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# Drivers of Climate Smart Agriculture Adoption in Smallholder Farming Households in Nigeria

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**Abstract:** One of the greatest recognized threats to agricultural productivity in several regions of the world is climate change. Tackling the challenges to agricultural production requires the adoption of innovative sustainable practices capable of increasing resilience and mitigating climate change impacts. This paper examined the determinants of climate smart agricultural practices (CSAP) adoption among smallholders in Nigeria. Using cross-sectional data from 1,534 farmers across six agro-ecological zones (AEZ), the study applies descriptive statistics and Multivariate Probit Regression model to assess farmers' perceptions of climate variability and the socio-economic, institutional, and environmental factors shaping CSAP adoption. Results show that farmers perceived climate change differently, noting slight increases in daytime temperature, longer dry seasons, and declining rainfall. Early-maturing and drought-tolerant varieties were most adopted, while agroforestry, irrigation, and green manuring remained limited. Significant complementarities exist among practices, as adopting one CSAP increases the likelihood of adopting others. Key drivers of adoption include age, education, off-farm income, credit access, cooperative membership, land ownership, and farm size. The study concludes that strengthening extension systems, enhancing land tenure security, and tailoring CSA interventions to local ecological conditions are essential for scaling climate-smart agriculture and strengthening the resilience of Nigeria's smallholder farming systems.

**Keywords:** risk; climate; climate smart agriculture; adoption; smallholder

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## 1. Introduction

Climate change remains one of the most critical threats to agricultural productivity globally, posing severe challenges to food security, livelihoods, and rural development. Agricultural productivity is highly sensitive to climatic variations, and even small changes in temperature, rainfall, or drought frequency can result in substantial yield losses (Ashalatha et al., 2012; Shaffril et al., 2018). Extreme weather events, including floods, droughts, and heatwaves, not only endanger crop and livestock production but also exacerbate existing vulnerabilities in rural communities. Conversely, agriculture has the potential to mitigate climate change by enhancing the soil's carbon sequestration capacity through sustainable land management practices.

Developing countries located within tropical regions are particularly vulnerable to these climatic shocks, as their agricultural systems depend heavily on rain-fed cultivation and are constrained by limited adaptive capacity (Kurukulasuriya and Mendelsohn, 2006; Mendelsohn et al., 2006; Cooper et al., 2008; Müller et al., 2011). Nigeria, being Africa's most populous nation and largest economy, exemplifies this vulnerability. Its diverse ecological zones—from the Sahel and Sudan savannahs in the north to the mangrove, rainforest, and coastal ecosystems in the south—face distinct yet interconnected climate-related risks. The country's long coastline (over 800 km) exposes it to rising sea levels and flooding, while northern regions increasingly experience desert encroachment, drought, and extreme heat (Apata et al., 2009; Opeyemi et al., 2021). These environmental pressures threaten food production, rural livelihoods, and national food security.

In response to these challenges, Climate-Smart Agriculture (CSA) has emerged as a strategic framework that integrates productivity, adaptation, and mitigation objectives. Defined by the Food and Agriculture Organization (FAO, 2013), CSA promotes agricultural practices that enhance productivity, strengthen resilience, and reduce greenhouse gas emissions while supporting food security and sustainable development goals. The CSA approach is built on three interlinked pillars: (i) sustainable productivity growth for food and nutrition security, (ii) climate adaptation to reduce vulnerability and build resilience, and (iii) mitigation through emission reduction and carbon sequestration (Campbell et al., 2014; Lipper et al., 2014; Steenwerth et al., 2014; Thornton et al., 2018; Antwi-Agyei et al., 2023).

Climate Smart Agriculture Practices (CSAP) encompass soil and water management, integrated crop-livestock systems, agroforestry, and precision agriculture technologies aimed at improving yields, incomes, and sustainability (Ogundari et al., 2018; Adesina and Loboguerrero, 2021; Opeyemi et al., 2021). Adoption of such practices can also enhance soil carbon storage, minimize fertilizer use, and promote climate-resilient crop varieties (Marinello et al., 2017; Pezzuolo et al., 2017; Camarotto et al., 2018; de Oliveira Ferreira et al., 2018; Adesina and Loboguerrero, 2021). Despite these proven benefits, the rate of CSA adoption among smallholder farmers in Nigeria remains significantly lower than expected (FAO and ICRISAT, 2019). Barriers such as low awareness, inadequate access to information and credit, weak institutional support, and socio-economic constraints continue to limit uptake (Opeyemi et al., 2021).

Existing studies in Nigeria have largely focused on the technical and environmental aspects of CSA—such as soil fertility management, irrigation efficiency, and improved crop varieties—while paying limited attention to the behavioural and socio-economic factors that influence farmers'

adoption decisions (Antwi-Agyei and Amanor, 2023; Kehinde et al., 2023). Critical dimensions such as farmers' risk perception, access to extension services, credit availability, land tenure security, and social capital are often underexplored (Ayinde et al., 2011). Furthermore, empirical analyses rarely examine how awareness, perception of climate risks, and actual utilization of CSA practices interact to shape adoption behaviour across Nigeria's diverse agro-ecological zones (Ayanlade et al., 2017).

This limited understanding represents a significant knowledge gap, as CSA adoption decisions are not purely technical or economic choices—they are complex, multidimensional processes shaped by behavioural, cultural, gendered, and contextual factors (Moser and Ekstrom, 2010; Below et al., 2012). Addressing this gap is particularly critical for Nigeria, where agriculture sustains the majority of rural livelihoods and contributes substantially to GDP and food security. Without deeper insight into the behavioural and institutional drivers of CSA adoption, generic policy interventions are ineffective in enhancing adaptive capacity.

Accordingly, this study investigates the drivers of CSA adoption among smallholder farming households in Nigeria, focusing on the interplay between farmers' awareness, perception, and utilization of CSA practices. It assesses how farmers perceive and respond to climate shocks, identifies socio-economic and institutional determinants influencing adoption behaviour, and evaluates the enabling and constraining factors within the Nigerian context. Findings from this study are expected to provide novel empirical evidence on how behavioural and socio-economic dynamics influence CSA adoption decisions, thereby informing targeted, evidence-based policies to strengthen Nigeria's agricultural resilience, enhance food security, and support the country's climate adaptation and sustainable development goals.

## 2. Literature Review

In addressing climate change risks, agriculture remains central to both the problem and the solution, given its dual role as a highly vulnerable sector and a contributor to greenhouse gas emissions (Lipper and Zilberman, 2018). The concept of Climate Smart Agriculture was introduced to reconcile the need for productivity growth, adaptation, and mitigation within sustainable agricultural systems (FAO, 2009; FAO, 2010; Lipper et al., 2014). Rather than prescribing a new sustainability framework, CSA provides a mechanism to embed adaptation and mitigation imperatives into existing agricultural policies and programs (Lipper and Zilberman, 2018). Empirical evidence shows that CSA adoption can enhance farmers' resilience, improve food security, and increase household income (Opeyemi et al., 2021; Wanjira et al., 2022). However, the extent and determinants of adoption vary across socio-economic, institutional, and environmental contexts.

'Wanjira et al. (2022) shows that there is great potential for increasing household income through the adoption of climate-smart crop varieties.' Their study in Kenya demonstrated that adopting CSA maize varieties improved household income by about 60%, thereby reducing poverty levels among smallholder farmers. Notably, younger farmers were more inclined to adopt CSA innovations than older farmers, suggesting age-related differences in openness to new technologies. Similarly, 'Tadesse and Ahmed (2023) found that sociodemographic factors influenced the participation and

intensity of CSA practices adoption in Ethiopia,' confirming that age, marital status, and education level play decisive roles. While younger and educated farmers were more likely to adopt, marital responsibilities appeared to reduce willingness to experiment with CSA. In contrast, it was observed among smallholder farmers in Zambia that older and more experienced farmers were more likely to adopt CSA practices, implying that experiential knowledge and climate risk awareness can sometimes outweigh youthful innovativeness. These findings reveal a regional contradiction regarding the role of age, pointing to context-specific social and institutional dynamics influencing adoption (Petros et al., 2025)

Entrepreneurial behaviour has also emerged as a key driver of CSA uptake. 'Kangogo et al. (2021) investigated the influence of farmers' entrepreneurial orientation (EO) on the adoption of CSA practices among smallholder potato farmers in Kenya,' demonstrating that risk-taking and proactiveness promote adoption of finance- and skill-intensive CSA practices, while innovativeness may deter adoption when technologies are capital demanding. This suggests that the nature of the CSA intervention interacts with farmers' personality traits and resource endowments, creating differentiated adoption patterns.

At a broader Sub-Saharan African scale, 'Kombat et al. (2021) revealed that poor policy coherence, limited private-sector engagement, weak institutional capacity, and poor access to finance hinder CSA adoption.' Their findings emphasize systemic barriers—particularly inadequate coordination and communication between farmers, researchers, and policymakers—that limit scaling. The authors advocate for bottom-up participatory approaches and multi-stakeholder collaboration to enhance the relevance and acceptability of CSA innovations. In Zambia, 'Nyirenda (2024) found that education, access to climate information, and participation in CSA-related programs positively influenced CSA adoption,' underscoring the importance of information access and climate perception.

A related debate concerns whether low adoption reflects lack of awareness or structural barriers. 'Autio et al. (2021) emphasised that there is conflict in the perceived awareness of CSA practices and utilization of CSA technologies between state actors and farmers.' Whereas policymakers attribute poor adoption to ignorance, farmers highlight market constraints, insecure land tenure, and lack of capital as key obstacles. This contradiction between perception and practice indicates that adoption challenges are as much socio-economic as informational.

Empirical findings from southern Africa also highlight multidimensional influences on adoption. Abegunde et al. (2020), studying South African smallholders, identified education, income, farm size, extension contact, and group membership as significant factors. Similarly, Opeyemi et al. (2021) stress that the combined application of multiple CSA practices yields greater resilience and productivity gains, suggesting that integration rather than singular adoption may be key to climate adaptation.

'Nkonki-Mandleni et al. (2018) revealed that gender, marital status, and farming continuity on the same land significantly affect CSA adoption behaviour,' while 'Antwi-Agyei and Amanor (2023)

showed that despite awareness of multiple CSA technologies, actual adoption remains low.’ The latter study noted that smallholders selectively implement knowledge-smart and weather-smart technologies, driven by education, social networks, access to credit, and government support. This points to the need for context-specific enabling environments that match technology complexity with farmers’ resource capacity. Complementarily, ‘Antwi-Agyei et al. (2021) observed that secure land tenure, access to finance, and climate information are critical enablers for adoption.’ Supporting this, ‘Oyawole et al. (2019) found that plot distance, off-farm participation, gender, and land ownership significantly influence adoption decisions,’ while Teklewold et al. (2019) further confirmed that larger and more distant farms are less likely to integrate multiple CSA practices due to labour and monitoring constraints.

‘Antwi-Agyei et al. (2023) revealed that in the adoption of CSA by farmers, there are differences in the acceptance of CSA practices based on their location,’ emphasizing that agroecological diversity shapes not only exposure to climate risk but also perceived utility and feasibility of specific CSA options. This aligns with global studies suggesting that local ecological, market, and institutional contexts jointly determine the intensity and diversity of CSA uptake (Lipper et al., 2014; FAO, 2017).

In synthesis, the reviewed literature underscores three recurring patterns: first, that socioeconomic and demographic variables such as age, education, and gender consistently influence CSA adoption, though their effects are context-dependent; second, that institutional and informational factors, including extension services, credit access, and land tenure, are critical yet unevenly distributed across regions; and third, that systemic constraints—policy incoherence, market failures, and resource limitations—remain persistent barriers to scaling CSA in Sub-Saharan Africa. However, gaps remain in understanding how local socio-cultural factors, particularly norms around risk, collective action, and innovation diffusion, interact with climate perception and economic incentives to shape adoption behaviour.

By situating the Nigerian experience within this broader regional and global context, this study contributes to bridging the empirical and theoretical gap in CSA adoption research, providing insights for policy and intervention design tailored to smallholder realities.

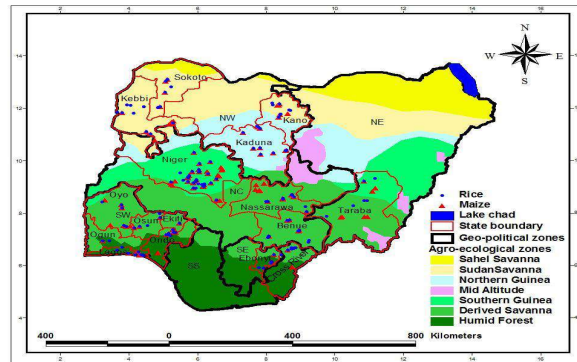
### **3. Materials and Methods**

#### *3.1. Study Area*

The study location is Nigeria. There are seven agro-ecological zones (AEZs) namely: Northern Guinea Savanna (NGS), Sahel Savanna (SAH), Sudan Savanna (SUD), Southern Guinea Savanna (SGS), Derived Savanna (DS), Rainforest (RF) and Mid Altitude (MA). These zones experience different climatic conditions ranging from rainfall patterns, sunlight intensity, and humidity amongst others. The humid rainforest zone experiences longer rainfall compared to the northern parts with lower rainfalls and shorter rainy season.

#### *3.2. Data and Sampling Procedure*

The data was drawn from the RAAF/PASANAO project on 'Incentivising Adoption of Climate-smart Practices in Cereals Production in Nigeria: Socio-cultural and Economic Diagnosis'. A total of 1534 households were extracted out of the 1747 maize and/or rice farming households drawn from a cross-sectional survey of 179 farming communities spread across 16 out of the 36 States in Nigeria known for rice and/or maize farmers using multistage sampling technique. Data was collected through personal interviews, Focus Group discussions, and choice experiments. Figure 1 is a map of Nigeria which shows the study area across the geopolitical zones and agro-ecological zones.



**Figure 1:** Map of Nigeria showing the study locations across the geopolitical zones and agro-ecological

### 3.3. Analytical Technique

The data were analysed using descriptive statistics and inferential statistics. Descriptive statistics such as frequencies, percentages, means, and charts were used to present the perception of farmers on climate variability and the level of adoption of a bouquet of CSAPs within the study area. To determine the level of interdependencies between the CSAs adopted by farmers and their determinants, the Multivariate Probit Regression was used.

#### 3.3.1. Multivariate Probit Regression Model

The Multivariate Probit Regression Model was used to determine the factors affecting CSAPs adoption. The model can be used to evaluate several correlated binary choices jointly adopted by farmers (Greene, 2003). There is a likelihood of interdependence of technology in CSAPs because farmers would usually adopt technologies simultaneously in a supplementary or complimentary manner. Farmers may likely adopt CSAPs if the expected benefit obtained from the technology is higher than the current technology. Let's assume  $U_0$  represent farmer's benefits from traditional management practices and  $U_k$  is the benefit of adopting the  $k$ th CSAPs: where  $k$  denotes drip or sprinkler irrigation (IRR), early maturing varieties (EMV), green manure (GM), crop rotation (CR) and Agroforestry (AGF). If the farmer decides to adopt the  $k$ th CSAPs on plot  $p$ , it will be expected that the net benefit (utility) for adopting the  $k$ th CSAP on plot will be greater than zero, then:

$$Y_{ipk}^* = U_k^* - U_0 > 0. \quad (1)$$

In this case, the net benefit ( $Y_{ipk}^*$ ) derived from the adoption of  $k$ th CSAPs by the farmer is a latent variable determined by the observed households', plot, and socio-economic characteristics  $X_{ip}$  (See Table 1) and the error term  $\varepsilon_{ip}$ :

$$Y_{ipk}^* = X_{ip}\beta_k + \varepsilon_{ip} \quad (k = IRR, EMV, GM, CR, AGF) \quad (2)$$

The net benefit to the farmer from choosing a combination of CSAP is not observed, however, the farmer's adoption decision is observable. The unobserved preferences in equation (2) can be translated into the observed binary outcome equation for each choice:

$$Y_{ipk} = \begin{cases} 1 & \text{if } Y_{ipk}^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (k = IRR, EMV, GM, CR, AGF) \quad (3)$$

Where:  $Y_{ipk}$  is the adoption of the  $k$ th CSAPs by the  $i$ th household on plot  $p$ .

With the possibility of adopting multiple CSAPs in the multivariate probit model, the error terms jointly follow a multivariate normal distribution with zero conditional mean and variance normalised

to unity. That is:  $\mu_{IRR}, \mu_{EMV}, \mu_{GM}, \mu_{CR}, \mu_{AGF} \xrightarrow{MVN} (0, \omega)$ . Thus, the resulting covariance matrix ( $\omega$ ) is:

$$\omega = \begin{bmatrix} 1 & \rho_{AB} & \rho_{AC} & \rho_{AD} & \rho_{AE} \\ \rho_{BA} & 1 & \rho_{BC} & \rho_{BD} & \rho_{BE} \\ \rho_{CA} & \rho_{CB} & 1 & \rho_{CD} & \rho_{CE} \\ \rho_{DA} & \rho_{DB} & \rho_{DC} & 1 & \rho_{DE} \\ \rho_{EA} & \rho_{EB} & \rho_{EC} & \rho_{ED} & 1 \end{bmatrix} \quad \text{Note: IRR = A; EMV = B; GM = C; CR = D; AGF = E}$$

Where:  $\rho$  is pairwise correlation coefficient of the error terms corresponding to any two CSAPs adopted. Equation (2) is a system of  $k$  equations as shown in equation 4 below:

$$\begin{aligned} Y_{1pk}^* &= \beta_1' X_{1i} + \varepsilon_{1i} & Y_{1pk} &= 1 \text{ if } Y_{1pk}^* > 0, Y_{1pk} = 0 \text{ otherwise} \\ Y_{2pk}^* &= \beta_2' X_{2i} + \varepsilon_{2i} & Y_{2pk} &= 1 \text{ if } Y_{2pk}^* > 0, Y_{2pk} = 0 \text{ otherwise} \\ & & & \vdots \\ Y_{Npk}^* &= \beta_k' X_{ki} + \varepsilon_{ki} & Y_{Npk} &= 1 \text{ if } Y_{Npk}^* > 0, Y_{Npk} = 0 \text{ otherwise} \end{aligned} \quad (4)$$

An adopter of a CSAP refers to a person that has used a practice for at least a planting season preceding the survey period. Of the bouquet of CSAPs presented to farmers, five CSAPs (irrigation, planting of early maturing varieties, agroforestry green manuring, and crop rotation) were selected. The explanatory variables choice was derived from insights from previous studies on adoption (Ehiakpor et al., 2019; Oladele et al., 2019; Tran et al., 2020; Phiri et al., 2022; Edewor et al., 2023). Agroecological zones dummies were included to identify how these areas influence the choice of CSAPs adoption. Table 1 describes the variables used in the MVP model.

Variables and their description include: Early Maturing Variety Cultivation (EMV) (1 = EMV adopted, 0 non-adopter); Green manuring – the deliberate cultivation and ploughing in of certain leguminous plants into the soil (1 = Green manure adopted, 0 non-adopter); Crop rotation: Growing appropriate mix of crops in rotation on same parcel (1 = Crop rotation adopted, 0 non-adopter); Agroforestry (cultivation of appropriate tree species along with crops on farmland either by block planting, alley cropping, etc.) (1 = Agroforestry adopted, 0 non-adopter); Use of Drip or Sprinkler Irrigation in upland/dryland conditions (1 = Irrigation adopted, 0 non-adopter); Age (years); Off farm

income (Naira); Sex (1 = if female, 0 male); Educational Level (Years); Access to credit (1=Yes, 0=No); Cooperative membership (1 = Yes, 0= No); Farm size (Hectares); Native (1 = Yes, 0= No); Household size (Number of persons); Lowland (1 = Yes, 0= No); Land ownership (1 = Yes, 0 = No); Derived savannah (1 = Yes, 0 = No); Northern Guinea Savannah (1 = Yes, 0 = No); Rain forest (1 = Yes, 0 = No); Southern Guinea Savannah (1 = Yes, 0 = No); Sudan Savanna (1 = Yes, 0 = No); Sahel savannah (1 = Yes, 0 = No).

#### 4. Results and Discussion

This section presents the findings of the result on the effect of climate change, the response and behaviour of farmers to climate shocks, adoption of CSA and the determinant of the adoption of CSA. Table 1 presents the summary statistics of the variables used in the study. The mean age (45 years) and large household size of 9 indicate active but labour-constrained households. Average education of 7.7 years, moderate (55%) credit access and land ownership (65%) access suggest fair potential for Climate Smart Agriculture (CSA) adoption. About 42% use early maturing varieties, 28% practice crop rotation, and 16% adopt agroforestry, while irrigation remains low (11%), reflecting limited infrastructure. These patterns highlight that education, credit access, and cooperative membership may likely be the key drivers of CSA adoption among Nigerian smallholders.

**Table 1.** Summary Statistics of the Socio-economic characteristics of farm households

Variable	Obs.	Mean	Std. Dev.	Skewness	Kurtosis
Age	2,534	44.703	12.266	0.000	0.369
Sex	2,560	0.127	0.333	0.000	0.000
Marital status	2,560	0.117	0.388	0.000	0.000
Education (years)	2,560	7.665	5.969	0.064	0.000
Credit access	2,560	0.549	0.498	0.000	0.000
Co-op Society Member	2,560	1.038	1.590	0.000	0.000
Farm size	2,527	3.800	6.872	0.000	0.000
Native	2,560	0.805	0.396	0.000	0.001
Household Size	2,560	9.363	6.753	0.000	0.000
Off farm income	2,560	89063.5	337912.5	0.000	0.000
Native	2,560	0.805	0.396	0.000	0.001
Low Land	2,560	0.374	0.484	0.000	0.000
Land Ownership	2,560	0.653	0.476	0.000	0.000
Early maturing varieties	2,513	0.416	0.493	0.000	0.000
Green manure	2,513	0.174	0.379	0.000	0.000
Crop rotation	2,513	0.282	0.450	0.000	0.000
Agroforestry	2,513	0.159	0.366	0.000	0.000
Irrigation	2,513	0.109	0.311	0.000	0.000

##### 4.1. Effect of Climate Change on Farmers' Livelihood

The effect of climate change on farmers across the Agro-ecological Zones in Nigeria is presented in Table 2. Across the six AEZs, most of the farmers reported that the most adverse effect of climate change led to a decline in crop yield with the highest (76.8%) and lowest (46.4%) effect felt in the RF and DS respectively. A decline in crop yield leads to income loss and may increase the propensity for farmers to tend to poverty. Decline in livestock productivity and the death of some livestock due to climate change was more prominent among farmers in SGS while total loss of crop/livestock was more prevalent in DS. The loss of a farmer's source of livelihood may increase the likelihood of food insecurity and poverty. This corroborates the findings of Phiri et al. (2022) and Edewor et al. (2023)

Some farmers reported that climate change led to the loss of properties. This was more prevalent amongst farmers in DS. Loss of properties such as houses, machines, vehicles or motorcycles may likely occur due to torrential rainfall, flood, increased frequency and/or intensity of storms and other wind related hazards. The incidence of climate change leading to the illness of a household member was more noticeable among farmers in RF. Some of the ailments may be due to increased dust and cold thereby causing asthma attacks, pneumonia, catarrh and flu amongst others. Some farmers across the AEZs reported that climate change brought about the death of a household member. This may be due to drowning after a torrential rainfall or flood and death from ailments amongst others. Very few of the farmers reported that climate change caused food shortage/insecurity as well as food price increase. This may be due to the fact that farmers hardly cultivate just a single plot of land in one location. Many tend to cultivate many plots in different locations. Only farmers in RF and SGS reported that climate change led to an increase in food prices.

**Table 2.** Effect of Climate Change on Farmers' Livelihood

Effect of Changes	DS	NGS	RF	SAH	SGS	SUD
Decline in crop yield	46.4	73.3	76.8	47.5	66.7	71.2
Decline in livestock productivity	3.6	0.0	3.0	3.4	6.7	4.8
Total loss of crop/livestock	32.1	11.1	4.1	27.1	3.3	11.6
Death of some livestock	0.0	0.0	3.3	3.4	4.2	3.4
Loss of properties	14.3	8.9	3.7	15.3	3.3	3.4
Illness of a household member	3.6	4.4	5.2	1.7	3.3	4.1
Death of a household member	0.0	2.2	2.2	1.7	5.8	1.4
Food shortage/ insecurity	0.0	0.0	1.1	0.0	4.2	0.0
Food price increase	0.0	0.0	0.7	0.0	2.5	0.0

Multiples Responses (%)

#### 4.2. Climate Smart Agricultural Practices Adoption

In this study, the 16-climate smart agricultural practices (CSAP) were classified into two categories. The categories are 'eight improved soil fertility and crop management practices' (Cultivation of early maturing and drought tolerant varieties, Cultivation of disease/pest-resistant varieties, Minimum Tillage, Farmyard Manure, intercropping cover crop, Crop Rotation, Micro-dosing and Integrated Pest/weed Management) and 'eight improved land and water management

practices' (Refuse incorporation into soil rather than burning, Green Manure, Terracing, Agroforestry, Drip or Sprinkler Irrigation, Controlled flooding, Construction of bounds and Mulching).

To determine the level of CSAP adoption, this study made use of two adoption categories (Non-adopters and Adopters). The non-adopters are those who have heard of a specific CSAP but have never used it or those who once used and stopped using while the adopters are those who are still using the CSAP. Table 3 shows the distribution of farmers according to their adoption of CSAPs. The result shows that majority of the farmers across all the AEZs adopted the CSAP 'Early maturing and drought tolerant varieties' except for the SAH AEZ where majority were non-adopters. Farmers will be able to harvest their crops early and recoup farm expenses when they adopt early maturing and drought tolerant varieties. Early maturing and drought tolerant varieties adoption was very high in SUD among the AEZs and very low in SAH. More farmers in SUD adopted the cultivation of disease/pest-resistant varieties compared to other AEZs. The adoption of this CSAP was lowest in SAH. This may be due to the unavailability of such seeds in communities under this AEZ.

Similarly, higher proportion of the farmers across NGS, RF, SAH, and SGS were non-adopters 'minimum/zero tillage' while most farmers in DS and SUD have adopted this technology. The ability to adopt may be because they had access to more information through government and non-governmental agencies extension contacts. More farmers adopted the use of "farmyard manure", 'intercropping cover crops' and 'crop rotation' across majority of the AEZs. Although for these three CSAP, more farmers in the RF and SGS were non-adopters. Furthermore, majority of the farmers across all the AEZs reported that they were non-adopters of "Micro-dosing" and "Integrated Pest/weed Management. With respect to these two methods, there was limited adoption due to lack of awareness. It was interesting to note that a high proportion of the farmers across the AEZs were unaware of these CSAP. Majority of the farmers in DS adopted the CSAP "incorporation of refuse into the soil rather than burning' and 'Green manuring - the deliberate cultivation and ploughing in of certain leguminous plants into the soil' compared to other AEZs while the lowest adopters were farmers in the SAH.

For the adoption of the CSA 'Terracing - construction of terraces on sloppy/hilly farmland' majority of the farmers were unaware of this CSA. This may be because its usefulness is more attached to cultivation on hilly farmlands. Adoption of terracing was highest amongst farmers in DS and lowest amongst farmers in the RF. The adoption of 'agroforestry- the integration and cultivation of appropriate tree species along with crops on farmland either by block planting or alley cropping' was very low as farmers across the AEZs reported that they were either unaware of the CSAP or they are aware but never tried the CSAP. Highest adopters were farmers in DS, and the least adopters were farmers in the SAH. The reason for the low adoption may be because most of the farmland used by many of the farmers were either communal lands or leased lands hence their inability to carry out long term or permanent activities on such lands.

**Table 3.** Climate Smart Agricultural Practices in Nigeria

Climate Smart Agricultural Practices	Adoption Categories	Der. Sav. (83)	North Gui. (150)	RF (550)	Sahel Sav. (127)	South Gui. (335)	Sudan Sav. (289)
Early maturing & drought tolerant varieties	Non-adopters	39.8	64.7	64.9	73.2	60.1	34.9
	Adopters	60.2	35.3	35.1	26.8	39.1	65.1
Disease/ pest-resistant varieties	Non-adopters	53.0	71.3	72.2	79.5	73.4	46.7
	Adopters	47.0	28.7	27.8	20.5	26.6	53.3
Minimum Tillage	Non-adopters	53.0	85.3	78.2	92.9	79.1	68.2
	Adopters	47.0	14.7	21.8	7.1	20.9	31.8
Farmyard Manure	Non-adopters	49.4	56.7	78.4	44.1	71.3	61.2
	Adopters	50.6	43.3	21.6	55.9	28.7	48.8
Intercropping cover crop	Non-adopters	48.2	65.3	74.2	58.3	77.6	62.3
	Adopters	51.8	34.7	25.8	41.7	22.4	37.7
Crop Rotation	Non-adopters	50.6	61.3	76.2	68.5	80.9	66.8
	Adopters	49.4	38.7	23.8	31.5	19.1	33.2
Micro-dosing	Non-adopters	63.9	84.0	83.5	74.8	84.2	75.8
	Adopters	36.1	16.0	16.5	25.2	15.8	24.2
Integrated Pest/ weed Mngt	Non-adopters	62.7	89.3	86.9	88.2	83.9	73.4
	Adopters	37.3	10.7	13.1	11.8	16.1	24.6
Refuse incorporation into soil	Non-adopters	38.6	88.0	68.5	83.5	74.0	58.1
	Adopters	61.4	22.0	31.5	16.5	26.0	41.9
Green Manure	Non-adopters	72.3	82.7	81.1	95.3	85.4	74.4
	Adopters	27.7	17.3	18.9	4.7	14.6	25.6
Terracing	Non-adopters	72.3	78.7	81.6	83.5	82.4	73.0
	Adopters	27.7	21.3	12.4	16.5	17.6	27.0
Agroforestry	Non-adopters	71.1	81.3	83.5	89.8	83.4	79.9
	Adopters	28.9	12.7	16.5	10.2	14.6	20.1
Drip or Sprinkler Irrigation	Non-adopters	74.3	88.7	87.6	97.6	91.9	81.0
	Adopters	15.7	11.3	12.4	2.4	8.1	19.0
Controlled flooding	Non-adopters	61.4	88.7	86.9	86.6	87.2	73.7
	Adopters	38.6	11.3	13.1	13.4	12.8	26.3
Construction of bounds	Non-adopters	55.4	84.7	88.2	92.1	83.1	74.4
	Adopters	44.6	15.3	11.8	7.9	14.9	25.6
Mulching	Non-adopters	55.4	86.7	79.3	87.4	77.0	68.9
	Adopters	44.6	13.3	20.7	12.6	23.0	31.1

Most farmers across all the AEZs were either unaware or aware of Drip or Sprinkler Irrigation in upland dryland conditions but have never used it. Adoption rate was very low; this may be because it is expensive to set up. The use of this technology will help in conserving water. The adoption of the use of controlled flooding before and during cultivation- that is alternate wet and dry systems - in flooded rice/lowland production systems was also very low in some AEZs, the reason been that the CSAP is specifically targeted at rice cultivation. Therefore, farmers cultivating other crops such as maize may be unaware of such or those without access to extension agents. Water

harvesting and conservation through the construction of bounds and Mulching were GAPs that were more adopted by farmers in DS and least adopted by farmers in the SAH.

#### 4.3. Factors affecting the adoption of Climate Smart Agricultural Practices in Nigeria

On the factors influencing the adoption of CSAP in Nigeria, the selection of the explanatory variables was based on empirical review of studies on technology adoption (Edewor et al., 2023; Phiri et al., 2022, Kehinde et al., 2022; Tran et al., 2020). The result of the MVP model is shown in Table 4. We rejected the hypothesis from each equation that all coefficients are mutually equal to zero at 1% ( $\text{Prob} > \chi^2 = 0.00$ ). This is evidence from the Wald chi-square test statistics ( $\chi^2(120) = 516.23$ ) result which implies the existence of some level of interdependence between the CSAP. The correlation result of the CSAP adoption can be found in Table 4. All the estimated correlation coefficients were statistically significant ( $P < 0.10$ ) and positive thus suggesting that the choice to adopt the CSAP are jointly determined with the practices complementing each other where they are jointly adopted on a single plot. Positive correlations exist between 'Agroforestry & early maturing variety', 'irrigation & early maturing variety', 'Crop rotation & early maturing variety', 'Green manure & early maturing variety', 'irrigation & agroforestry', 'crop rotation & agroforestry', 'green manure & agroforestry', 'Crop rotation & irrigation', 'Green manure & irrigation' and 'Green manure and crop rotation'.

The MVP result has shown that diverse factors (socioeconomic and institutional) affect CSAP adoption. Farmers' age had a positive influence on agroforestry and irrigation adoption. Majority of the surveyed farmers are still within their economically active ages. Young farmers may be more open to innovation and experience may also include the likelihood of either adopting or not adopting. This aligns with the finding of Edewor et al. 2023. The findings from literature on age affecting CSAP adoption are mixed (Tran et al., 2020). Off farm income had a positive influence on the adoption of agroforestry and green manure. This suggests that farmers will be more willing to adopt both practices with higher non-farm income. This aligns with the findings of Oyawole et al. (2019). The sex of the household head had a significant and negative influence on the adoption of early maturing variety and green manure. This implies that the adoption of both practices will be higher among female headed households as compared to the males. The adoption of green manure was significantly influenced by farmers' education. Higher educational status implies that farmers would be more willing to adopt green manure. Farmers with more education can carefully weigh the merits and demerits of any practices that affect their livelihood. This is in line with (Coulibaly et al., 2016; Nurie et al., 2013; Kehinde et al., 2022). Credit access also had a positive and significant influence on the adoption of agroforestry, green manure, and crop rotation. This aligns with that of Ajadi et al. (2015). A rational farmer will make production decisions that will be beneficial to production with additional funding. Furthermore, the likelihood of adopting early maturing variety and agroforestry increases with being a member of a cooperative (social capital). Cooperative membership is beneficial to most farmers (Oyawole et al. 2019) because it gives them the opportunity to access funds, relevant production information, informal training offers and other group benefits.

**Table 4.** Factors Affecting the Adoption of Climate Smart Agriculture Practices in Nigeria

	Early mature var		Agroforestry		Drip Irrigation		Crop rotation		Green manure	
	Coeff.	Z	Coeff.	Z	Coeff.	Z	Coeff.	Z	Coeff.	Z
Age	0.00	-1.44	0.01**	2.3	0.01*	1.9	0.00	1.12	0.00	0.75
Off farm income	0.00	0.77	0.00**	2.44	0.00	-0.39	0.00	-0.31	0.00***	2.7
Sex	-0.29***	-3.43	0.06	0.63	-0.18	-1.62	-0.06	-0.64	-0.25**	-2.46
Educational level	0.01	1.44	0.00	0.43	0.00	-0.04	0.01	1.65	0.01*	1.79
Credit Access	0.00	0.05	0.12*	1.77	0.03	0.4	0.16***	2.78	0.11*	1.78
Cooperative Society	0.08***	4.52	0.04**	2.07	-0.02	-0.95	-0.03	-1.52	-0.01	-0.75
Farm size (Ha)	0.00	0.97	0.01**	2.24	-0.02***	-2.87	0.00	0.61	0.00	0.46
Native	0.00	-0.05	0.24***	2.71	0.23**	2.28	0.06	0.84	0.16*	1.84
Household size	0.00	0.84	-0.02***	-4.81	-0.02***	-2.83	-0.01	-1.15	0.00	0.79
Low Land	0.02	0.32	0.00	0.01	0.13*	1.78	-0.16***	-2.68	0.00	-0.03
Land Ownership	0.01	0.09	0.25***	3.64	0.07	0.98	0.10*	1.75	0.06	0.9
Derived Savanna	0.64***	4.52	0.87***	4.95	1.04***	4.67	0.44***	3.1	0.91***	5.04
NGS	0.14	1.01	0.57***	3.16	0.83***	3.71	0.30**	2.14	0.48***	2.59
Rainforest	0.08	0.72	0.41***	2.64	0.78***	3.82	-0.30***	-2.56	0.59***	3.59
SGS	-0.31***	-2.59	0.55***	3.48	0.78***	3.83	-0.30**	-2.42	0.30*	1.84
Sudan Savanna	0.70***	5.8	0.77***	4.72	1.08***	5.2	0.10	0.81	0.81***	4.95
Constant	-0.35	-2.11	-2.13***	-9.95	-2.31***	-9.56	-0.73***	-4.15	-1.91***	-8.39
rho21	0.132***	3.62	0.036			rho42	0.323***	9.36	0.035	
rho31	0.168***	4.23	0.040			rho52	0.256***	6.61	0.039	
rho41	0.181***	5.56	0.033			rho43	0.249***	6.66	0.037	
rho51	0.247***	6.95	0.036			rho53	0.155***	3.36	0.046	
rho32	0.344***	8.05	0.043			rho54	0.292***	7.99	0.037	

Wald chi2(80) = 516.23; Log pseudolikelihood = -5730.4607; Prob > chi2 = 0.0000; Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: chi2(10) = 326.132 Prob > chi2 = 0.0000. Robust standard error in parenthesis. \*\*\*, \*\*, and \* denote significance at 1%, 5% and 10%

The characteristics of the farmer’s plot play a highly significant role in their decision to adopt a specific agricultural practice. While an increase in the farm size cultivated by farmers increased the likelihood of adopting agroforestry, it had a negative and significant influence on irrigation. This is similar to the findings of (Oladele et al., 2019) who found that cultivating more farmland influenced farmers’ decision to adopt CSAP. Likewise, a farmer who is a native of the rural community in which agricultural production occurs is more likely to adopt agroforestry and irrigation as compared to the

other practices which were not significant. Farmers who are native of the community in which they dwell cannot afford to make long term production investment as compared to non-natives.

Our findings on the influence of household size on CSAP adoption corroborates that of (Mujeyi et al., 2019) where they discovered a positive association between the adoption of sustainable practices and household size. Additionally, there is a likelihood that farmers that cultivate more lowlands will adopt irrigation while farmers that cultivate on highlands will adopt crop rotation. Irrigation use will boost production during a period with limited or no rainfall. Land ownership positively influenced the adoption of agroforestry and crop rotation. This is a fact as secure land tenure may motivate the farmers to invest in the adoption of long-term investment practices such as agroforestry. This finding is in line with that of Kehinde et al (2023), Asaaga et al. (2020) and Nigussie et al. (2017) who reported that secure land tenure boosted agricultural production in Nigeria, Ethiopia, and Ghana. The decision to adopt specific CSAP varied across different AEZs.

#### 4.4. Robustness check

We checked for multicollinearity among the explanatory variables, and the results are presented in Table 5. The Variance Inflation Factor (VIF) values presented in the appendix range between 1.05 and 4.27, with a mean VIF of 1.63, indicating that all variables are well below the critical threshold of 5 (Appendix I). This confirms the absence of multicollinearity and suggests that the independent variables are not highly correlated (Gujarati & Porter, 2009). Thus, the model estimates are statistically reliable and stable. The results further validate the robustness of the regression analysis, ensuring that parameter estimates are unbiased and efficient (Wooldridge, 2015). This diagnostic check is essential for ensuring that the regression model captures the true effects of socio-economic and institutional factors on Climate Smart Agriculture (CSA) adoption without distortions caused by overlapping explanatory variables.

Table 5 presents the results of the linear regression estimation of the correlates of CSA adoption, proxied by the adoption of improved crop varieties among smallholder farmers. The model explains 8.1% of the variation in adoption decisions, with an F-statistic of 5.75 significant at the 1% level, suggesting a good fit for cross-sectional data. Cooperative society membership has a strong and positive effect on the adoption of improved varieties ( $\beta = 0.036$ ,  $p < 0.01$ ), implying that belonging to a co-operative society enhances access to shared knowledge, information, and inputs—key factors in technology diffusion (Adesina et al., 2000; Abebaw & Haile, 2013). Likewise, regional variations are evident, as farmers in the Rainforest, Sahel savanna, and Southern Guinea Savanna zones are significantly less likely to adopt early maturing varieties compared to those in the Northern Guinea Savanna, thus reflecting differences in agroecological suitability and institutional support (Arslan et al., 2015; FAO, 2021). Other variables such as education, land ownership, and access to credit show positive but insignificant effects, suggesting that while they contribute to adoption, their influence may depend on complementary factors such as extension services and market access (Nhemachena & Hassan, 2007). Overall, the findings emphasize the importance of social capital and spatial factors in shaping CSA adoption among smallholder households in Nigeria.

**Table 5:** Linear regression estimate of the correlates of the Climate Smart Agriculture Adoption

Explanatory Variable	Coef.	Std. Err	T-value
Log Age	-0.019	0.055	-0.34
Log Off farm income	0.010	0.009	1.15
Sex	-0.094	0.049	-1.9*
Log Education (years)	0.039	0.035	1.12
Credit access	-0.022	0.032	-0.68
Coop Society membership	0.036	0.009	3.92***
Log Farm size (Ha)	-0.011	0.016	-0.67
Native	-0.011	0.042	-0.26
Log Household Size	-0.025	0.024	-1.07
Low Land	-0.005	0.032	-0.14
Land Ownership	0.021	0.032	0.64
Derived Savanna	0.039	0.074	0.54
Rain forest	-0.169	0.062	-2.75***
Sahel Savanna	-0.269	0.087	-3.08***
Southern Guinea Savanna	-0.271	0.065	-4.17***
Sudan Savanna	0.091	0.072	1.26
Constant	0.503	0.255	1.97
Number of observations	1054	R-squared	0.081
F (16, 1037)	5.75	Adj R <sup>2</sup>	0.067
Prob > F	0.000	Root MSE	0.481

## 5. Conclusions

The study examined the determinants of Climate Smart Agriculture Practices adoption among smallholder farming households in Nigeria using data from 1,534 rice and/or maize farmers across six agro-ecological zones. Findings reveal that climate change significantly threatens agricultural productivity, with farmers reporting adverse effects such as declining crop yields, livestock losses, property damage, and food insecurity. While several Climate Smart Agricultural Practices were identified, adoption rates vary widely across regions and practices. Early-maturing and drought-tolerant varieties were the most widely adopted practices, especially in the Sudan Savanna, while adoption of practices such as agroforestry, drip irrigation, and green manuring remained very low due to limited awareness and high costs. The study's multivariate probit regression analysis shows that CSAPs adoption is influenced by a mix of socioeconomic, institutional, and environmental factors, including age, off-farm income, education, access to credit, cooperative membership, farm size, land ownership, and agro-ecological zones. Importantly, the results highlight significant complementarities among practices, implying that adopting one often increases the likelihood of adopting others.

Given Nigeria's vulnerability to climate change and its reliance on rain-fed agriculture, promoting broader and more effective adoption of CSAPs is essential for improving resilience,

enhancing productivity, and ensuring food security. Based on the findings, the study recommends strengthening agricultural extension services by training agents to provide technical support and promote climate-smart practices like agroforestry and drip irrigation. Farmers should be encouraged to join cooperatives for better access to credit, inputs, and shared learning. Investments in affordable, climate-resilient seeds, efficient irrigation, and community water systems are essential. Securing land tenure for smallholders will encourage long-term sustainable practices. Lastly, climate-smart strategies should be tailored to each agro-ecological zone, emphasizing drought-tolerant crops and irrigation in arid areas, and soil fertility and pest management in humid zones.

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## Appendix

**Appendix I:** VIF Post estimation test for multicollinearity among the covariates included in the model

Variables	VIF	1/VIF
Sex	1.08	0.926
Log Farm size	1.07	0.939
Log Off farm income	1.06	0.947
Land Ownership	1.05	0.949
Log Education (Years)	1.25	0.801
Log Household Size	1.22	0.821
Log Age	1.12	0.893
Native	1.12	0.894
Credit access	1.11	0.898
Low Land	1.11	0.899
Co-op Society	1.11	0.902
Rain forest	4.27	0.234
South Guinea Savanna	3.16	0.317
Sudan Savanna	2.39	0.419
Derived Savanna	2.19	0.456
Sahel Savanna	1.74	0.575
Mean VIF	1.63	