers expressed favourable perceptions of SAPs, including low chemical input use, minimization of adverse effects on health, safety, wildlife, water quality, and the environment, as well as the ability to produce abundant food without depleting the earth's resources [12]. The study therefore revealed that most farmers perceived SAPs as beneficial. A substantial amount of attention has also been paid to the positive contribution of SAPs to ecosystem sustainability. Amin et al. [7] reported that cover cropping, crop rotation, and minimal tillage have environmental benefits such as carbon sequestration, reduced nutrient leaching and erosion, and improved insect pollination.

A study among yam farmers in Akure Metropolis, Ondo State, Nigeria investigated the determinants of adopting sustainable agricultural practices and found that age, household size, income, and education level were significant determinants [8]. Older farmers were less likely to adopt practices such as leaving crop residue, while household size positively influenced the adoption of labour-intensive practices like cover cropping. Income also played a critical role, as higher-income farmers were more likely to adopt resource-intensive SAPs such as organic fertilizers, crop rotation, and improved seeds [8].

Another study evaluated the factors influencing the adoption and intensity of sustainable agricultural practices among young rice farmers in Ogun State, Nigeria [48]. The SAPs adopted by the rice farmers included farm planning and the use of cropping calendars, planting at appropriate spacing, appropriate use of agrochemicals, careful site selection, preference for clay-loamy soils, timely planting, attention to market demand and supply trends, and quality improvement practices for rice. The result of the double-hurdle regression revealed that years of education, farm size, and output influenced both the adoption and intensity of SAP use [48].

2.3 Conceptual framework

Figure 1 presents the conceptual framework underpinning the relationship between sustainable agricultural practice (SAP) adoption and household welfare among smallholder farmers. The framework illustrates the pathways through which farmer characteristics and institutional support influence the intensity of SAP adoption and, subsequently, household welfare. It also incorporates the instrumental variable used to address the potential endogeneity of SAP adoption in the empirical analysis.

At the first stage, farmer and farm characteristics are hypothesized to influence the adoption of sustainable agricultural practices. These characteristics include age, education, farming experience, household size, marital status, income, access to credit, land ownership, membership of farmers' associations, and awareness of SAPs. These socioeconomic factors

determine farmers' capacity, willingness, and opportunity to invest in sustainable farming practices. For example, education and farming experience enhance farmers' ability to acquire and utilize technical knowledge, while secure land ownership provides incentives for long-term investments in sustainable land management. Similarly, membership of farmers' associations facilitates knowledge sharing, collective action, and access to agricultural inputs and services.

The framework further recognizes the importance of information and institutional support in promoting SAP adoption. Extension services, agricultural training programmes, farmer organizations, credit institutions, and climate information services constitute the major channels through which farmers obtain technical knowledge, advisory services, and financial resources required for adopting sustainable agricultural practices. These institutional mechanisms enhance farmers' awareness of sustainable technologies, reduce information asymmetry, and improve access to production resources, thereby encouraging greater adoption intensity.

These socioeconomic and institutional factors jointly influence the intensity of SAP adoption, which is measured as the number of sustainable agricultural practices adopted by each household. Because farmers often adopt several complementary practices simultaneously rather than a single technology, the study conceptualizes SAP adoption as a multidimensional construct represented by a composite adoption index. This approach captures the cumulative effect of multiple sustainable practices on household welfare rather than the isolated contribution of individual technologies.

The framework acknowledges that SAP adoption may be endogenous, as unobserved household characteristics such as managerial ability, entrepreneurial orientation, risk preferences, and motivation may simultaneously influence both adoption decisions and household welfare. To account for this potential endogeneity, distance to the nearest extension service centre is incorporated as an instrumental variable. The instrument is expected to influence SAP adoption through farmers' access to agricultural information, training, and advisory services but is assumed not to affect household welfare directly after controlling for other socioeconomic characteristics. This enables the identification of the causal effect of SAP adoption on household welfare.

The central proposition of the framework is that greater SAP adoption improves household welfare, measured in this study using household poverty status based on the Foster–Greer–Thorbecke (FGT) poverty indices and per capita household expenditure. Sustainable agricultural practices are expected to improve soil fertility, conserve natural resources, enhance input-use efficiency, and increase agricultural productivity. These improvements translate into higher farm income, increased household consumption, and a lower probability of household poverty.

Ultimately, increased adoption of sustainable agricultural practices is expected to generate broader development outcomes, including improved farm productivity, higher household income, reduced poverty, enhanced household welfare, and more sustainable rural livelihoods. The framework therefore illustrates both the direct determinants of SAP adoption and the causal pathway through which sustainable agricultural practices contribute to improved welfare among smallholder farming households in Ogun State.

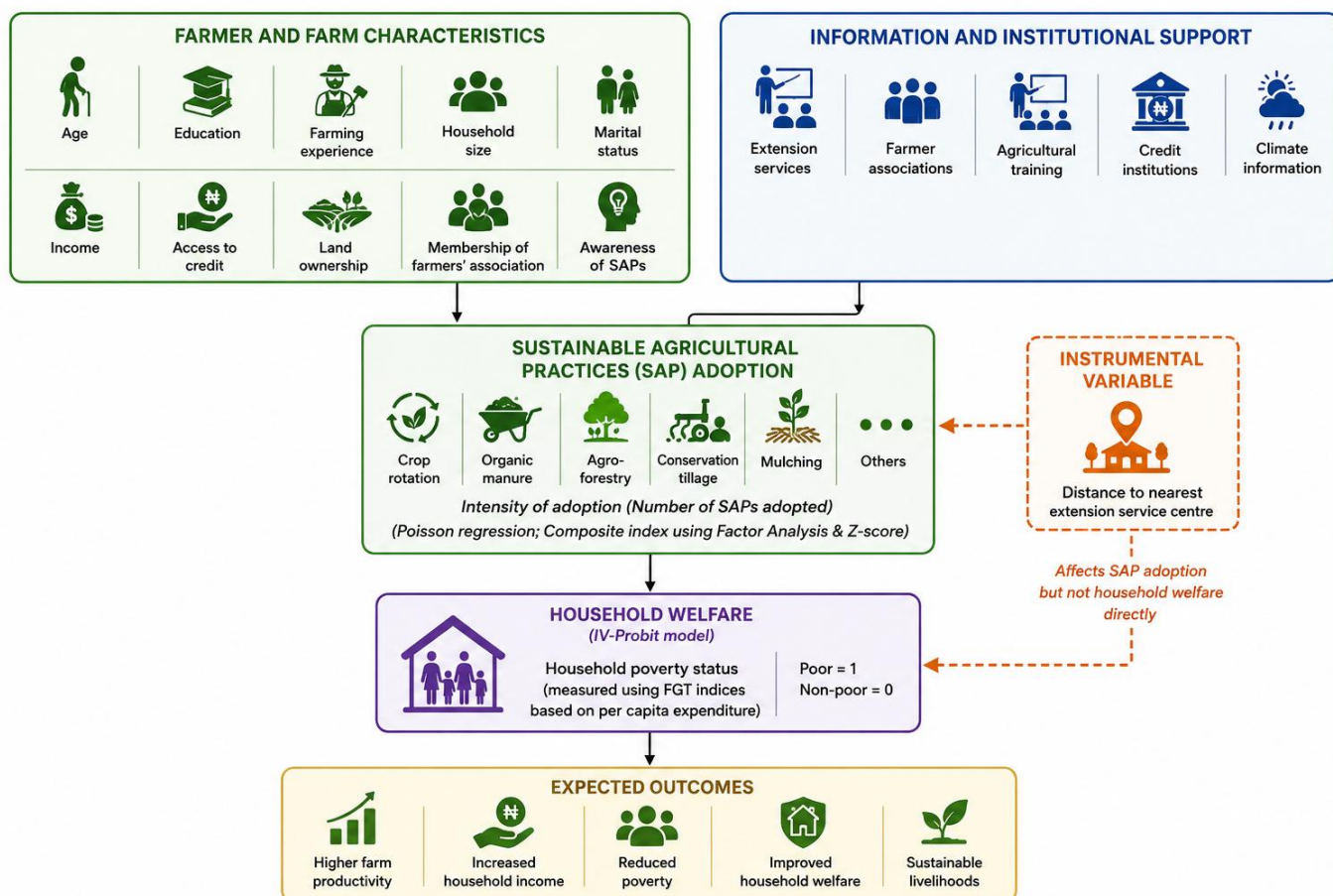


Fig 1. Conceptual framework linking SAP adoption and household welfare

3 Methodology

3.1 Study area

This study was conducted in Ogun State, located in the South-West geopolitical zone of Nigeria. Ogun State lies approximately between latitudes 6.2°N and 7.8°N and longitudes 3.0°E and 5.0°E [64]. The state is bounded by Lagos State to the south, Oyo State to the north, Ondo State to the east, and the Republic of Benin to the west, with Abeokuta serving as the state capital [64]. Agriculture constitutes a major economic activity in the state and remains an important source of livelihood for rural households, with crop production dominating smallholder farming systems [64]. Major food crops commonly cultivated in the state include cassava, maize, rice, yam, and cocoyam, while the agricultural production system is largely smallholder-based [64].

The climate of Ogun State is tropical and is characterized by distinct wet and dry seasons [64]. The rainy season generally extends from April to October, while the dry season lasts from November to March [64]. Temperature in the state ranges from about 23°C to 32°C, with climatic conditions that are generally favourable for crop production [64]. The state also possesses extensive arable land suitable for agricultural activities, thereby making it a suitable environment for the cultivation of arable and perennial crops as well as the adoption of sustainable farming practices [64, 68].

The soils in Ogun State are generally suitable for agricultural production, although continuous cultivation under smallholder farming systems often necessitates improved soil fertility

management and sustainable land-use practices to maintain productivity over time. Consequently, the state provides a suitable setting for examining the adoption of organic farming practices and other sustainable agricultural innovations among smallholder farmers. The ecological characteristics of the state, its strong agricultural base, and the prevalence of smallholder production systems make Ogun State an appropriate location for investigating the factors influencing the adoption of organic farming practices.

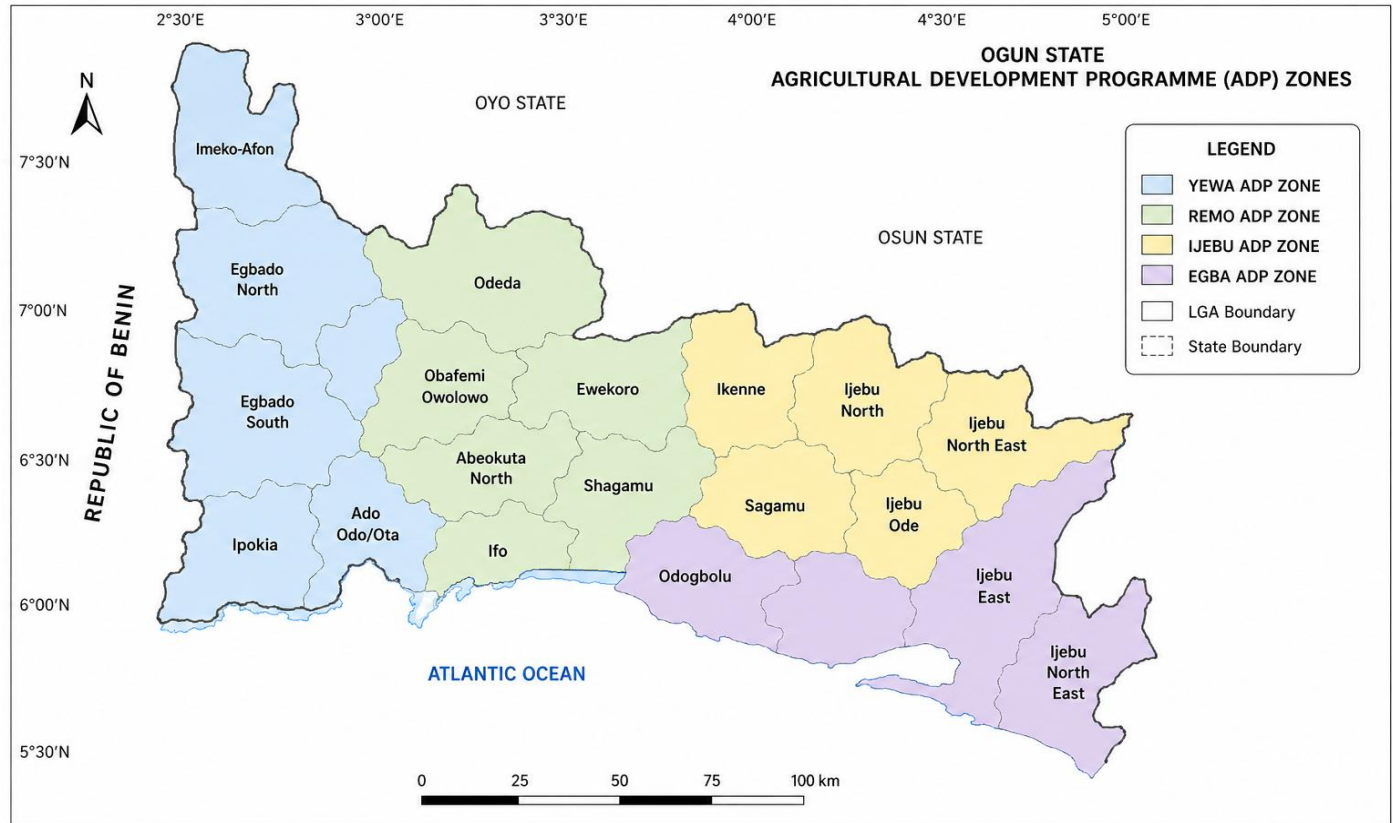


Fig 2. Map of Ogun State showing the ADP zones

3.2 Sampling technique

A multistage sampling procedure was employed to select respondents for the study. In the first stage, two Agricultural Development Programme (ADP) zones were randomly selected from the four ADP zones in Ogun State on the basis of the concentration of smallholder farming activities. In the second stage, two blocks were randomly selected from each of the selected ADP zones, resulting in a total of four blocks. In the third stage, two cells were randomly selected from each of the four blocks, giving a total of eight cells. In the final stage, 30 smallholder farmers were randomly selected from each of the eight cells, producing an initial sample size of 240 respondents. Data were collected from the selected farmers using a structured questionnaire. After data cleaning, validation, and consistency checks, 211 questionnaires were found suitable for analysis, representing 87.9% of the total sample. This high response rate indicates that the dataset is reliable and adequate for empirical analysis.

3.3 Analytical tools

This study used four analytical tools: descriptive statistics, Foster–Greer–Thorbecke (FGT) poverty indices, Poisson regression, and an Instrumental Variable Probit (IV-Probit) model. Descriptive statistics (frequencies, percentages, means, and standard deviations) were used to describe respondents' socioeconomic characteristics and SAP adoption patterns.

3.3.1 Foster, Greer, and Thorbecke (FGT) poverty indices

To assess the welfare status of farm households, the study used the Foster, Greer, and Thorbecke (FGT) poverty indices developed by Foster et al. [17]. Household welfare was measured using per capita household expenditure as the welfare indicator. The FGT approach is one of the most widely used methods for poverty analysis and has been extensively applied in studies of agricultural household welfare across sub-Saharan Africa [27, 43, 2, 42]. The general FGT poverty index is expressed as:

$$P_{\alpha} = \frac{1}{n} \sum_{i=1}^q \left(\frac{z-y_i}{z} \right)^{\alpha} \quad (1)$$

Where:

P_{α} = FGT poverty index

n = total number of households in the sample ($n = 211$)

q = number of households below the poverty line

z = poverty line

y_i = per capita annual expenditure of household i

α = poverty aversion parameter ($\alpha \geq 0$), which determines the weight placed on the depth of poverty

Poverty line (Z)

Using the relative poverty approach, the poverty line is defined as two-thirds of the mean per capita household expenditure:

$$Z = \frac{2}{3} \bar{Y} \quad (2)$$

where:

Z = poverty line

$\bar{Y}$ = mean per capita household expenditure.

Poverty headcount index

$$P_0 = \frac{q}{n} \quad (3)$$

where:

P_0 = poverty headcount index

q = number of poor households ($y_i < Z$)

n = total number of households.

Poverty depth

$$P_1 = \frac{1}{n} \sum_{i=1}^q \left(\frac{z-y_i}{z} \right) \quad (4)$$

where:

P_1 = poverty gap index

y_i = per capita expenditure of the i^{th} poor household

Z = poverty line.

This measures the average shortfall of poor households' expenditure from the poverty line.

Poverty intensity

$$P_2 = \frac{1}{n} \sum_{i=1}^q \left(\frac{Z - y_i}{Z} \right)^2 \quad (5)$$

where:

P_2 = poverty severity index.

3.3.2 Poisson count regression model

To identify the socioeconomic and institutional factors influencing the intensity of SAP adoption among farm households, this study employed a Poisson regression model. The dependent variable is the number of Sustainable Agricultural Practices (SAPs) adopted by household i , where $Y_i \in \{0, 1, 2, \dots, 10\}$. The outcome is discrete and non-negative, making OLS inappropriate, as it assumes continuity and may yield invalid predictions such as negative or fractional values [20, 22]. Instead, the model assumes Y_i follows a Poisson distribution with conditional mean

$$\lambda_i = E(Y_i | X_i) \quad (6)$$

Where X_i is a vector of explanatory variable.

Formally, the model assumes that, conditional on the explanatory variables X_i , the outcome follows a Poisson distribution:

$$Y_i | X_i \sim \text{Poisson}(\lambda_i) \quad (7)$$

with conditional mean:

$$E(Y_i | X_i) = \lambda_i \quad (8)$$

To ensure positivity of the expected count, a log-linear specification is used:

$$\ln(\lambda_i) = X_i \beta \quad (9)$$

The empirical specification estimated in this study is:

$$\ln(\lambda_i) = \beta_0 + \beta_1 \text{AGE} + \beta_2 \text{MSTAT} + \beta_3 \text{HHS} + \beta_4 \text{EDUC} + \beta_5 \text{INC} + \beta_6 \text{FEXP} + \beta_7 \text{ASSO} + \beta_8 \text{EXT} + \beta_9 \text{LOAN} + \beta_{10} \text{LOWN} + \beta_{11} \text{AWARE} + \varepsilon_i \quad (10)$$

Where:

λ_i = expected number of SAPs adopted

AGE = age of household head (years)

MSTAT = marital status (1 = married, 0 = otherwise)

HHS = household size (number of persons)

EDUC = level of education (years)

INC = income from major occupation (₦)

FEXP = farming experience (years)

ASSO = membership of farmers' association (1 = member, 0 = otherwise)

EXT = access to extension services (1 = had access, 0 = otherwise)

LOAN = access to credit (1 = had access, 0 = otherwise)

LOWN = land ownership (1 = owned, 0 = otherwise)

AWARE = awareness of SAPs (aware = yes, 0 = otherwise)

ε_i = error term

3.3.3 Factor analysis and Z-Score standardization of the SAP composite index

Before estimating the IV-Probit model, a composite SAP adoption index was constructed for each household. This was done by first applying Principal Factor Analysis (PFA) to reduce the ten correlated binary SAP indicators into key latent factors, followed by standardizing the resulting

factor scores using Z-scores. The final composite index (Z-score) was then used as the endogenous variable representing SAP adoption intensity in the IV-Probit model.

The Z-score transformation is defined as:

$$Z_i = \frac{X_i - \mu}{\sigma} \quad (11)$$

Where:

Z_i = standardized SAP composite adoption index for household i

X_i = raw composite factor scores for household i

μ = sample mean of all composite factor scores

σ = sample standard deviation of all composite factor scores

3.3.4 Instrumental variable probit (IV-Probit) model

To address potential endogeneity arising from unobserved household characteristics that may jointly influence sustainable agricultural practices (SAP) adoption and household welfare, this study employs distance to the nearest agricultural extension service center as an instrumental variable in the IV-probit model. The choice of this instrument is motivated by its strong relevance to SAP adoption decisions. Households located farther from extension service centers are less likely to receive timely agricultural information, training, and technical support on sustainable farming practices. Consequently, geographical proximity to extension services is expected to significantly influence farmers' probability of adopting SAP. Importantly, the validity of this instrument rests on the exclusion restriction, which assumes that distance to extension services affects household welfare only indirectly through SAP adoption. This assumption is plausible because the location of extension offices is exogenously determined by administrative and institutional planning rather than individual household welfare status. Moreover, after controlling for key covariates such as household income, education, farm size, and access to markets, geographical distance is not expected to exert a direct influence on household welfare outcomes. Therefore, variation in distance to extension services provides exogenous variation in SAP adoption that is not directly correlated with the error term in the welfare equation. This makes it an appropriate instrument for identifying the causal effect of SAP adoption on household welfare. The endogenous variable, SAP adoption intensity (Z-score), is instrumented using distance to extension services (DES), which captures household exposure to climate information and SAP-related advisory services. The instrument satisfies the relevance and exclusion restrictions required for identification.

First-stage equation:

$$Z_score_i = X_i\alpha + \gamma DES_i + v_i \quad (12)$$

Second-stage structural equation:

$$Poverty_Status_i^* = \beta_1 Z_score_i + X_i\beta_2 + \varepsilon_i \quad (13)$$

$Poverty_Status_i = 1$ if $Poverty_Status_i^* > 0$, 0 otherwise

The error terms v_i and ε_i are assumed to be jointly normally distributed with zero means, unit variance (for the probit disturbance), and a correlation coefficient ρ , such that:

$$\rho = \text{corr}(v_i, \varepsilon_i) \quad (14)$$

This parameter captures the extent of endogeneity between SAP adoption intensity and poverty status. A statistically significant ρ indicates the presence of endogeneity and justifies the IV-Probit specification. The same vector of exogenous covariates X_i is included in both equations and comprises AGE, MSTAT, HHS, EDUC, INC, LAND, FEXP, ASSO, EXT, LOAN, and LOWN.

4 Results

4.1 Demographic characteristics

The socioeconomic characteristics of rural households were presented in Table 1. The result showed that more than thirty percent (30.81%) of the household heads are within the age range of 36–45 years, with a mean age of 36 ± 10.64 years. This implies that a relatively large proportion of respondents are within their economically active and productive years. The implication is that most farmers are physically and cognitively capable of adopting Sustainable Agricultural Practices (SAP), which often require learning, adaptation, and consistent management. This may positively support SAP adoption, thereby enhancing household welfare through improved productivity and resource efficiency. The result further reveals that more than half (55.45%) of the household heads were married. This implies that most respondents operate within family-based decision-making units with dependents. This implies that married household heads may have stronger incentives to adopt sustainable practices to secure long-term food security and income stability. The implication is that SAP adoption among such households may translate into improved welfare through enhanced household consumption and reduced vulnerability. Household size indicates that above sixty percent (66.35%) of the respondents have 4–6 persons in their household, with a mean household size of 4 ± 1.79 persons. This implies that medium-sized households dominate the study area and there is availability of labour which may reduce dependence on hired labour, thereby lowering production costs and facilitating the implementation of labour-intensive sustainable practices such as mulching, intercropping, and organic manure application. The implication is that SAP adoption may be more feasible and welfare-enhancing in such households. The results revealed that most (33.65%) of respondents have no formal education, while others have varying levels of education up to tertiary level. This implies a mixed level of human capital among the farmers. Education is expected to influence awareness, comprehension, and adoption of SAP. The implication is that the lower educational attainment may reduce the likelihood of SAP adoption in the study area and this may have a negative influence on farmers' productivity and welfare in the long-run. The occupational distribution shows that 44.55% of respondents are primarily engaged in farming. This implies that agriculture is the main livelihood source in the study area. In relation to SAP and welfare, reliance on farming means that improvements in production efficiency through SAP are likely to translate directly into household welfare gains. The implication is that SAP-induced productivity improvements may have strong welfare effects in the study population.

For farm size, 41.71% of respondents cultivate between 1.01–2.00 hectares, with a mean cultivated area of 1.81 ± 1.36 hectares. This implies that smallholder farming predominates in the study area. In relation to SAP, small farm sizes may either facilitate or constrain adoption depending on the practice, but generally, SAP such as soil conservation and integrated farming systems are more manageable on small plots. The implication is that SAP adoption among smallholders may improve land productivity and household welfare through higher output per hectare. The mean farming experience is 5.32 ± 5.49 years, with 88.15% of respondents having less than 10 years of experience. This implies that most farmers are relatively new in farming activities. The implication is that limited experience may reduce familiarity with sustainable techniques, potentially slowing adoption. The result revealed that 54.98% of respondents do not belong to any cooperative or farmer organization. This implies weak social capital and institutional participation; lack of group membership may limit exposure to sustainability innovations and collective learning. The implication is that strengthening farmer organizations may enhance SAP adoption and improve household welfare through better access to inputs, credit, and information. Access to extension services revealed that 61.61% of respondents have no extension contact. This

implies weak institutional support for agricultural knowledge dissemination, limited extension access may significantly constrain awareness and adoption of sustainable practices. The implication is that improving extension outreach is essential for promoting SAP and achieving welfare improvements among rural households. Land ownership status revealed that 81.04% of respondents own their farmland. This implies relatively high tenure security among farmers, secure land ownership encourages long-term investment in soil fertility and conservation practices. The implication is that land tenure security is likely to promote SAP adoption, thereby enhancing productivity and improving household welfare in the long run.

Table 1 Socioeconomic characteristics of the farmers

Variable	Frequency	Percentage	Mean	Standard deviation
Age (years)				
1-25	48	22.75	36	10.64
26-35	55	26.07		
36-45	65	30.81		
46-55	31	14.69		
>55	12	5.69		
Total	211	100.00		
Marital status				
Single	10	4.74		
Married	117	55.45		
Divorced	84	39.81		
Total	211	100.00		
Household size (number of persons)				
1-3	64	30.33	4	1.79
4-6	140	66.35		
7-9	7	3.32		
Total	211	100.00		
Level of education				
No formal education	71	33.65		
Primary	18	8.53		
Senior secondary	50	23.70		
NCE/OND	46	21.80		
HND/BSc	26	12.32		
Total	211	100.00		
Major occupation				
Civil servant	41	19.43		
Farming	94	44.55		
Others	22	10.43		
Trading	54	25.59		
Total	211	100.00		
Area cultivated				
<1.00	1	0.47	1.81	1.36
1.01-2.00	88	41.71		
2.01-3.00	31	14.69		
3.01-4.00	84	39.81		

4.01-5.00	3	1.42		
>5.00	4	1.90		
Total	211	100.00		
Farming experience				
<10	186	88.15	5.32	5.49
10-20	19	9.00		
21-30	6	2.84		
Total	211	100.00		
Membership of association				
No	116	54.98		
Yes	95	45.02		
Total	211	100.00		
Access to extension services				
No	130	61.61		
Yes	81	38.39		
Total	211	100.00		
Land ownership				
Owned	171	81.04		
Rent	34	18.96		
Total	211	100.00		

Source: Data analysis, 2026

4.2 Sustainable agricultural practices (SAPs) adopted by the farmers

The distribution of sustainable Agricultural practices (SAP) adopted by rural households is presented in Table 2. The result showed a generally high level of adoption of several SAP components, although the pattern indicates a clear distinction between widely adopted practices that are relatively low-cost and short-term, and less adopted practices that require higher investment, labour, or long-term planning. The result revealed that above half (60.66%) of respondents practice intercropping. This implies that most farmers integrate multiple crops on the same plot. Intercropping enhances land-use efficiency, stabilizes output under climate variability, and reduces production risk. The implication is that this practice supports more stable farm income and improves household welfare through reduced exposure to shocks. Mixed farming is practiced by more than two-third (75.83%) of respondents integrates both crop and livestock systems, mixed farming promotes resource recycling, income diversification, and risk spreading. The implication is that households adopting this system are better insulated against income fluctuations, thereby improving welfare stability.

Crop rotation is adopted by more than seventy percent (71.56%) of respondents. This implies that a large proportion of farmers maintain soil fertility through sequential cropping patterns, crop rotation improves soil health, reduces pest build-up, and sustains long-term productivity. The implication is that this practice supports continuous farm output and contributes to long-term household welfare improvement. Integrated pest management (IPM) is adopted by more than half (52.61%) of respondents. This implies moderate adoption of environmentally friendly pest control strategies, the implication is that although adoption is not universal, these practices contribute to cost savings and improved net farm returns where implemented. Compost use is reported by more than seventy percent (76.30%) of respondents, indicating high reliance on organic soil fertility management. This implies that many farmers prioritize soil health through

locally available inputs, compost improves soil structure and nutrient availability while reducing dependence on inorganic fertilizers. The implication is that this practice significantly contributes to productivity enhancement and household welfare through reduced input costs and improved yields.

Organic manure or fertilizer use records the highest adoption rate at 91.94%. This implies that almost all farmers engage in at least one form of organic soil fertility management, this reflects a strong preference for affordable and accessible sustainability practices. The implication is that this widespread adoption is likely a key driver of productivity gains and welfare improvements in the study area. In contrast, adoption of more capital-and knowledge-intensive practices remains low. Mulching is practiced by 40.76% of respondents, agroforestry by 26.54%, and conservation tillage by 27.01%. This implies that long-term soil conservation and ecosystem-based practices are less widely adopted. These practices are critical for climate resilience, soil regeneration, and long-term sustainability. The implication is that limited adoption may constrain future productivity growth and weaken long-term welfare gains, especially under increasing climate stress.

Table 2 SAPs adopted by the farmers

Sustainable agricultural practices	Frequency	Percentage
Intercropping		
No	83	39.34
Yes	128	60.66
Total	211	100.00
Mixed farming		
No	51	24.17
Yes	160	75.83
Total	211	100.00
Crop rotation		
No	60	28.44
Yes	151	71.56
Total	211	100.00
Integrated pest management		
No	100	47.39
Yes	111	52.61
Total	211	100.00
Natural pest predator		
No	107	50.71
Yes	104	49.29
Total	211	100.00
Mulching		
No	125	59.24
Yes	86	40.76
Total	211	100.00
Compost		
No	50	23.70
Yes	161	76.30
Total	211	100.00
Agroforestry practice		

No	155	73.46
Yes	56	26.54
Total	211	100.00
Conservation tillage		
No	154	72.99
Yes	57	27.01
Total	211	100.00
Organic manure/fertilizer		
No	17	8.06
Yes	194	91.94
Total	211	100.00

Source: Data analysis, 2026

4.3 Poverty estimates

The poverty estimates of rural households are presented in Table 3. The results showed that mean total household income is ₦170,512.30 $\pm$ 199,248.10. This indicates a very high dispersion in income levels across households, suggesting substantial inequality in earnings within the study area. The implication is that while a small proportion of households earn relatively high incomes, a large share remained economically vulnerable, reflecting uneven welfare outcomes. The mean per capita income is ₦54,292.71 $\pm$ 58,740.28. This implies that income distribution at the individual household member level is also highly unequal. The implication is that average income levels mask significant deprivation among poorer households, thereby understating the depth of vulnerability. The estimated poverty line is ₦36,195.14, and the poverty headcount ratio is 0.559. This implies that 55.9% of the sampled households live below the poverty line, this indicates that more than half of rural farming households are poor. The implication is that poverty remains widespread in the study area, and household welfare is generally low despite engagement in agricultural activities.

The poverty depth index is 0.193. This implies that, on average, poor households would require about 19.3% of the poverty line income to move out of poverty, this suggests that poverty is moderately deep. The implication is that a substantial income gap exists between poor households and the poverty threshold, requiring meaningful income-enhancing interventions. The poverty severity index (squared poverty gap) is 0.090, this implies that 9% of the rural households are the poorest among the poor. The implication is that some households experience more severe deprivation than others, the implication is that poverty is unevenly distributed within the poor population, necessitating targeted interventions for the most vulnerable households.

Table 3 Poverty estimates among the rural households

Variable	Mean	Std. Dev.
Total household income	170512.300	199248.100
Mean per capita income	54292.710	58740.280
Poverty line	36195.140	0.000
Poverty headcount	0.559	0.498
Poverty depth	0.193	0.230
Poverty intensity	0.090	0.143

Source: Data analysis, 2026

4.4 Determinants of SAP Adoption

The Poisson regression results presented in Table 4 identify the significant determinants of sustainable agricultural practices (SAPs) adoption among rural households, with marginal effect providing the magnitude of each influence. The model is statistically significant (Wald $\chi^2 = 582.95$, $p < 0.01$), confirming that the selected variables jointly explain variation in SAP adoption intensity. The result revealed that age has a negative and significant effect on SAP adoption, the marginal effect revealed that 1% increase in age will likely reduce SAP adoption by 3.3%. This implies that older farmers adopt fewer SAP components, this suggests that flexibility, openness to innovation, and adaptability decline with age. The implication is that ageing farmers are less likely to benefit fully from SAP-driven productivity gains, thereby limiting potential welfare improvements unless targeted support is provided.

Level of education has a positive and highly significant effect on SAP adoption, the marginal effect revealed that 1% increase in years spent in school will probably increase SAP adoption by 13.9%. This implies that educated farmers adopt more SAP components, education enhances farmers' ability to understand environmental and economic benefits of sustainable practices. The implication is that human capital development is a key pathway through which SAP adoption translates into improved productivity and welfare outcomes.

Farming experience is also positive and highly significant on SAP adoption, the marginal effect revealed that 1% increase in farming experience will probably increase SAP adoption by 15.6%. This implies that more experienced farmers adopt a greater number of SAP components, this is because experience improves managerial ability and risk perception. The implication is that accumulated farming knowledge strengthens adoption behaviour, thereby enhancing productivity and household welfare over time.

Membership of association significantly increases SAP adoption, the marginal effect revealed that 1% increase in membership status will probably increase SAP adoption by 84.5%. This implies that farmers in cooperatives adopt substantially more SAP than non-members, this highlights the importance of social capital in facilitating information sharing, peer learning, and collective action. The implication is that strengthening farmer organizations can significantly enhance SAP diffusion and improve rural welfare through improved access to inputs, credit, and knowledge.

Access to loan has a negative and significant effect on SAP adoption, the marginal effect revealed that farmers that have access to loan are more likely to reduce SAP adoption by 60.7% than their counterparts. This implies that credit access is associated with lower SAP adoption intensity, this suggests inefficiencies in credit allocation or use, where borrowed funds may not be directed toward sustainable investments. The implication is that financial interventions must be better aligned with SAP objectives to ensure that credit contributes to productivity growth and welfare improvement.

Land ownership has a strong positive and highly significant effect on SAP adoption. This implies that landowners adopt significantly more SAP components than non-owners, secure tenure encourages long-term investment in soil conservation and sustainable land management. The implication is that land tenure security is a fundamental structural driver of SAP adoption and a key pathway for sustainable welfare improvement.

Awareness of SAP is also positive and highly significant, the marginal effect revealed that farmers that are aware of SAP are more likely to adopt. This implies that awareness substantially increases the number of SAP components adopted, this demonstrates that information access is a critical determinant of behavioural change. The implication is that strengthening extension

services and awareness campaigns will significantly enhance SAP adoption and, consequently, household welfare.

Table 4 Poisson regression estimates of determinants of SAP adoption

Variable	Coef.	Robust Std. Err.	z	P>z	dy/dx
Age	-0.006**	0.003	-2.070	0.038	-0.033
Marital status	-0.019	0.059	-0.330	0.743	-0.111
Household size	-0.017	0.012	-1.430	0.153	-0.096
Level of education	0.024***	0.004	5.420	0.000	0.139
Income from major occupation	8.22E-08	6.95E-08	1.18	0.237	4.72E-07
Farming experience	0.027***	0.003	8.610	0.000	0.156
Membership of association	0.147**	0.066	2.240	0.025	0.845
Access to extension services	-0.026	0.074	-0.350	0.723	-0.150
Access to loan	-0.106**	0.051	-2.070	0.038	-0.607
Landownership	0.481***	0.071	6.810	0.000	2.761
Awareness of SAP	0.253***	0.042	5.980	0.000	1.450
Constant	1.035***	0.114	9.090	0.000	
Diagnostic statistics					
Wald chi ² (11)	582.95***				
Prob > chi ²	0.000***				
Pseudo R ²	0.0946				
Log pseudolikelihood	-407.021				

Source: Data analysis, 2026

***, ** and * means significant at 1%, 5% and 10% respectively.

4.5 Composite index of SAP adoption

4.5.1 Retained factors

To address the multidimensional nature of sustainable agricultural practices (SAPs), exploratory factor analysis was employed to construct a composite SAP adoption index from the ten observed practices. The use of factor analysis was motivated by the fact that SAP adoption is a latent construct that cannot be adequately represented by any single practice. Instead, farmers often adopt several complementary practices simultaneously, making factor analysis an appropriate data reduction technique for capturing the common underlying dimension of sustainable farming behaviour. The factor extraction results as shown in Table 5 indicate that four factors had variance values greater than one, jointly explaining 67.41% of the total variation in SAP adoption behaviour. Specifically, the first factor accounted for 20.60% of the total variance, followed by the second (16.97%), third (16.61%), and fourth (13.23%) factors. The cumulative variance explained exceeds the commonly recommended threshold of 60%, suggesting that the retained factors adequately capture the underlying variation in farmers' adoption of sustainable agricultural practices. Consequently, the factor solution provides a reliable representation of the multidimensional adoption behaviour observed among rural households.

Table 5 Number of retained factors

Factor	Variance	Difference	Proportion	Cumulative
Factor1	2.05968	0.36221	0.2060	0.2060
Factor2	1.69747	0.03621	0.1697	0.3757
Factor3	1.66126	0.33817	0.1661	0.5418
Factor4	1.32309	.	0.1323	0.6741

Source: Data analysis, 2026

4.5.2 Factor loading, uniqueness and communalities

The factor loadings as shown in Table 6 further demonstrate that all SAP indicators contribute meaningfully to the latent adoption construct. Compost application records the highest loading (0.8883), followed by organic manure/fertilizer use (0.8711), integrated pest management (0.8419), natural pest predator (0.7827), and intercropping (0.7736). These relatively high loadings indicate that these practices contribute most strongly to explaining variation in sustainable agricultural practices behaviour among the sampled households. Similarly, conservation tillage (0.6491), agroforestry (0.6430), mulching (0.6901), crop rotation (0.4615), and mixed farming (0.4488) also load positively on the retained factors, indicating that they form important components of the overall SAP adoption framework, although with relatively smaller contributions.

The communality estimates further confirm the suitability of the selected indicators. The communalities range from 0.4704 for mixed farming to 0.8079 for compost application, indicating that between 47.0% and 80.8% of the variation in each observed practice is explained by the common latent factors. Correspondingly, the uniqueness values are generally low, ranging from 0.1921 to 0.5296, suggesting that most of the variability in the SAP indicators is shared rather than being practice-specific. This confirms that the selected practices measure a common underlying construct and justifies their aggregation into a single adoption index.

Table 6 Factor score, uniqueness and communality estimates

Variable	Factor Score	Uniqueness	Communality
Intercropping	0.7736	0.2970	0.703
Mixed farming	0.4488	0.5296	0.4704
Crop rotation	0.4615	0.3575	0.6425
Integrated pest management	0.8419	0.2868	0.7132
Natural pest predator	0.7827	0.3374	0.6626
Mulching	0.6901	0.2996	0.7004
Compost	0.8883	0.1921	0.8079
Agroforestry practice	0.6430	0.4574	0.5426
Conservation tillage	0.6491	0.2742	0.7258
Organic manure/fertilizer	0.8711	0.2269	0.7731

Source: Data analysis, 2026

Following factor extraction, the predicted factor scores were generated and subsequently normalized to produce a standardized SAP adoption index. Normalization transformed the factor scores into a bounded measure that facilitates interpretation and comparison across households while preserving the relative ranking of adoption intensity. The normalized SAP index was then employed as the potentially endogenous explanatory variable in the Instrumental Variable Probit (IV-Probit) model to examine whether adoption of sustainable agricultural practices improves

household welfare. Using a normalized composite index rather than individual practices minimizes multicollinearity, reduces measurement error associated with single-practice indicators, and more accurately reflects the multidimensional nature of sustainable agricultural adoption.

4.6 Welfare implication of SAPs adoption

Results in Table 7 presents the estimates of the instrumental variable probit (IV-Probit) model used to examine whether the adoption of sustainable agricultural practices (SAPs) improves household welfare. The IV-Probit estimator was employed because SAP adoption is potentially endogenous; unobserved factors such as managerial ability, entrepreneurial skills, and farmers' motivation may simultaneously influence both the decision to adopt SAPs and household welfare. Failure to account for this endogeneity would produce biased and inconsistent estimates. To address this concern, distance to the nearest extension centre was used as an instrumental variable. The rationale is that farmers located farther from extension centres are less likely to receive information and technical support required for SAP adoption, while distance does not directly determine household poverty after controlling for other socioeconomic characteristics. The diagnostic statistics validate the use of the IV-Probit model. The overall model is highly significant (Wald $\chi^2 = 140.71$; $p < 0.01$), indicating that the explanatory variables jointly explain household poverty status. More importantly, the estimated correlation between the error terms of the SAP adoption and welfare equations is positive and statistically significant ($\text{corr}(e.Z_score, e.Status) = 0.705$; $p < 0.01$). This confirms the presence of endogeneity, implying that unobserved factors jointly influence SAP adoption and household welfare. Consequently, estimating a conventional probit model would have produced biased estimates, thereby justifying the use of the IV-Probit estimator. Likewise, the significant estimate of the standard deviation of the first-stage disturbance term ($\text{sd}(e.Z_score) = 0.652$; $p < 0.01$) further supports the presence of substantial unobserved heterogeneity in SAP adoption.

The estimated marginal effect of the SAP composite adoption index (Z-score) is negative and highly significant. The marginal effect of -0.757 indicates that a 1% increase in normalized SAP composite index reduces the probability of a household being poor by approximately 75.7%, holding other factors constant. The finding provides strong evidence that adoption of sustainable agricultural practices substantially improves household welfare by reducing poverty. The result suggests that farmers who adopt a greater number of sustainable practices benefit from improved soil fertility, more efficient resource utilization, enhanced productivity, lower production risks, and greater resilience to environmental shocks, all of which translate into higher incomes and improved living standards. This finding directly supports the study hypothesis that SAP adoption contributes significantly to poverty reduction among rural farming households.

Age has a negative and statistically significant effect on poverty, with a marginal effect of -0.096 . This implies that an increase in the age of the household head by 1% reduces the probability of being poor by 9.6%. The result suggests that older farmers may have accumulated productive assets, farming knowledge, and stronger social networks over time, enabling them to better manage agricultural activities and improve household welfare.

Marital status positively influences poverty at the 10% significance level. The marginal effect indicates that being married increases the probability of household poverty by 65.1% compared to their unmarried counterparts. This may reflect the greater financial responsibilities associated with larger family obligations, which increase household consumption needs and place pressure on available income, particularly where farm productivity remains low.

Table 7 IV-Probit estimates of impact of SAP adoption on household welfare

Variable	dydx	Robust Std. Err.	z	P>z
SAP adoption composite score	-0.757***	0.261	-2.900	0.004
Age	-0.096***	0.024	-4.000	0.000
Marital status	0.651*	0.354	1.840	0.066
Household size	0.572***	0.164	3.490	0.000
Level of education	0.076**	0.031	2.440	0.015
Income from major occupation	1.19E-07	6.20E-07	0.19	0.847
Area cultivated	0.040	0.172	0.230	0.815
Farming experience	0.117***	0.034	3.480	0.001
Membership of association	-1.071*	0.626	-1.710	0.087
Access to extension services	0.802	0.745	1.080	0.282
Access to loan	-1.236***	0.403	-3.060	0.002
Landownership	-0.308	0.491	-0.630	0.531
Constant	0.753	0.870	0.870	0.386
Diagnostic statistics				
corr(e.Z_score,e.Status)	0.705***	0.150		
sd(e.Z_score)	0.652***	0.037		
Wald chi ² (12)	140.71			
Prob > chi ²	0.000***			

Source: Data analysis, 2026

***, ** and * means significant at 1%, 5% and 10% respectively.

Household size has a positive and highly significant marginal effect (0.572, $p < 0.01$), indicating that 1% increase in household member increases the probability of being poor by 57.2%. Although larger households may provide additional family labour, they also increase dependency and consumption requirements, the additional labour generated may not sufficiently offset the increased household expenditure, thereby increasing the likelihood of poverty.

Education exhibits a positive and statistically significant association with poverty status. The marginal effect of 0.076 ($p < 0.05$) indicates that a 1% increase in years of schooling increases the probability of being poor by 7.6%. This suggests that, within the study context, farmers with higher levels of education are more likely to fall within the poor category. A plausible explanation is that more educated farmers may allocate part of their time and resources to non-farm activities or salaried employment, thereby reducing their commitment to farming and the welfare gains derived from it.

Farming experience significantly influences household welfare. The marginal effect (0.117) suggests that experience substantially affects poverty outcomes through improved managerial ability, better production decisions, and more efficient resource utilization. Experienced farmers are generally better equipped to cope with production uncertainties and maximize the benefits derived from sustainable agricultural practices.

Membership of farmers' associations is statistically significant at the 10% level with a marginal effect of -1.071 . This indicates that belonging to farmer organizations significantly reduces the likelihood of household poverty. Membership facilitates access to information, extension support, production inputs, credit opportunities, and collective marketing, thereby strengthening household livelihoods and improving welfare.

Access to credit also has a negative and highly significant effect on poverty. The marginal effect indicates that access to credit substantially reduces the probability of household poverty. Credit enables farmers to purchase quality inputs, adopt sustainable agricultural technologies, expand production, and smooth consumption during adverse periods. Consequently, improved financial inclusion strengthens the poverty-reducing effects of SAP adoption.

In all, the IV-Probit results demonstrate that adoption of sustainable agricultural practices significantly improves household welfare by reducing the probability of poverty, even after correcting for endogeneity. The results further highlight that the socioeconomic characteristics complement welfare-enhancing effects of SAP adoption. The significant endogeneity diagnostics confirm that correcting for self-selection into SAP adoption is essential to obtain consistent estimates.

5 Discussion

5.1 Household characteristics and sustainable agricultural practice adoption

The socioeconomic characteristics of the sampled households indicate that the farming population possesses considerable potential for the adoption of sustainable agricultural practices (SAPs). The relatively young mean age of 36 years suggests that most respondents are within their economically active years and are physically capable of implementing labour- and knowledge-intensive farming practices. Similar observations have been reported among farming households where the predominance of economically active adults was considered advantageous for agricultural production because of their ability to undertake physically demanding farm operations and adapt to improved production practices [40, 57, 13]. However, the regression results revealed that age negatively influenced SAP adoption, indicating that younger farmers were more likely to adopt sustainable practices than their older counterparts. This finding suggests that although the farming population is relatively young, younger farmers remain more receptive to innovation, while older farmers may be more inclined to rely on established production methods. This finding is consistent with previous studies showing that younger farmers were more likely to adopt labour-intensive sustainable land management practices, particularly soil and water conservation technologies, whereas older farmers tended to favour less physically demanding innovations [24, 47, 6, 58, 15].

The predominance of married households and medium-sized families reflects the family-based nature of agricultural production in the study area. Similar household structures have been reported among smallholder farmers, where marriage was considered important for farm enterprise development because spouses jointly contribute to agricultural production and household management [19]. Likewise, moderate household sizes provide an important source of family labour for farming activities, particularly in smallholder production systems where hired labour is often limited [70, 13]. Nevertheless, the welfare analysis indicates that larger households face a significantly higher likelihood of poverty, suggesting that the increased consumption burden associated with additional household members outweighs the productive benefits derived from family labour. Similarly, the positive association between marital status and poverty implies that greater household responsibilities may constrain household welfare despite continued engagement in farming. This observation supports earlier findings that although larger households can improve labour availability, they also increase household expenditure on food and other basic needs, thereby heightening the risk of food insecurity and poverty when productivity gains are insufficient to offset rising consumption demands [13].

Education emerged as one of the strongest determinants of SAP adoption, demonstrating that human capital enhances farmers' ability to understand, evaluate, and implement sustainable production practices. Educated farmers are generally more capable of interpreting technical information, appreciating the long-term benefits of conservation practices, and making informed production decisions. This finding corroborates previous studies which reported that education positively facilitates the adoption of agricultural innovations and sustainable farming technologies by improving farmers' managerial capacity and receptiveness to new information [57, 9, 71, 50, 55]. Similarly, farming experience positively influenced SAP adoption, suggesting that accumulated practical knowledge enables farmers to better evaluate production risks and appreciate the benefits of integrating sustainable practices into their farming systems. This finding agrees with previous studies showing that years of farming experience enhance farmers' knowledge, technical competence, and confidence in adopting improved agricultural technologies [20, 8, 71, 50].

Institutional characteristics further reinforce these findings. Although the descriptive statistics reveal limited extension contact and relatively low participation in farmer organizations, both membership in farmer associations and awareness significantly increased the likelihood of SAP adoption, underscoring the importance of social learning, collective action, and information dissemination in promoting sustainable agriculture. Farmer organizations facilitate knowledge sharing, improve access to agricultural information and inputs, and strengthen farmers' capacity to adopt new technologies through peer learning and institutional support. Similar positive effects of cooperative membership on technology adoption have been reported in the literature [37, 33, 50, 65, 55]. Likewise, extension services and agricultural training have consistently been identified as critical drivers of SAP adoption because they improve farmers' technical knowledge, expose them to improved production practices, and reduce information constraints associated with new technologies [71, 42, 35, 62]. Furthermore, secure land ownership significantly encouraged SAP adoption by providing farmers with the confidence to undertake long-term investments in soil conservation and sustainable land management. This finding is consistent with previous studies showing that secure access to land and larger farm holdings increase farmers' willingness to invest in environmentally sustainable technologies whose benefits accrue over time [30, 38, 6].

5.2 Sustainable agricultural practice adoption patterns

The adoption pattern demonstrates that farmers preferentially adopt sustainable agricultural practices that require relatively low financial investment while generating immediate production benefits. Organic manure, compost application, mixed farming, crop rotation, and intercropping recorded the highest adoption rates, suggesting that farmers favour practices based on locally available resources that improve soil fertility, reduce production costs, and stabilize farm output. Similar adoption patterns have been reported in previous studies where soil fertility management practices, crop rotation, mixed farming, intercropping, and integrated pest management ranked among the most widely adopted sustainable agricultural practices because they are relatively affordable, compatible with existing farming systems, and provide visible agronomic benefits within a short period [63, 40, 12]. Likewise, the high level of awareness and practice of crop rotation observed among farming households in an earlier study further supports the view that farmers are more willing to adopt practices that are familiar, require limited financial investment, and contribute directly to improved soil and water management [13]. The preference for these practices reflects the production realities of smallholder farmers, who typically operate under resource constraints and therefore prioritize technologies that minimize production costs while

improving productivity. Mixed farming, for instance, enables efficient recycling of farm resources by integrating crop and livestock enterprises, thereby reducing expenditure on external inputs through the use of crop residues as livestock feed and animal manure as organic fertilizer. Similarly, organic manure and compost application improve soil fertility using locally available materials, reducing dependence on costly inorganic fertilizers. Earlier studies have likewise shown that sustainable agricultural practices such as mixed farming, crop rotation, and integrated pest management contribute to higher profitability and productivity through reduced input costs, improved resource-use efficiency, and enhanced resilience to production risks [69, 12, 21].

Conversely, the comparatively lower adoption of agroforestry, conservation tillage, and mulching suggests that farmers are less inclined to adopt practices whose benefits are realized over a longer period or which require greater technical knowledge, higher labour inputs, or substantial initial investment. Similar observations have been reported in previous studies, where the adoption of sustainable agricultural practices remained relatively low because farmers lacked adequate technical knowledge, extension support, and information regarding appropriate soil management techniques [53, 13]. Likewise, labour-intensive conservation practices have been found to be less attractive to farmers because of the physical demands associated with their implementation, particularly where access to labour-saving technologies is limited [15]. Findings from Burkina Faso and related studies also showed that successful adoption of multiple sustainable agricultural technologies depends not only on farmers' willingness but also on access to technical training, climate information, adaptation information, credit, and institutional support [26, 71, 35, 65].

5.3 Household poverty and welfare

Despite widespread engagement in agriculture, poverty remains pervasive among rural households in the study area. More than half of the sampled households fall below the estimated poverty line, indicating that participation in agricultural production alone is insufficient to guarantee satisfactory living standards. This finding is consistent with earlier studies showing that smallholder farming households in Nigeria and other developing countries often remain poor despite active involvement in agriculture, largely because production is undertaken at a subsistence scale and is constrained by low productivity, limited asset endowment, and unstable returns to farming. For instance, a substantial proportion of farming households experienced food insecurity despite depending heavily on agriculture for their livelihoods [13], while smallholder farmers who had not fully adopted eco-friendly agricultural practices were characterized by weak welfare outcomes, reflecting the fragility of rural livelihoods under low-input production systems [55].

The poverty depth and severity indices further demonstrate that many poor households remain substantially below the poverty threshold, suggesting that poverty in the study area is not merely widespread but also intense and persistent. This indicates that a considerable proportion of rural households face chronic deprivation and are highly vulnerable to adverse shocks, including low farm productivity, rising input costs, climatic variability, and fluctuations in output prices. Similar concerns emerge from previous studies which show that rural households often experience significant welfare constraints because agricultural production is not sufficiently remunerative to offset the burden of household consumption and livelihood risks. For example, food insecurity persisted partly because household resources were inadequate to guarantee stable access to preferred and sufficient food [13], while welfare analysis showed that even among adopters of eco-friendly agricultural practices, welfare gains could remain weak where farmers operated under severe resource limitations and low production economies of scale [55].

These findings suggest that productivity constraints, limited access to productive resources, market imperfections, and institutional weaknesses continue to undermine rural livelihoods. Smallholder farmers often operate on limited landholdings, depend heavily on family labour, face inadequate access to extension services, credit, and technical information, and are exposed to market and production risks that reduce the welfare returns to farming. Similar explanations have been advanced in previous studies, where low productivity, poor institutional support, and restricted access to productive assets were identified as major constraints to improved welfare and food security among farm households [53, 55, 13]. The persistence of poverty among farming households therefore implies that agricultural participation alone is not enough; rather, welfare improvement depends on the extent to which farming systems can generate sustained productivity growth, stable income, and resilience to shocks.

Sustainable agricultural practices represent an important pathway for improving long-term household welfare. By enhancing soil fertility, conserving moisture, improving resource-use efficiency, lowering dependence on costly external inputs, and reducing exposure to pest, soil degradation, and climate-related risks, SAPs can strengthen the productivity and profitability of smallholder farming systems. Previous studies have similarly argued that the promotion and adoption of sustainable agricultural practices can improve household welfare through higher productivity, increased income, and reduced food insecurity [46, 54, 12]. The implication is that policies aimed at reducing rural poverty should not focus solely on expanding agricultural participation, but also on promoting farming practices and institutional arrangements that improve the efficiency, resilience, and welfare returns of agricultural production.

5.4 Determinants of sustainable agricultural practice adoption

Human capital variables play an important role in shaping the intensity of SAP adoption. Education and farming experience significantly increased adoption intensity, whereas age exerted a negative influence, indicating that knowledge acquisition, practical farming skills, and openness to innovation are central to sustainable agricultural decision-making. The positive effect of education suggests that educated farmers are better able to understand, evaluate, and implement improved farming practices, particularly those that require technical knowledge and long-term planning. This agrees with earlier studies which reported that education enhances farmers' capacity to process information, appreciate the benefits of improved technologies, and adopt sustainable practices more readily [56, 9, 71, 50, 55]. Similarly, the positive effect of farming experience implies that farmers who have spent more years in agriculture are better positioned to assess production risks, learn from past outcomes, and integrate sustainable practices into their farming systems. This is consistent with earlier studies showing that accumulated farming experience improves technical competence and increases the likelihood of adopting agricultural innovations [20, 8, 70, 50]. By contrast, the negative effect of age suggests that younger farmers are more inclined to adopt sustainable practices than older farmers, who may be more attached to conventional production methods. Similar findings have been reported in previous studies, where younger farmers were generally more willing to adopt sustainable agricultural technologies, particularly those that are labour-intensive or require adjustment to existing production practices [24, 48, 6, 58].

Institutional variables also strongly influenced adoption behaviour. Membership in farmer associations significantly increased SAP adoption, indicating that collective action and social learning remain important channels through which farmers gain access to information, training, and productive resources. Farmer organizations often facilitate knowledge exchange, improve access to agricultural innovations, and strengthen farmers' capacity to respond to production

challenges through peer learning and institutional support. This finding is consistent with previous studies showing that membership in farmer groups or cooperatives positively influences the adoption of improved and sustainable farming practices [36, 33, 50, 65, 55]. Likewise, awareness of sustainable agricultural practices significantly promoted adoption, reinforcing the central role of information dissemination in driving behavioural change. This finding supports the argument that farmers are more likely to adopt sustainable practices when they are adequately informed about their agronomic and economic benefits. Similar evidence has been reported in earlier studies, where awareness of irrigation, crop rotation, and drainage practices preceded adoption [13], and where agricultural training, technical support, and extension services were shown to increase farmers' adoption of sustainable practices [71, 42, 34].

Secure land ownership also significantly encouraged SAP adoption, suggesting that farmers with tenure security are more willing to undertake long-term investments that improve soil quality and environmental sustainability. Since many sustainable agricultural practices, such as soil fertility management, agroforestry, and conservation measures, generate benefits over time rather than immediately, farmers are more likely to adopt them when they are confident of retaining control over the land on which such investments are made. This result is in line with previous studies showing that secure access to land and larger farm holdings encourage farmers to invest in sustainable technologies with long-term payoffs [30, 39, 6].

An interesting finding is the negative relationship between access to credit and SAP adoption. Although credit is generally expected to relax liquidity constraints and facilitate technology adoption, the result suggests that borrowed funds may not necessarily be directed toward sustainable agricultural activities. Instead, loans may be diverted to household consumption, repayment of existing obligations, or conventional production practices that generate quicker financial returns. This finding aligns with the divergent evidence reported in the literature on the role of credit in technology adoption. While access to credit has been found to positively support the adoption of agricultural practices in some studies [1, 25], others reported no significant effect or showed that the direction of the effect depends on the specific technology combination being considered [45, 48]. The result therefore highlights the need to align agricultural credit programmes more closely with sustainable farming objectives through targeted financing mechanisms, better monitoring of credit use, and complementary technical support that encourages the productive use of borrowed funds in sustainable agricultural investments.

5.5 Welfare effect of sustainable agricultural practice adoption

The IV-Probit results provide robust evidence that sustainable agricultural practice adoption significantly improves household welfare after correcting for potential endogeneity. The significant correlation between the error terms of the adoption and welfare equations confirms that unobserved household characteristics simultaneously influence both SAP adoption and poverty status, thereby justifying the use of the instrumental variable approach. This supports the argument that adoption decisions are not random and that failure to account for self-selection and endogeneity may lead to biased and inconsistent estimates of welfare effects. Similar concerns were raised in earlier studies, where the presence of sample selectivity and unobserved heterogeneity justified the use of more rigorous estimation procedures such as MESR, heterogeneous treatment effect models, and other endogeneity-correcting approaches in evaluating the welfare effects of sustainable agricultural practices [10, 23, 27, 35, 55]. In particular, the significance of the selectivity correction terms reported in earlier studies and the emphasis on

hidden bias arising from unobserved factors both reinforce the need to correct for endogeneity when estimating the welfare impact of agricultural technology adoption [23, 55].

The negative and highly significant effect of the SAP composite adoption index demonstrates that increasing the intensity of sustainable agricultural practice adoption substantially reduces the probability of household poverty. This finding indicates that the combined adoption of multiple sustainable practices generates complementary benefits through improved soil fertility, enhanced resource-use efficiency, reduced production risks, increased resilience to environmental shocks, and higher agricultural productivity. Similar evidence from the literature suggests that the adoption of sustainable agricultural practices can improve household welfare by raising productivity, reducing input costs, and strengthening food security. For instance, the promotion and adoption of sustainable farm practices have been shown to offer an opportunity to improve productivity and income substantially while reducing food insecurity [46]. Increased engagement in sustainable agricultural practices has also been associated with reduced household food insecurity [53], while the adoption of integrated pest management, crop rotation, and mixed cropping has been linked to higher profit efficiency and better returns on investment among smallholder farmers [12]. Similarly, the adoption of improved crop varieties has been shown to contribute positively to household food security and per capita food consumption [66, 24, 35]. Evidence from earlier studies further demonstrates that the joint adoption of multiple sustainable agricultural practices can increase crop yields and strengthen food security because complementarities among technologies improve soil nutrient use, water efficiency, and resilience under production stress [23]. These studies support the present result that the welfare effect of SAP adoption is not limited to a single productivity channel, but rather emerges through the cumulative and complementary effects of multiple practices on production efficiency, profitability, and household welfare.

The welfare model further demonstrates that the benefits of SAP adoption are influenced by household socioeconomic characteristics. Older farmers were found to experience lower poverty, possibly because accumulated farming knowledge, productive assets, and stronger social networks improve their capacity to manage agricultural risks and make more efficient production decisions. This interpretation is consistent with earlier findings that age and farming experience can improve efficiency and welfare where they reflect greater practical knowledge and mastery of farm operations [4, 52]. Membership in farmer organizations and access to credit also reduced the likelihood of poverty, underscoring the importance of institutional support in strengthening rural livelihoods [3]. As reported in earlier studies, farmer organizations improve access to information, social learning, and production support, while credit relaxes financial constraints and facilitates investment in productivity-enhancing practices and inputs [36, 32, 49, 64]. In contrast, larger households and married households exhibited higher poverty risks, suggesting that the welfare burden associated with larger family size and household responsibilities may outweigh the productive gains from family labour. This observation is consistent with the argument advanced in earlier work that although household size may increase labour availability, it also raises food consumption and household expenditure, thereby increasing the likelihood of food insecurity and poverty when income growth is insufficient [13].

Overall, these findings indicate that sustainable agricultural practices significantly contribute to poverty reduction, but the magnitude of their welfare effects depends on the broader socioeconomic and institutional environment within which farmers operate. Similar conclusions emerge from the literature, which shows that the benefits of sustainable agricultural technologies are strengthened by access to extension services, agricultural training, cooperative membership,

climate and adaptation information, secure land ownership, and productive assets [70, 41, 34, 38, 6]. Consequently, maximizing the welfare benefits of SAP adoption requires complementary investments in farmer education, effective extension systems, secure land tenure, functional farmer organizations, and well-targeted rural financial services. These institutional and socioeconomic conditions enhance farmers' capacity to adopt sustainable technologies effectively and ensure that the productivity gains from adoption translate into sustained poverty reduction and improved rural welfare.

6 Conclusion

This study examined the determinants of sustainable agricultural practice (SAP) adoption and evaluated its effect on household welfare among smallholder farming households in Ogun State, Southwestern Nigeria. Using Poisson regression, the study identified the socioeconomic and institutional factors influencing the intensity of SAP adoption, while exploratory factor analysis was employed to construct a composite SAP adoption index that captures the multidimensional nature of sustainable farming behaviour. To account for the potential endogeneity of SAP adoption in the welfare equation, an instrumental variable probit (IV-Probit) model was estimated using distance to the nearest extension service centre as an instrument. The findings demonstrate that SAP adoption significantly improves household welfare by reducing the probability of poverty. This result remains robust after correcting for endogeneity, suggesting that investments in sustainable agricultural practices generate welfare benefits beyond their environmental advantages. The evidence indicates that farmers adopting a broader portfolio of sustainable practices are better positioned to improve resource-use efficiency, enhance resilience to production shocks, and strengthen their livelihood outcomes. The study further showed that adoption intensity is influenced by several household and institutional characteristics. Education, farming experience, membership of farmer associations, land ownership, and awareness of sustainable agricultural practices significantly promote SAP adoption, whereas increasing age and access to credit reduce adoption intensity. These findings highlight that adoption decisions are shaped not only by farmers' personal characteristics but also by institutional support systems and access to productive resources. The welfare analysis further reveals that household poverty is significantly associated with age, marital status, household size, education, farming experience, membership of farmer associations, and access to credit. While the positive association of education and farming experience with poverty appears contrary to conventional expectations, the result suggests that human capital and accumulated farming experience alone may not guarantee improved welfare where labour-market opportunities, commercialization, and productivity-enhancing investments remain limited. This finding underscores the importance of complementary institutional and economic conditions for translating household capabilities into improved welfare outcomes. The study makes an important contribution to the growing literature on sustainable agriculture by demonstrating that the welfare effects of SAP adoption should be evaluated using approaches that explicitly address potential endogeneity. By combining a multidimensional SAP adoption index with an IV-Probit framework, the study provides more reliable evidence on the welfare implications of sustainable agricultural practices than approaches that treat adoption as exogenous or rely on single-practice indicators. From a policy perspective, the findings suggest that efforts to promote sustainable agriculture should extend beyond encouraging adoption alone. First, strengthening agricultural extension systems is essential for increasing farmers' awareness and technical capacity to implement multiple sustainable practices. Improving the accessibility and effectiveness of extension services would enhance knowledge dissemination and facilitate wider

adoption of SAPs. Second, government and development partners should invest in programmes that strengthen farmer organizations because membership significantly enhances both SAP adoption and household welfare through improved information exchange, collective action, and access to productive resources. Third, interventions that improve land tenure security are likely to encourage long-term investments in sustainable land management practices. Fourth, rural financial programmes should be redesigned to ensure that agricultural credit is effectively linked to sustainable agricultural investments, given the observed disconnect between credit access and SAP adoption. Loan products tied to climate-smart and sustainable farming investments, accompanied by technical advisory services, may improve both adoption and welfare outcomes.

Despite these contributions, the study has some limitations. The analysis is based on cross-sectional data, which limits the ability to capture dynamic changes in adoption behaviour and welfare over time. Although the IV-Probit approach addresses endogeneity arising from unobserved factors, future studies could employ panel data or experimental and quasi-experimental designs to strengthen causal inference. Future research may also examine the heterogeneous welfare effects of individual SAP combinations across different farm sizes, agroecological zones, and gender groups to provide more targeted policy recommendations.

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Author contributions

Kazeem Aboaba: Conceptualization, Writing—original draft, Writing—review and editing, Formal analysis, Methodology, Conceptualization; Ayi Nsa: Writing—review and editing, Supervision, Conceptualization; Jamiu Wahab: Writing—review and editing, Conceptualization; Tohib Obalola: Writing- review and editing, Methodology; Alaba Akinsulu: Methodology, Supervision; Peace Nwaerema: Supervision, Writing—review and editing, project coordination.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval

The study protocol, including the survey instrument and procedures involving human participants, was reviewed and approved by the Research and Ethics Committee of the College of Agricultural Management and Rural Development (COLAMRUD), Federal University of Agriculture, Abeokuta, Nigeria, with Approval No. UNAAB/COLAMRUD/AEFM/PG/16/0653. Written informed consent was obtained from all participants prior to data collection, and participation was voluntary.

Ethical accordance

The study was conducted in accordance with the ethical requirements and guidelines of the Research and Ethics Committee of the College of Agricultural Management and Rural Development (COLAMRUD), Federal University of Agriculture, Abeokuta, and the ethical

principles of the Declaration of Helsinki. The privacy, anonymity, and confidentiality of all participants were maintained throughout the study, and the information collected was used solely for research purposes.

Consent to participate

Informed consent was obtained from all participants prior to their participation in the study. Participants were informed of the purpose of the study, that their participation was voluntary, and that they could decline to participate or withdraw at any time without any adverse consequences.

Consent to publish declaration

Not applicable.

Clinical trial number

Not applicable.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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