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Incorporating Climate Resilient Sustainable Agricultural Practices in Southwest Nigeria Smallholder Farming Systems

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Abstract: Smallholder farmers in Southwest Nigeria face increasing production risks due to climate change, as their farming systems are largely rain-fed and most farms are smaller than three hectares. Although previous studies have documented farmers' perceptions and coping responses, limited attention has been given to the combined use of sustainable agricultural practices (SAPs) as scalable resilience strategies. This paper addresses this gap by drawing on original survey data from 500 smallholder households across the six states of Southwest Nigeria, supplemented by a structured literature review of regional evidence. The determinants of adoption and the resilience outcomes of high-impact SAP combinations were examined using logistic and multiple regression models. The results show that integrated SAP bundles, particularly cover cropping, crop rotation, agroforestry, and organic soil amendments,



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generate greater resilience gains than single practices. Farms adopting four or more SAPs remained productive during periods of moderate climate stress, with yield stability exceeding 80%. Institutional access to extension services emerged as the strongest institutional predictor of increased SAP integration. Based on these findings, the study proposes a four-pillar framework focused on context-specific practice selection, capacity building, institutional support, and knowledge systems. The results provide policymakers, development programmes, and extension agencies with practical policy implications for enhancing climate resilience in Southwest Nigeria and comparable agro-ecological systems.

Keywords: sustainable agriculture; smallholder farming; climate change adaptation; Southwest Nigeria; climate-smart agriculture; agroforestry; food security.

将气候韧性可持续农业实践融入尼日利亚西南部小农农业系统

摘要：尼日利亚西南部的小农户正面临气候变化带来的日益增加的生产风险，因为其农业生产系统主要依赖雨养农业，且大多数农场面积小于三公顷。尽管以往研究已经记录了农户对气候变化的认知及其应对措施，但对于将可持续农业实践（SAPs）组合作为可规模化韧性策略的研究仍然有限。本文通过利用尼日利亚西南部六个州500户小农家庭的原始调查数据，并结合区域证据的结构化文献综述，弥补了这一研究空白。本研究采用逻辑回归和多元回归模型，考察了可持续农业实践采纳的决定因素以及高影响力SAP组合的韧性结果。研究结果表明，综合性SAP组合，特别是覆盖作物、轮作、农林复合经营和有机土壤改良措施，比单一实践能够带来更大的韧性提升。采纳四种或更多SAPs的农场在中等气候压力时期仍能保持生产力，其产量稳定性超过80%。获得农业推广服务的制度性渠道被证明是促进SAP整合程度提高的最强制度性预测因素。基于这些发现，本研究提出了一个四支柱框架，重点包括因地制宜的实践选择、能力建设、制度支持和知识系统。研究结果为政策制定者、发展项目和农业推广机构提供了实践性政策启示，有助于增强尼日利亚西南部及类似农业生态系统中的气候韧性。

关键词：可持续农业实践；小农农业系统；气候韧性；气候变化适应；尼日利亚西南部；气候智慧型农业；农林复合经营。

1. Introduction

Smallholder agriculture in Sub-Saharan Africa is already being destabilized by climate change, with significant potential consequences for food security, incomes, and rural livelihoods (Lipper et al., 2014; Thornton et al., 2011). This particularly exposes Nigeria as the agriculture industry is mostly rain-fed and smallholder-dominated. In Southwest Nigeria (Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti), the planting calendar is weakening due to warmer temperatures and rainfall imbalances. This leads to more frequent extremes that increase the risk of crop production (Sylla et al., 2016; Dosio & Panitz, 2016).

These weather pressures combine with systemic structural limitations: small-scale farms, inadequate irrigation, limited access to credit, and under-resourced extension services. Farmers are adapting, though

adoption of practice types is not balanced, particularly of information-intensive and input-intensive options. This leaves a time difference between adaptation awareness and effectiveness.

The core policy challenge is therefore to move beyond documenting whether adaptation occurs toward understanding how to integrate SAPs into coherent, scalable bundles that are scalable to enhance resilience across diverse local conditions. Available literature offers useful information regarding the perceptions of farmers and individual practices, yet a smaller number of studies offer operational instructions on the combinations of practices, motivations to adopt these practices, and the institutional channels to scale (Abid et al., 2015; Li et al., 2013; Adimassu & Kessler, 2016).

The research paper fills that gap by evaluating the most effective SAPs portfolios for use in smallholder

systems in Southwest Nigeria, identifying the factors that influence adoption intensity, and outlining the policy structure that can facilitate widespread adoption. The discussion is grounded in the ideals of Climate-Smart Agriculture and Sustainable Intensification, but it is applied to the realities of local farming systems.

It is against this backdrop that the study proposes to fill this gap by providing a solution to the lack of translation of climate change impact documentation into practical adaptation planning, by establishing an evidence-based framework through which SAPs can be incorporated into the smallholder farming systems of Southwest Nigeria. The research questions used in the study are:

1. Which are the most viable and SAPs that can be applied to smallholder farming systems in the agro-ecological environment of Southwest Nigeria?

2. What are the relationships between socio-economic and institutional factors that affect the use of SAPs by the smallholder farmers in the region?

3. Which mixes or packages of sustainable agricultural activities can produce the most benefits in climate resilience of smallholder farms when climate change is projected to occur?

4. Which policy and institutional frameworks are needed to upscale the integration of SAPs across Southwest Nigerian smallholder agriculture systems?

To answer these questions, the study is designed as an empirical cross-sectional study that will use a combination of primary survey data and a systematic literature review. Five hundred smallholder farm households were surveyed in Southwest Nigeria, and the data were used to determine the determinants of adoption, resilience, and effective SAPs combinations using regression and scenario-based analysis. It allows a relevant comparison of the level of integration with the policy considerations, without losing sight of the background of the observed farm-level conditions.

The rest of this paper will be organized as follows: Section 2 will describe climate trends, the smallholder system, relevant SAPs, and integration structures. The empirical methodology and analytical method are described in Section 3. The results are described in Section 4; the implications and the offered integration framework are discussed in Section 5; and the suggested improvements are presented in the conclusion in Section 6.

2. Literature Review

2.1 Climate Change Trends and Projections for Southwest Nigeria

This paper presents climate change trends and projections in Southwest Nigeria.

Over the past decades, there has been sustained warming and increased rainfall variability in southwest

Nigeria, though rainfall amounts have shown mixed year-to-year trends (Odekunle, 2004; Sylla et al., 2016). Farmers are reporting a rise in rainfall onset uncertainty, longer dry periods during seasons, and an increased frequency of heavy rainfall events, leading to floods and erosion (Adebisi-Adelani & Oyesola, 2014).

The regional forecasts show a further rise in temperatures until the middle of the century, with rainfall becoming less predictable, more erratic, and more severe (Dosio & Panitz, 2016; Sylla et al., 2016). In rain-fed systems, a combination of heat stress and rainfall instability increases production risk more than changes in annual rainfall totals. The literature thus favors a low-regret adjustment plan that focuses on practices that enhance soil moisture buffering, stabilize yields, and reduce exposure to climate shocks (Hallegatte, 2009).

2.2 Southwestern Nigeria Smallholder Farming Systems.

The Southwest Nigerian smallholder systems are generally 1-3 hectares in size, mostly rain-fed, and operate a mixed crop-livestock production system. This diversity offers some risk buffering and increased management complexity during climate stress. The major crops are maize, cassava, and yams, as well as vegetables and tree crops such as cocoa and oil palm.

The literature portrays a farming population that is both able and limited: there is ample and localized experience and knowledge, but restricted access to extension services, inexpensive credit, quality inputs, and market infrastructure. The following institutional constraints are the core of why high-impact innovations are not always adopted equally.

Investment behavior is further determined by land tenure arrangements. In regions where tenure is considered secure, farmers tend to embrace longer-term farming practices such as agroforestry and soil reclamation. In the case of uncertain tenure and access to credits, short-term production needs will prevail (Deininger & Feder, 2009). Any integration plan should thus incorporate agronomic recommendations and institutional facilitation.

2.3 Climate Change Adaptation through sustainable Agricultural practices.

The literature narrows to five SAPS clusters with direct implications for Southwest Nigeria. To begin with, soil and water conservation practices (cover cropping, mulching, organic amendments, minimum tillage) enhance moisture retention, reduce erosion, and stabilize productivity (Poeplau et al., 2015; Hobbs et al., 2008). Second, diversification (crop rotation, intercropping, mixed farming, improved varieties) is an approach to risk distribution that decreases volatility in yields sensitive to climate (Cairns et al., 2013).

Third, agroforestry has high potential for adaptation and co-benefits, including microclimate control, soil enhancement, and diversified incomes, yet the adoption process is usually slow due to delayed payback and limited availability of planting material (Franzel et al., 2001; Mbow et al., 2014). Fourth, on-farm water technologies, such as rainwater collection and water-saving irrigation, are technically significant but are often constrained by their costs and maintenance requirements (Rockstrom et al., 2010). Fifth, information-based practices, such as weather advisories and participatory extension, are vital for making timely farm decisions but are poorly applied in situations where information is neither local, trusted, nor actionable (Hansen et al., 2011; Davis et al., 2012).

Within these clusters, there is an indication that the benefits of resilience are greater when practices are co-complemented rather than when they are advocated as isolated interventions.

2.4 Conceptualizations of Incorporating Sustainable Agricultural Practices.

Three frameworks are most applicable to SAPs integration in the region. Climate-smart agriculture focuses on meeting the three goals of productivity, adaptation, and mitigation (Lipper et al., 2014). Sustainable intensification focuses on the optimal utilization of resources on diminishing farmlands (Garnett et al., 2013). A socio-ecological systems perspective holds that adoption outcomes are influenced not only by farm-level decision-making but also by extension systems, markets, tenure, and collective action at the local level (Ostrom, 2009).

This systems perspective is supported by evidence in West Africa. Effective examples include the combination of technical practices, institutional support, and farmers' learning networks, as well as a regular implementation system (Sendzimir et al., 2011). In Southwest Nigeria, the researchers identified four useful design principles: context-specific targeting, promotion of SAPs bundles, direct treatment of adoption constraints, and coordination at farm, community, and policy levels.

3. Methodology

3.1 Research Design

The research design presented in this study is an empirical, cross-sectional study to investigate SAPs integration among smallholder farmers in Southwest Nigeria. A structured questionnaire that addressed socio-economic characteristics, SAPs adoption, climate exposure, and indicators of farm performance was used to collect primary data about 500 farm households in Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti.

The methodological workflow consisted of three steps, i.e., (i) systematic literature review to inform the conceptual and analytical framework; (ii) field data collection and cleaning; and (iii) statistical analysis consisting of descriptive profiling, regression modelling, and scenario analysis.

3.2 Literature Review Approach

The peer-reviewed journals and development-policy databases searched in Scopus, Web of Science, and Google Scholar served as the sources for the literature review (Section 2). A combination of terms such as climate change, smallholder agriculture, sustainable agricultural practice, climate-smart agriculture, Southwest Nigeria, West Africa, adaptations, agroforestry, soil conservation, and crop diversification was used as search terms. Published articles from 2000 to 2025 that focused on empirical research in Nigeria and tropical West Africa were deemed more important and thus reviewed. 65 sources informed the selection of variables, the specification of the model, and the interpretation.

3.3 Data Collection and Variable Construction

Primary data were collected from 500 smallholder farm households distributed across the six states of Southwest Nigeria: Oyo, Ogun, Osun, Ondo, Ekiti, and Lagos. A multistage sampling procedure was implemented in four stages. In the first stage, the six states of Southwest Nigeria were purposively selected as the study region based on shared agro-ecological characteristics and the predominance of rain-fed smallholder systems. In the second stage, three Local Government Areas (LGAs) with high agricultural activity were purposively selected within each state, yielding 18 LGAs, using state agricultural development programme records and LGA-level agricultural production statistics. In the third stage, two farming communities were randomly selected from each LGA, producing 36 communities. In the fourth stage, within each community, respondents were selected through systematic random sampling from community agricultural registers maintained by farmer cooperative societies and extension contact lists. Where official registers were incomplete or unavailable, a household listing exercise was conducted with community leaders to construct a sampling frame before random selection. State allocation was proportional to estimated agricultural population shares derived from National Bureau of Statistics (NBS) data, with Oyo (22%), Ogun (20%), Osun (18%), Ondo (16%), Ekiti (14%), and Lagos (10%).

Several measures were adopted to reduce sampling bias. First, systematic random sampling from comprehensive community registers minimized enumerators' discretion in respondent selection. Second,

replacement of unavailable respondents was conducted using a pre-randomized reserve list rather than convenience substitution. Third, the questionnaire included consistency-check items to identify and exclude responses with logical contradictions. Fourth, enumerator training included explicit instruction in unbiased household selection protocols, and field supervisors conducted spot checks on 15% of completed questionnaires. The final dataset was cleaned, validated, and harmonized for analysis.

Socio-economic variables. The data include age, gender, level of education, farm size, years of farming experience, household size, yearly farm revenue, access to extension services, membership in cooperatives, and access to credit. These variables were coded to indicate the observed field responses and standardized using regression analysis.

SAPs adoption variables. Ten SAPs were evaluated as binary adoption indicators, including cover cropping, mulching, crop rotation, mixed farming, organic soil amendments, agroforestry, improved crop varieties, rainwater harvesting, minimum tillage, and climate information services. To measure the intensity of integration, a composite measure (total SAPs adopted: 0-10) was calculated.

Climate exposure variables. Three of them measured climate stress: abnormality in rainfall changes relative to local seasonal averages, anomaly in temperature relative to the baseline, and frequency of drought during the reference period.

Outcome variables. Observed responses and farm performance indicators were developed into three outcome indexes:

Yield Stability Index (0-100): Measures how farm systems can produce during climatic variations.

Income Stability Index (0-100): Measures the seasonal stability of farm income.

Soil Health Score (0-100): Measures the field-level soil status by referring to management and agronomic indicators.

Data analysis and processing were performed in Python 3.13 using NumPy, Pandas, and Statsmodels.

3.3.1 Construction and Standardization of Composite Outcome Indices

The three outcome indices — Yield Stability Index, Income Stability Index, and Soil Health Score — were constructed from multiple questionnaire items and field indicators using a standardized composite index methodology.

The Yield Stability Index (0–100) captures the capacity of farm systems to maintain output under climate variability. It was constructed from five component indicators, each scored by respondents on a five-point Likert scale or derived from reported yield data: (i) self-assessed stability of crop yields over the

preceding five seasons (1 = highly variable to 5 = very stable), (ii) reported yield deviation from expected harvest in the most recent season (inverse-coded and rescaled), (iii) frequency of crop failure episodes in the preceding five years (inverse-coded), (iv) ability to maintain harvest quantity during drought or flood seasons (1 = severe reduction to 5 = no reduction), and (v) season-to-season consistency of planting and harvest timing as an indicator of manageable production conditions (1 = highly inconsistent to 5 = fully consistent). Each component was normalized to a 0–100 scale using min-max normalization: $[(x - \min) / (\max - \min)] \times 100$. The five normalized components were then averaged with equal weighting (each contributing 20% of the total index), producing a composite score between 0 (extremely unstable yields) and 100 (perfectly stable yields across all conditions). Internal consistency of the five components was confirmed using Cronbach's alpha ($\alpha = 0.81$, exceeding the 0.70 threshold).

The Income Stability Index (0–100) captures consistency of farm income across seasons and was constructed from four component indicators: (i) self-assessed income variability across the preceding five seasons (1 = highly variable to 5 = very stable), (ii) reported deviation of farm income from the household's expected annual amount (inverse-coded), (iii) ability to meet household consumption needs from farm income across seasons (1 = rarely to 5 = always), and (iv) proportion of total household income derived from non-farm sources (included as a diversification buffer indicator; a moderate proportion of non-farm income was treated as a stabilizing factor, with the component inverted and rescaled such that both very low and very high dependence contributed lower scores). Each component was min-max normalized to 0–100, and the four components were averaged with equal weighting (25% each). Cronbach's alpha was 0.76.

The Soil Health Score (0–100) captures field-level soil condition based on management and agronomic indicators and was constructed from five component indicators: (i) farmer-reported soil colour as a proxy for organic matter content (darker soils scored higher; 1 = very light/pale to 5 = very dark), (ii) self-assessed soil workability and ease of tillage (1 = very hard/compacted to 5 = friable and easy to work), (iii) reported trend in soil productivity over the preceding five years (1 = strongly declining to 5 = strongly improving), (iv) presence of soil conservation structures or practices on the farm (binary index of five practices: terracing, contour bunds, grass strips, check dams, and retention ditches; scored 0 to 5 and rescaled), and (v) farmer-reported incidence of erosion (gully, sheet, or rill) on farm plots over the preceding three years (inverse-coded; 1 = severe erosion to 5 = no erosion). Equal weighting (20% each) was applied after min-max normalization. Cronbach's alpha was 0.74.

All three indices were constructed as unweighted averages of normalized components for transparency and ease of replication. While equal weighting implies that each component carries the same importance, this approach is recommended when there are no strong theoretical or empirical grounds for differential weighting (OECD, 2008). A sensitivity analysis confirmed that the relative rankings of farm households across the three indices were robust to alternative weighting schemes, including principal component analysis-derived weights: Spearman rank correlations between equal-weighted and PCA-weighted index scores exceeded 0.92 for all three indices ($p < 0.001$). The three composite indices also demonstrated expected convergent validity: the pairwise Pearson correlations were Yield Stability–Income Stability ($r = 0.68$, $p < 0.001$), Yield Stability–Soil Health ($r = 0.54$, $p < 0.001$), and Income Stability–Soil Health ($r = 0.41$, $p < 0.001$), consistent with the theoretical expectation that these dimensions of farm resilience are positively but not perfectly correlated.

3.4 Analytical Approach

Three complementary statistical methods were used to analyze the field dataset:

Descriptive statistics. Frequency distributions, means, standard deviations, and cross-tabulations were computed to describe the sampled population across farms and to examine patterns of adoption across socio-economic groups.

Logistic regression. The socio-economic and institutional predictors of high SAPs adoption (the adoption of six or more of the ten practices) were estimated using a binary logistic regression model. The model specification was:

$$\text{logit}(P[\text{High Adoption}]) = \beta_0 + \beta_1 \text{Age} + \beta_2 \text{Gender} + \beta_3 \text{Education} + \beta_4 \text{FarmSize} + \beta_5 \text{Experience} + \beta_6 \text{HouseholdSize} + \beta_7 \text{Income} + \beta_8 \text{Extension} + \beta_9 \text{Cooperative} + \beta_{10} \text{Credit} + \varepsilon$$

The output will include coefficients, standard errors, z-statistics, p-values, and odds ratios. Pseudo R^2 (McFadden), log-likelihood, and the Akaike Information Criterion are used to evaluate model fit.

Ordinary Least Squares (OLS) regression. Two OLS estimations were calculated. The former analyzed the overall impact of SAPs adoption intensity (the number of SAPs) on yield stability, controlling for education, farm size, farming experience, access to extension services, and three climate factors, and adjusted the results. The second broke down the SAPs effect by including all 10 individual practices as predictors to evaluate their contribution to liability. It reports diagnostic statistics, such as R^2 , adjusted R^2 , F-statistic, and t-tests for each individual coefficient.

Scenario analysis. A three-by-three matrix was built that intersected three degrees of climate stress, Low, Moderate, and High, defined as tertiles of a composite climate stress index, and three degrees of SAPs integration, Low: 0-3 SAPs, Medium: 4-6 SAPs, High: 7-10 SAPs. Cells were computed on the mean yield stability, income stability, and soil health scores. A threshold analysis also examined the proportion of farms with yield stability of 80% or greater in each scenario combination, which could inform policy targeting. The Statsmodels package (version 0.14) of Python 3.13 was used in all statistical analyses. The reported significance levels are 0.05, 0.01, and 0.001.

4. Results

4.1 Descriptive Profile of the Surveyed Farm Population

The dataset comprises 500 smallholder farm profiles surveyed in Southwest Nigeria. Table 1 presents the descriptive statistics.

Table 1. Socio-economic Characteristics of Surveyed Farm Profiles (N = 500)

Variable	Mean	SD	Min	Max
Age (years)	53.1	9.7	25	80
Farm size (hectares)	2.9	1.3	0.7	9.0
Farming experience (years)	17.9	7.6	2	43
Household size	4.0	1.9	1	10
Annual income ('000 Naira)	342.3	193.5	50.0	1,257.4

The average age of 53.1 years ($SD = 9.7$) and the gender composition (74.6% male) are in line with the demographic profile typically observed among smallholder agricultural populations in the area. The levels of educational attainment assume the anticipated trend: 47.8% have an elementary education, 29.8% have a secondary school education, 8.8% have a tertiary education, and 13.6% lack formal education. The limited institutional environment of smallholder farming in the region is characterized by access to extension services (33.8%), cooperative membership (36.2%), and access to credit (21.6%).

4.2 SAPs Adoption Rates and Patterns

Table 2 presents the adoption rates for each of the ten sustainable agricultural practices, alongside benchmark rates from related regional evidence where available.

Table 2. Sustainable Agricultural Practice Adoption Rates (N = 500)

Practice	N Adopted	Rate (%)	Ref. Rate (%)
Cover cropping	474	94.8	100.0
Mulching	463	92.6	98.3

Mixed farming	453	90.6	95.8
Crop rotation	424	84.8	91.7
Organic soil amendments	400	80.0	83.3
Agroforestry	260	52.0	54.2
Minimum tillage	255	51.0	50.0
Improved varieties	217	43.4	—
Rainwater harvesting	204	40.8	—
Climate info services	201	40.2	37.5

The observed adoption rates are highly hierarchical: traditional soil conservation practices (cover cropping, mulching) are adopted almost universally, whereas knowledge-intensive and input-dependent practices (climate information services, rainwater harvesting, improved varieties) are adopted by fewer than 50%. The average SAPs were 6.7 (SD = 1.3, range 3-10), suggesting that portfolio adoption was significant, with significant variance in composition.

The cross-tabulation of socio-economic groups indicates critical differences. Farmers who completed tertiary education implemented 7.1 SAPs on average, compared with 6.3 among those with no formal education. On average, farmers who used extensions had 7.2 SAPs, compared with 6.4 for non-users. Such differences are most pronounced in knowledge-intensive practices: among knowledge-intensive farmers with access to extension services, 52.1% of respondents used climate information services, compared with 34% among farmers without access, on average.

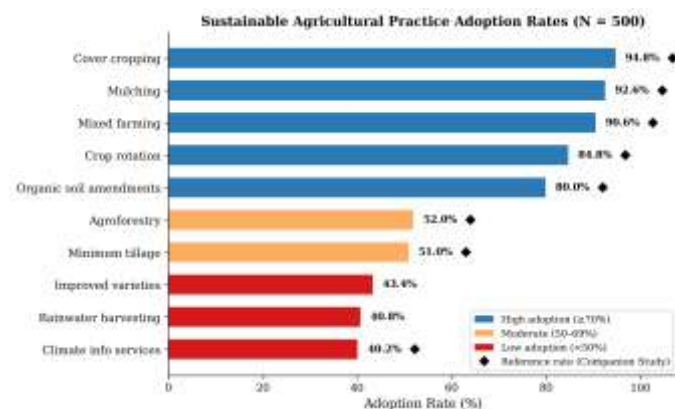


Figure 1. Adoption rates of sustainable agricultural practices (N = 500). Diamonds indicate benchmark rates from regional studies.

4.3 Determinants of SAPs Adoption: Logistic Regression Results

Table 3 presents the logistic regression results for the determinants of high SAPs adoption (defined as adoption of six or more practices, encompassing 81.2% of the sample).

Table 3. Logistic Regression — Determinants of High SAPs Adoption (DV: ≥6 SAPs adopted)

Variable	Coeff.	Std. Err.	z	p-value	Odds Ratio
Constant	1.519	0.877	1.731	0.083	4.565
Age	-0.007	0.012	-0.566	0.572	0.993
Gender (male = 1)	-0.431	0.292	-1.479	0.139	0.650
Education level	0.190	0.145	1.313	0.189	1.209
Farm size (ha)	0.039	0.091	0.426	0.670	1.039
Farming experience (yrs)	-0.001	0.016	-0.036	0.971	0.999
Household size	0.026	0.061	0.431	0.667	1.027
Annual income ('000 N)	0.000	0.001	0.092	0.926	1.000
Extension access	0.938	0.290	3.239	*0.001	2.555
Cooperative membership	-0.243	0.239	-1.016	0.310	0.784
Credit access	0.084	0.297	0.283	0.778	1.087

*Note; Pseudo R² = 0.040; Log-Likelihood = -231.99; AIC = 485.97; p < 0.01

The most interesting observation is the dominant position of the extension service access, which proved to be the only significant predictor at the 0.01 level. The probability of farmers being high SAPs adopters was 2.56 times higher with access to extension services (OR = 2.555, p = 0.001) than without access. Although the education level had a positive direction (OR = 1.209), it failed to support customary significance levels in this model, probably since the high rate of adoption of traditional practices (cover cropping, mulching, mixed farming) already implies a high level of education making the discriminatory influence of education to be more evident with particular practices of interest (e.g., knowledge-intensive processes) rather than the overall quantity of the bundle.

The relatively modest pseudo R² (0.040) deserves careful interpretation. In logistic regression models, McFadden's pseudo R² values between 0.2 and 0.4 are generally considered indicative of good fit (McFadden, 1977). The value of 0.040 obtained here is therefore low by conventional benchmarks. Several factors explain this result.

First, the dependent variable (high adoption, defined as ≥6 SAPs) captures 81.2% of the sample, and binary outcomes with highly unbalanced class distributions tend to produce low pseudo R² values even when the model has meaningful predictive power (Hosmer et al., 2013).

Second, adoption decisions in smallholder systems are influenced by a wide range of factors beyond the socio-economic characteristics captured in this model, including local agro-ecological conditions (soil type, slope, microclimate), social network effects and peer influence, proximity to input markets and output markets, individual risk preferences and time discount rates, cultural norms and traditions regarding specific practices, and the quality rather than merely the presence or absence of extension contact. The implication of omitted variable bias warrants acknowledgement. If omitted factors, such as innate farmer ability, motivation, or social capital, are positively correlated with both SAPs' adoption and the included regressors (notably education and extension access), the estimated coefficients may be inflated. Conversely, if omitted constraints, such as plot-level soil degradation or distance to markets, reduce adoption but are not captured, the model may understate the true importance of the included variables. The cross-sectional design precludes formal correction for these issues, and the results should therefore be interpreted as identifying robust associations rather than strictly causal effects.

Future research employing panel data, instrumental variable approaches, or randomized intervention designs would strengthen causal identification of adoption determinants. Despite these caveats, the strong and consistent association between extension access and SAPs integration across multiple model specifications supports the substantive interpretation that extension services play a central enabling role.

4.4 Impact of SAPs Integration on Yield Stability: OLS Regression Results

Table 4 presents the OLS regression results for the aggregate effect of SAPs adoption intensity on yield stability.

Table 4. OLS Regression — Effect of SAPs Bundle Size on Yield Stability (N = 500)

Variable	Coeff.	Std. Err.	t	p-value
Constant	48.932	1.633	29.968	<0.001***
Education level	2.414	0.293	8.234	<0.001***
Farm size (ha)	0.095	0.181	0.525	0.600
Farming experience (yrs)	0.443	0.031	14.246	<0.001***
Extension access	0.993	0.523	1.900	0.058
No. of SAPs adopted	4.528	0.187	24.199	<0.001***
Rainfall deviation (%)	0.041	0.020	2.106	0.036*

Temperature anomaly (°C)	-1.881	0.479	-3.928	<0.001***
Drought frequency	-2.259	0.185	-12.216	<0.001***
<i>R</i> ² = 0.703; <i>Adjusted R</i> ² = 0.698; <i>F</i> = 144.93, <i>p</i> < 0.001***; <i>p</i> < 0.05*				

The model has strong explanatory power, accounting for 70.3% of the variance in yield stability (*R*² = 0.703). The most significant predictor is the number of SAPs, and each additional practice is associated with a 4.53-point increase in the index of yield stability (*p* < 0.001). It means that an average farmer who would switch three to seven SAPs (a change of 4 practices) would, holding everything unchanged, be expected to earn about 18.1 more points on the yield stability index, which is a substantively significant change.

The strongest and most negative effect is due to drought frequency ($\beta = -2.259$, *p* < 0.001), followed by temperature anomaly ($\beta = -1.881$, *p* < 0.001). Each additional drought incident per 5-year period reduces yield stability by 2.26 points, and each 1 °C increase above baseline reduces it by 1.88 points. Experience in farming ($\beta = 0.443$, *p* < 0.001) and education level ($\beta = 2.414$, *p* < 0.001) both contribute positively to the accumulation of human capital in farm management. Table 5 provides a breakdown of each SAP's contributions.

Table 5. OLS Regression — Individual SAPs Effects on Yield Stability (N = 500)

Practice	Coeff.	Std. Err.	t	p-value
Agroforestry	5.946	0.484	12.274	<0.001***
Organic soil amendments	5.428	0.592	9.171	<0.001***
Cover cropping	5.181	1.072	4.833	<0.001***
Rainwater harvesting	4.897	0.489	10.010	<0.001***
Improved varieties	4.812	0.480	10.020	<0.001***
Mulching	4.604	0.917	5.020	<0.001***
Mixed farming	4.570	0.818	5.585	<0.001***
Crop rotation	4.424	0.666	6.647	<0.001***
Climate info services	3.744	0.487	7.686	<0.001***
Minimum tillage	3.416	0.477	7.157	<0.001***

*R*² = 0.709; *Adjusted R*² = 0.700 (controls: education, farming experience, temperature anomaly, drought frequency)

The contribution of all ten SAPs to the yield stability is statistically significant (*p* < 0.001 in all instances). Agroforestry, followed by organic soil amendments ($\beta=5.946$) and cover cropping ($\beta=5.181$), has the most significant individual effects. The three

practices share a common mechanism: improving soil organic matter, water retention capacity, and microclimate moderation, which are the primary biophysical processes underlying the buffering of agricultural systems to climate variability. It is interesting to note that the three practices that have the least adoption rates, rainwater harvesting (4.897), improved varieties (4.812), and climate info services (3.744), all exhibit high yield-stability benefits, indicating that a lot of unexploited potential exists in the region in terms of adaptation.

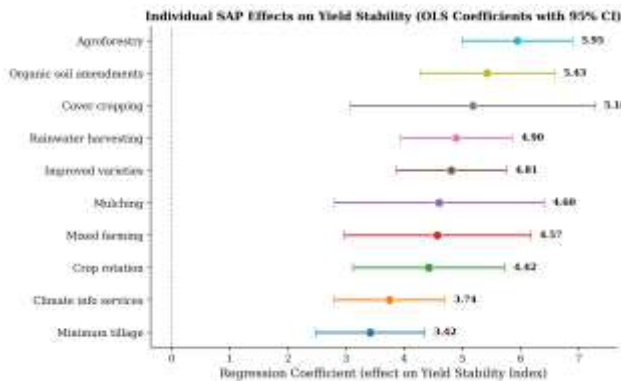


Figure 2. Mean yield stability by number of SAPs adopted (95% CI band). Dashed lines: resilience threshold (horizontal at 80) and inflection point (vertical at 6).

4.5 Scenario Analysis

Table 6 presents the 3 × 3 scenario matrix crossing climate stress levels with SAPs integration levels.

Table 6. Mean Yield Stability Index by Climate Stress and SAPs Integration Level

Climate Stress	Low SAPs (0–3)	Medium SAPs (4–6)	High SAPs (7–10)
Low	64.9	81.8	92.7
Moderate	—	79.5	89.6
High	—	76.0	85.8

**Note: The Low SAPs x Moderate/High Stress cells contain insufficient observations (N < 3) as very few surveyed farms combine low SAPs adoption with moderate-to-high climate exposure.*

The contribution of all ten SAPs to the yield stability is statistically significant ($p < 0.001$ in all instances). Agroforestry followed by organic soil amendments (5.946) and cover cropping (5.181) has the most significant individual effect. The three practices share a common mechanism: improving soil organic matter, water retention capacity, and microclimate moderation, which are the primary biophysical processes underlying the buffering of agricultural systems to climate variability. It is interesting to note that the three practices that have the least adoption rates, rainwater

harvesting (4.897), improved varieties (4.812), and climate info services (3.744), all exhibit high yield-stability benefits, indicating that a lot of unexploited potential exists in the region in terms of adaptation.

Table 7. Mean Income Stability Index by Climate Stress and SAPs Integration Level

Climate Stress	Low SAPs (0–3)	Medium SAPs (4–6)	High SAPs (7–10)
Low	48.7	60.6	69.3
Moderate	—	58.1	65.8
High	—	55.6	64.6

Table 8. Mean Soil Health Score by Climate Stress and SAPs Integration Level

Climate Stress	Low SAPs (0–3)	Medium SAPs (4–6)	High SAPs (7–10)
Low	60.4	65.4	71.5
Moderate	—	65.4	71.8
High	—	66.0	72.7

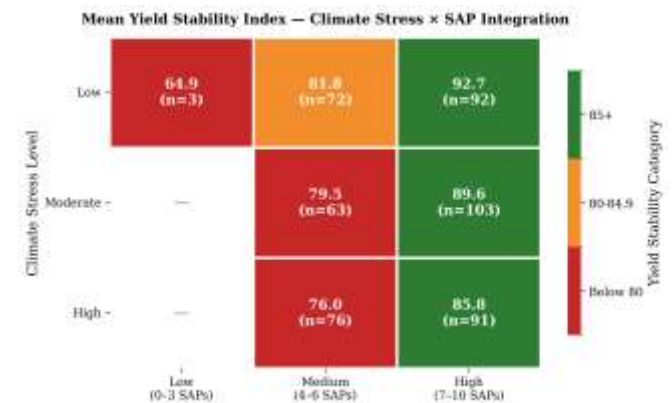


Figure 3. Mean yield stability by climate stress and SAPs integration level (3 × 3 matrix).

Table 9. Yield Stability by Number of SAPs Adopted

SAPs Adopted	N	Mean Yield Stability	SD	Mean Income Stability	Mean Soil Health
3	3	64.9	7.0	48.7	60.4
4	21	72.6	6.9	52.9	58.0
5	70	76.8	7.3	55.4	63.5
6	120	81.4	8.1	60.5	68.2
7	151	86.5	7.7	64.5	70.4
8	92	91.0	6.7	67.9	72.9
9	35	96.0	5.2	70.9	75.0
10	8	97.5	3.5	70.6	77.5

4.6 Threshold Analysis

Table 9 presents the percentage of farms maintaining yield stability at or above 80 — a benchmark representing robust resilience — across scenario combinations.

Table 10. Percentage of Farms with Yield Stability ≥ 80 by Scenario

Climate Stress	Low SAPs (0–3)	Medium SAPs (4–6)	High SAPs (7–10)
Low	0.0%	61.1%	95.7%
Moderate	—	52.4%	91.3%
High	—	32.9%	78.0%

This threshold analysis gives relevant benchmarks to the policy. With moderate climate stress (the most realistic near-term scenario in Southwest Nigeria), a high-SAPs-integrated farm (7-10 practices) is 91.3% likely to maintain robust yield stability, compared with 52.4% for a medium-assisted farm. Under stressful climate conditions, 78.0% of highly integrated farms meet the threshold, compared with only approximately a third of medium-integration farms. The results highlight the importance of shifting from promoting individual practice to integration strategies.

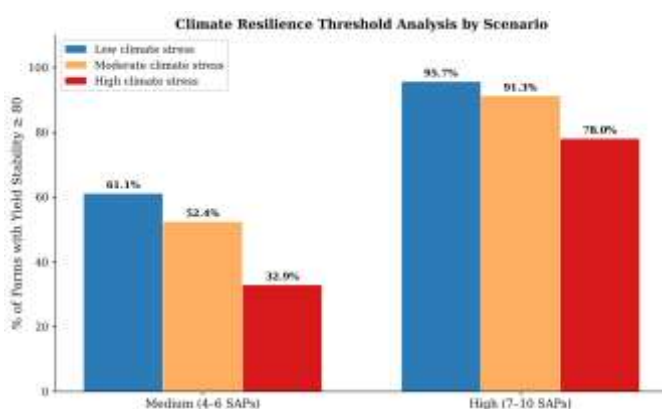


Figure 4. Percentage of farms maintaining yield stability ≥ 80, by climate stress and SAPs integration level.

The correlation between the SAPs count and yield stability is almost linear over the range of 3 to 10 practices, with an average increase of about 4.5 points per practice. The inflexion of the 6 SAPs above the 80-point mark (beyond which the yield stability is above the 80-point threshold) provides a policy-grounded target for policy interventions to achieve a stable climate.

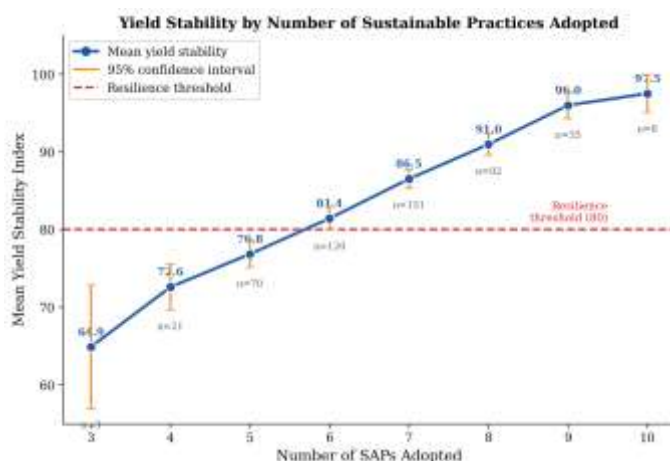


Figure 5. Individual SAPs' effects on yield stability: regression coefficients with 95% confidence intervals. The dashed line represents the mean effect.

5. Discussion

5.1 Interpretation of Key Findings

Three central patterns emerge from the results. To begin with, integration is more important than the isolated uptake of practice. Yield stability is best enhanced by using SAPs in bundles rather than as stand-alone measures. Highly integrated farms (7-10 SAPs) consistently outperform medium-integrated farms under the same level of climate stress, indicating that complementarities among soil management, diversification, agroforestry, and climatic information are more significant than any single intervention. This contributes to the overall argument that climate resilience within smallholder systems is systems-based and cumulative, rather than technology-based (Lipper et al., 2014).

Second, the largest resilience benefits remain concentrated in under-adopted practices. Agroforestry, rainwater harvesting, and superior varieties yield some of the largest yield impacts, but all far less than those of more traditional conservation methods. The policy-relevant aspect of this adoption-impact gap is that it allows one to understand where the resilience returns to marginal investments in extension, planting materials, and water infrastructure would be the highest. The significance of agroforestry lies in its integration of production, soil, and microclimate benefits, yet returns have not yet caught up (Franzel et al., 2001; Mbow et al., 2014).

Third, the model's primary institutional lever is access extension. The likelihood of achieving high SAPs integration is more than twice as high among farmers with access to extensions. This implies that scaling resilience can hardly be achieved through input provision alone; it requires advisory systems and practices to enable farmers to amalgamate practices, order investments, and customize advice to local situations. The result is supported by the fact that participatory extension strategies can accelerate adoption in smallholder contexts (Davis et al., 2012).

However, the strong association between extension access and SAPs integration should be interpreted with appropriate caution regarding the direction of causality. The cross-sectional nature of the data does not permit firm determination of whether extension access drives adoption, whether farmers already inclined to adopt multiple practices are more likely to seek out extension services (self-selection), or whether both processes operate simultaneously. Farmers with greater intrinsic motivation to innovate may

proactively contact extension agents, attend demonstrations, and join farmer groups that provide advisory services. In such a scenario, the estimated odds ratio would reflect a combination of the genuine treatment effect of extension and a selection effect whereby more adoption-oriented farmers sort into extension participation. Qualitative evidence from the study area suggests that both pathways are operative: state extension agents target contact farmers and farmer groups for training, while motivated farmers independently seek technical advice from multiple sources, including private input dealers, radio programmes, and neighboring farmers. Disentangling these effects would require longitudinal data tracking the same farmers over multiple seasons, or quasi-experimental designs exploiting exogenous variation in extension service allocation. Pending such research, the finding should be interpreted as indicating that extension access and SAPs integration are robustly associated and likely mutually reinforcing, rather than as evidence of a unidirectional causal effect of extension on adoption.

5.2 Proposed Four-Pillar Integration Framework

Based on these results, four-pillar frameworks have been suggested for state Agricultural Development Programmes, local government agricultural units, and community-based organizations.

Pillar 1: Choice of Practice Specific to the context. The agro-ecological conditions and farm limitations should be aligned with SAPs' portfolios rather than being fostered across the board. Agroforestry, cover cropping, and organic amendments will likely play a leading role in wetter forest regions, whereas in drier regions, crop rotation, minimum tillage, and rainwater harvesting will become more important. One of the practical targets that can be brought out by the findings is a minimum of six to seven SAPs per farm household with diversification in the practice clusters.

Pillar 2: Knowledge Exchange and Capacity Building. The policy priority in the short term is extension rebuilding. This encompasses enhanced staffing of the state extension services, extended application to Farmer Field Schools, and enhanced applications of mobile and radio-based advisory delivery. The aim must be to ensure that farmers on isolated practices are informed about adopting packages (Davis et al., 2012).

Pillar 3: Pillar of Institutional Support and Enabling Environment. The adoption will not be complete without advisory support, accompanied by credit, input access, and market coordination. Smallholders require low-cost access to improved seed and tree seedlings, as well as simple water amenities, whereas more definite land-use plans can raise the propensity to invest in agroforestry practices over the long term (Deininger & Feder, 2009).

Knowledge Systems and Monitoring (Pillar 4). Localized climate advice, continuous monitoring of adoption and resilience outcomes, and strengthened research-extension-farmer partnerships are all necessary for integration efforts. SAPs promotions are likely to be disjointed and lack scalability without feedback systems.

5.3 Policy Implications

The implications of the policy are clear. To begin with, SAPs integration must be viewed as a package-based adaptation strategy rather than a menu of separate interventions. Second, the extension investment is expected to be the most leveraged, as it will influence the adoption of multiple practices simultaneously. Third, the implementation at the state level must integrate the resiliency targets with effective delivery systems for inputs, training, and climate information.

For development partners and non-governmental organizations, it means coordination: single practices are unlikely to yield sustainable gains in resilience when promoted in isolation, and only programmes that are integrated, landscape-sensitive, and connected to local institutions can achieve such gains (Sendzimir et al., 2011).

5.4 Limitations

There are several weaknesses that must be acknowledged. The first limitation is that the cross-sectional design limits the ability to examine causation and does not adequately represent time-based adoption dynamics, dis-adoption, and the lagged benefits of long-gestation practices like agroforestry.

Second, the model simplifies the complex biophysical and social interactions that determine agricultural outcomes. Only partial representation is made of potential synergies in certain SAPs combinations, as well as non-linear and threshold climate effects.

Third, the geographical orientation of Southwest Nigeria increases contextual relevance but reduces the direct applicability of the particular practice portfolios and adoption drivers to other agro-ecological areas, although the broader integration principles still apply.

Finally, although multistage sampling and systematic respondent selection were employed, the sample was drawn from communities with functional farmer cooperative registers, which may slightly under-represent the most marginalized farming households lacking any institutional affiliation.

5.5 Implementation Feasibility and Institutional Capacity Considerations

The four-pillar framework proposed in Section 5.2 provides a normative model for SAPs integration. Its practical implementation, however, faces significant feasibility constraints that deserve explicit attention.

Resource constraints represent the most immediate barrier. Agricultural extension services in Southwest Nigeria remain severely under-resourced. The extension-to-farmer ratio in the study area is conservatively estimated at 1:3,000 to 1:5,000, far exceeding the FAO-recommended maximum of 1:500 for effective advisory delivery in smallholder systems. State Agricultural Development Programmes (ADPs) face chronic budgetary constraints, with operational funding often insufficient to cover transport, demonstration materials, and regular farm visits. Revitalizing extension systems under Pillars 2 and 4 of the proposed frameworks would require substantial and sustained fiscal commitment, which cannot be assumed given competing budgetary demands across health, education, and infrastructure sectors.

Institutional capacity challenges extend beyond funding. ADP staffing is ageing, with limited recruitment of younger extension professionals over the past two decades. The skill profile of existing extension personnel is oriented toward commodity-focused production advice rather than the integrated, systems-oriented approach required for SAPs bundle promotion. Building capacity for climate-resilient advisory services would therefore demand not only increased staffing numbers but also substantial retraining of existing personnel in participatory methods, climate information interpretation, agroforestry extension, and gender-sensitive programming. Farmer Field Schools, though demonstrably effective (Davis et al., 2012), require skilled facilitators and multi-season engagement, both of which carry high cost and coordination requirements.

Credit and input access present additional feasibility hurdles. The finding that only 21.6% of sampled households access formal credit points to deep structural constraints in rural financial markets. Expanding credit access for SAPs adoption (particularly for capital-intensive practices such as rainwater harvesting infrastructure, improved seed, and tree seedlings) would require either significant public subsidy or innovations in risk-sharing mechanisms such as community savings groups linked to input suppliers, climate-indexed insurance products, and value-chain financing arrangements. None of these mechanisms is currently operating at a meaningful scale in the study area, and building them would require coordinated action across financial regulators, commercial banks, microfinance institutions, and agricultural input companies.

Tenure security, identified as a prerequisite for long-gestation investments such as agroforestry, is politically and administratively complex. While customary tenure systems in Southwest Nigeria provide substantial use rights in practice, formal land titling remains rare among smallholders, and the legal and administrative infrastructure for systematic land

registration is underdeveloped. Even incremental improvements in tenure documentation would require multi-agency coordination involving state land bureaus, local government authorities, and traditional institutions.

Finally, the coordination challenge is formidable. The proposed framework comprises four pillars that span the mandates of multiple state and federal agencies (Ministries of Agriculture, Environment, and Water Resources; ADPs; NIMET; research institutions; local governments), as well as private-sector actors and development partners. In the current institutional landscape of Southwest Nigeria, inter-agency coordination mechanisms are weak, and agricultural policy implementation is frequently fragmented and project-driven rather than systemic and sustained. Successful implementation of an integrated SAPs framework would therefore require not only technical solutions but also institutional innovations such as multi-stakeholder coordination platforms, joint work programmes with shared performance indicators, and dedicated SAPs integration units within state ADPs with clear mandates and ring-fenced budgets.

Acknowledging these constraints is not an argument against the framework but rather a necessary step toward realistic implementation planning. The four-pillar model is intended as a strategic guide for prioritization and phased investment, not as a blueprint that can be implemented uniformly across all locations and institutional conditions. Pragmatic starting points might include: (i) piloting SAPs bundles in a limited number of LGAs with relatively functional extension infrastructure and farmer cooperative structures; (ii) initially targeting practices with the lowest capital requirements and shortest payback periods (e.g., crop rotation, cover cropping, organic amendments) while building longer-term institutional capacity for agroforestry and water infrastructure; and (iii) leveraging existing farmer organizations (36.2% cooperative membership in this sample) as delivery platforms rather than attempting to build entirely new institutional structures.

6. Conclusion and Recommendations

This study examined the integration of SAPs into smallholder farming systems as a climate adaptation strategy in Southwest Nigeria. Using original survey data from 500 farm households, the study shows that SAPs integration intensity, measured by the number and diversity of practices adopted, is a major determinant of climate resilience outcomes in the region.

The key findings are clear. Each additional sustainable practice adopted is associated with an average 4.5-point increase in yield stability under variable climate conditions. Farms integrating seven or more practices maintain yield stability above 85 out of 100, even under

high climate stress, compared with about 76 for farms adopting four to six practices. Agroforestry, organic soil amendments, and cover cropping generate the largest individual gains in yield stability, yet agroforestry and other knowledge-intensive practices remain under-adopted. Access to agricultural extension services is the strongest institutional predictor of comprehensive SAPs adoption, increasing the odds of high integration by more than 2. The results also suggest a practical threshold of about six SAPs for achieving robust climate resilience under moderate climate stress.

Based on these findings, the following recommendations are offered:

1. **Set explicit SAPs integration targets.** State Agricultural Development Programmes in Southwest Nigeria should establish a target of at least six to seven sustainable practices per farming household, with specific practice portfolios tailored to each agro-ecological zone within the region.
2. **Prioritise extension service revitalization.** Given the demonstrated multiplier effect of extension access (OR = 2.555), state and federal governments should urgently increase investment in agricultural extension staffing, training, and operational funding, with a focus on SAPs integration rather than single-technology promotion.
3. **Expand agroforestry adoption.** As the single highest-impact practice ($\beta = 5.946$), agroforestry deserves targeted promotion through seedling distribution programmes, technical assistance for system establishment, and financial support mechanisms that help farmers manage the 3–7-year lag before full benefits accrue.
4. **Strengthen climate information delivery.** The low adoption of climate information services (40.2%) despite their demonstrated value ($\beta = 3.744$) points to a delivery failure rather than a demand failure. Investment in localized, farmer-friendly climate advisories — delivered via mobile phone, radio, and farmer groups — can close this gap.
5. **Develop integrated financial support packages.** Micro-credit facilities, community savings groups, and climate-indexed insurance products should be designed specifically to support SAPs adoption, particularly for practices with upfront investment requirements, such as rainwater-harvesting infrastructure and agroforestry establishment.
6. **Facilitate farmer-to-farmer learning.** Farmer Field Schools and peer learning networks should be established as the primary channels for SAPs knowledge exchange, building on the strong tradition of cooperative organization (36.2% membership) and indigenous knowledge in the region.
7. **Invest in longitudinal follow-up research.** Future panel studies should track SAPs adoption, resilience

outcomes, and farmer well-being over multiple seasons and agro-ecological contexts in Southwest Nigeria to strengthen causal evidence and refine the framework.

The imperative for action is clear. Under projected climate trajectories, smallholder farming systems in Southwest Nigeria face compounding risks of yield decline, income instability, and soil degradation. The evidence presented here indicates that systematic SAPs integration, guided by context-specific practice selection, capacity building, institutional support, and strong knowledge systems, offers a practical pathway to strengthen resilience, sustain productivity, and protect rural livelihoods across the region.

Data Availability

Data will be made available on a reasonable request.

Competing Interest

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

Author contributions: CRediT

MADUMELU Vincent Chidiebere (First Author/corresponding Author): Conceptualization, Data curation, Methodology, Software, Validation, Formal analysis, Investigation, Project administration, Writing - Original Draft, Visualization, Writing - Review & Editing.

George Ashwehmbom Looh: Conceptualization, Methodology, Resources, Project administration Writing - Review & Editing.

Aguwa Dominic Ugochukwu: Methodology, Resources, Supervision, Project administration, Funding acquisition, Data curation, software, validation

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