ADOPTION OF CLIMATE-SMART AGRICULTURAL PRACTICES AND ITS EFFECT ON COCOA YIELD IN ONDO STATE, NIGERIA

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Abstract

Agricultural development in Nigeria is threatened by climate change, reducing Cocoa farmers' productivity in Ondo State. Despite the potential of Climate-Smart Agricultural (CSA) practices to mitigate the challenges of climate change, their adoption remains low. Previous studies have examined the extent of CSA among farmers. However, the linkage between CSA practices and cocoa yield has not been well documented. This study investigated the effect of adopting climate-smart agricultural practices on cocoa yield in Ondo state, Nigeria. Also, the determinants of CSA practices adoption were identified and its effectiveness as an adaptation strategy was evaluated. A multi-stage sampling technique was used to select 250 cocoa farmers in Ondo State. Primary data were collected with the aid of a semi-structured questionnaire. Data were analyzed using descriptive statistics and endogenous switching regression model. Cocoa farming was male dominated. Adopters of CSA practices were more (54.0%) than non-adopters (46%). The mean farm size of the adopters was 2.9 hectares while the non-adopters had 1.4 hectares. Access to climate information, land ownership, and farming experience determined the adoption of CSA. Mean yield of the adopters was 1213.33kg/ha and 1040.61kg/ha for non-adopters. The adoption of CSA practices led to an increase in yield by 244.232kg/ha. The adoption of CSA practices increased cocoa yield in Ondo State, Nigeria. Training programs that focus on experiential learning can enhance farmers' education, drive widespread adoption, and improve the livelihoods of cocoa farmers.
Keywords: Climate change, adoption, climate-smart agricultural practices, endogenous switching regression

Introduction

Agriculture is a vital sector in Nigeria, contributing 29.44% to the GDP and employing about 70% of the workforce (*Q1 2024_GDP Report*, n.d.). Cocoa farming is essential for income generation and foreign exchange, especially in Ondo State. It has supported thousands of smallholder farmers for years, providing a means of livelihood. However, climate change poses significant challenges to cocoa production, threatening its sustainability and the farmers' livelihoods.

Climate refers to the regular weather conditions of a specific area, including rainfall patterns and average temperatures. Climate change occurs when these patterns shift over the medium to long term (Morgan & Werner, n.d.). Changes in rainfall, rising temperatures, and erratic weather have significantly affected cocoa yields and bean quality (Bomdzele & Molua, 2023). Cocoa is particularly vulnerable due to its dependence on consistent water and sensitivity to temperature extremes, and it is highly susceptible to environmental changes (Suh & Molua, 2022). Such changes often last for decades or longer and can result from both natural variability and human activities (Attiogbé et al., 2022; Kavita Shah et al., 2019). In Ondo State, where agriculture relies on rainfall, the effects of climate change are particularly evident. Cocoa farmers face challenges such as reduced yields, lower-quality produce, and increased pest infestations, all exacerbated by changing climatic conditions (Bukola et al., 2021; Intergovernmental Panel on Climate Change [IPCC], 2022). Drought, marked by prolonged low rainfall, leads to water shortages, causing plants to wilt, high seedling mortality, smaller beans, and decreased yields due to pest attacks (Seleiman et al., 2021). This situation highlights the urgent need for adaptive strategies to support farmers and maintain productivity(Lamidi, n.d.). Although climate change poses significant threats, it also offers an opportunity to introduce innovative farming practices that could enhance resilience (Hussain et al., 2022).

Cocoa farmers have traditionally relied on indigenous knowledge to adapt to climate change. However, this knowledge alone, without accurate climate information, may not prepare farmers to respond to climatic conditions outside their experience/knowledge (Napogbong et al., 2021). Integrating climate information can enhance indigenous practices, creating a robust adaptation strategy. In response to these challenges, the Food and Agriculture Organization (FAO) promotes Climate Smart Agriculture (CSA) as a sustainable agricultural approach. Implementing CSA practices can mitigate the negative effects of climate change and improve agricultural outputs (Trinh Thi & Zhou, 2025) . Organic fertilizer is vital for Climate-Smart Agriculture (CSA) as it boosts productivity and supports environmental sustainability. By improving soil fertility, structure, and microbial activity, organic fertilizers enhance nutrient cycling and water retention, leading to healthier cocoa trees and higher yields. Nigeria, which was once the world's second-largest cocoa producer, is now fourth, primarily due to weather changes, poor management, and oil exploration (Kongor et al., 2024). Ondo State remains the largest cocoa producer in Nigeria. Some studies have examined the extent of Climate-Smart Agriculture (CSA) among farmers (Adebisola & Ayodeji, 2022; Ojo et al., 2023; Oyawole et al., 2021; Victory et al., 2022). It is against the above background that this research work aims to examine the adoption of climate-smart agricultural practices and its effect on cocoa yield in Ondo state, Nigeria. This research identifies the climate-smart agricultural practices adopted, estimates the level of adoption of climate-smart agricultural practices, determines the factors influencing the adoption of climate-smart agricultural practices, and analyzes the effect of the adoption of climate-smart agricultural practices on cocoa yield in the area.

Methodology

The study was carried out in Ondo state. Ondo State has a land mass of about 14798.8 square kilometers and it lies entirely approximately on latitude $5^0$45' and $8^0$15' North and longitude $4^0$45' East. This means that the State lies entirely in the tropics. The temperature of the state throughout the year ranges between 21^0C and 29^0C and the humidity is relatively high. The annual rainfall varies from 2000mm in the southern part of the state to 1500mm in the northern areas of the state (Bukola et al., 2021). Cocoa in Nigeria is mostly grown in eighteen states with Ondo State being the leading cocoa-producing state in Nigeria, contributing the highest amount of cocoa production (Blessing et al., 2022).

Primary data on respondents' socioeconomic characteristics, types of Climate-Smart Agriculture (CSA) practices, cocoa output, farm size, and access to climate-related resources were collected using a semi-structured questionnaire. The study used multi-stage procedure. First, three local governments in Ondo State - Ile-Oluji/Oke Igbo, Ondo West, and Idanre, were purposively selected for their high cocoa production. Second, towns and villages with significant cocoa activity were randomly sampled. At the third stage, samples were selected proportionate to size, 30% of cocoa farmers in each of the 18 villages. Multi-stage sampling procedure was used to select 250 cocoa farmers in Ondo State.

Data were analyzed using descriptive statistics to profile the socioeconomic characteristics of respondents and assess the adoption of climate-smart agricultural (CSA) practices among cocoa farmers in Ondo State. The analysis included frequency distribution, means, and percentages. The frequency of various CSA practices, such as organic fertilizers, integrated pest management, diversified cropping, improved varieties, and irrigation, was recorded and ranked. A farmer is considered an adopter if they adopt at least one CSA practice. Endogenous Switching Regression (ESR) model was used to analyze the effect of adopting

Climate-Smart Agriculture practices on cocoa yield, addressing endogeneity and self-selection bias (Agbenyo et al., 2022) through the Heckman selection correction method (Saadu et al., 2024). In the first stage, a probit model was employed to predict CSA adoption (1=adopted, 0=non-adopted) as given in equation 1:

$$\Pr(T_i = 1) = \emptyset(\beta_0 + \beta_1 \text{Age}_i + \beta_2 \text{Sex}_i + \beta_3 \text{Household size}_i + \beta_4 \text{Educational status}_i + \beta_5 \text{Farm size}_i + \beta_6 \text{Land Ownership}_i + \beta_7 \text{Farm experience}_i + \beta_8 \text{Off- farm income}_i + \beta_9 \text{Access to credit}_i + \beta_{10} \text{extension agent access}_i + \beta_{11} \text{farm organization membership}_i + \beta_{12} \text{climate change awareness}_i + \beta_{13} \text{climate information access}_i + \varepsilon_i) \quad (1)$$

Where: Pr represents the probability of CSA practices adoption, $\emptyset$ is the Cumulative distribution function of standard normal distribution, T is the CSA adoption status, Ti=1 if the farmer adopts CSA practices, 0 otherwise. Age (years), sex (1,0), household size (number), education status (years), farm size(ha), farming experience (years), off-farm income (₦), access to agricultural credit (1,0), access to extension agent (1,0), membership of farm organization (1,0), awareness of climate change (1,0) and access to climate information (1,0) were the independent variables. The variables in this study were chosen based on prior research on the adoption of Climate-Smart Agriculture (CSA) practices in Nigeria (Jellason et al., 2021; Okpokiri et al., 2021; Victory et al., 2022). These factors significantly influence smallholder farmers' adoption behavior in those studies and that justified their consideration in this study. Climate information and awareness of climate change are vital instrumental variables (Saadu et al., 2024), as they are crucial for farmers' adoption of CSA practices (Mireille Dohmen et al., 2018). However, they do not directly affect yields. The empirical validity of the Endogeneity-Selection-Regression (ESR) instruments is also tested.

The second stage of the endogenous switching model is the outcome equation (yield measured in kg/ hectare). The model represented various switching regimes with binary outcomes. The switching regimes are expressed as:

$$lnY_{1i} = \alpha_0 + \alpha_1 X_{1i} + \alpha_2 X_{2i} + \alpha_3 X_{3i} + \alpha_4 X_{4i} + \alpha_5 X_{5i} + \alpha_6 X_{6i} + \alpha_7 X_{7i} + \alpha_8 X_{8i} + \alpha_9 X_{9i} + \alpha_{10} X_{10i} + \alpha_{11} X_{11i} + \varphi_1 \rho_1 + \mu_{1i}$$

for adopters of CSA (2)

$$lnY_{0i} = \delta_0 + \delta_1 X_{1i} + \delta_2 X_{2i} + \delta_3 X_{3i} + \delta_4 X_{4i} + \delta_5 X_{5i} + \delta_6 X_{6i} + \delta_7 X_{7i} + \delta_8 X_{8i} + \delta_9 X_{9i} + \delta_{10} X_{10i} + \delta_{11} X_{11i} + \varphi_0 \rho_0 + \mu_{0i}$$

for non-adopters of CSA (3)

lnY_i = Log transformed yield of cocoa farmer i for each regime (kg/ hectare).

Where; X_1 = Age of household head (years), X_2 = Sex of households (male = 1, female = 0) X_3 = Household size (number), X_4 = Educational status of household (years), X_5 = Farm size (hectares),X_6 = Land Ownership (owned=1, non-owned=0), X_7 = Farming experience of household head (years), X_8 = Off-farm income (naira), X_9 = Access to agricultural credit (yes = 1, no = 0),X_{10} = Access with extension agent (yes = 1, no = 0), X_{11}= Membership of farm organization (yes=1, no=0),φ_1 and φ_0 are the Inverse mills ratio (IMR) controlling for selection bias, ρ_1 *and* ρ_0 are the correlation coefficients measuring unobserved factors affecting both adoption and yield, μ_{1i} *and* μ_{0i} are the error terms

The average treatment effect (ATE) which explains the difference between the actual outcome and the hypothetical outcome if the adopters had not adopted the CSA practices is expressed as:

$$ATET = E[\gamma_{1i} \setminus T_i = 1] - E[\gamma_{0i} \setminus T_i = 1] \quad (4)$$

$$ATU = E[\gamma_{1i} \setminus T_i = 0] - E[\gamma_{0i} \setminus T_i = 0] \quad (5)$$

$$ATE = E(\gamma_{1i}) - E(\gamma_{0i}) \quad (6)$$

Results and Discussion

Socioeconomic characteristics of cocoa farmers

Most respondents are male (84.4%) and married (89.2%). Adopters of climate-smart agriculture (CSA) practices have an average age of 56.4 years, while non-adopters average 51.4 years, suggesting cocoa farming is mainly undertaken by older individuals due to younger people's disinterest in agriculture caused by urban migration. Respondents' average household size is 5.1 for adopters and 4.5 for non-adopters. The average years of schooling is 9.9 for adopters and 10.2 for non-adopters, indicating a relatively high literacy level. Additionally, adopters have more farming experience, averaging 18.3 years compared to 12.2 years for non-adopters, and they cultivate larger farms, averaging 2.9 hectares versus 1.4 hectares for non-adopters (Tables 1a, 1b and 1c).

Adoption of CSA practices

The most commonly adopted CSA practice is organic fertilizer use (62.40%), followed by integrated pest management (IPM) at 57.20% and diversified cropping at 56.80%. The use of improved cocoa seeds or seedlings ranks fourth at 42.40%, while irrigation is the least adopted practice at 26.40% among farmers in the study area (Table 2). The Climate-Smart Agricultural (CSA) practices analyzed in this study were selected based on both literature and field data. During the design of the data collection instrument, we engaged with cocoa farmers and key stakeholders to identify the CSA strategies they were aware of, had access to, or were already implementing. The selected practices reflect those that had the most significant level of awareness and adoption among cocoa farmers in the study area. Therefore, they represent the most context-relevant CSA practices for cocoa farmers in Ondo State.

Saadu et al., 2024 noted that organic and inorganic fertilizer applications are widely adopted. This is also consistent with findings from (Ojoko et al., 2017) and (Saliu Akinlabi Tiamiyu, 2018), which indicates low adoption of water management practices due to limited technical knowledge and inadequate capital for necessary inputs. The result also shows that 54% of respondents have adopted Climate-Smart Agriculture (CSA) practices, incorporating techniques like integrated pest management, improved seed, organic fertilizers, diversified cropping, and irrigation. In contrast, 46% of cocoa farmers in the study area continue to use traditional farming methods (Table 3).

Table 1a: Distribution of adopters and non-adopters by socio-economic Characteristics

Variable	Adopters		Non-adopters	
	Frequency	Percentage(%)	Frequency	Percentage(%)
Sex				
Female	18	13.3	21	18.3
Male	117	86.7	94	81.7
Age				
≤ 30	2	1.5	1	0.9
31-40	14	10.4	19	16.5
41-50	18	13.3	32	27.8
51-60	59	43.7	44	38.3
61-70	29	21.5	18	15.7
71-80	13	21.5	18	15.7
Mean	56.4(10.860)		51.4(8.988)	

Source: Field Survey, 2024

Table 1b: Distribution of adopters and non-adopters by socio-economic Characteristics

Variable	Adopters		Non-adopters	
	Frequency	Percentage (%)	Frequency	Percentage (%)
Marital Status				
Single	3	2.2	5	4.3
Married	12.2	90.4	101	87.8
Divorced	-	-	4	3.5
Widowed	10	7.4	5	4.3
Household size				
≤3	18	13.3	18	15.7
4-6	86	63.7	91	79.1
7-9	31	23.0	5	4.3
>9	-	-	1	0.9
Mean	5.1(1.501)		4.5(1.477)	
Farm size (ha)				
≤1.0	72	53.3	88	76.5
1.1-5.0	38	28.1	19	16.5
5.1-10.0	25	18.5	8	7.0
Mean	2.9(2.818)		1.4(1.283)	

Source: Field Survey, 2024

Table 1c: Distribution of adopters and non-adopters by socio-economic Characteristics

Variable	Adopters		Non-adopters	
	Frequency	Percentage(%)	Frequency	Percentage(%)
Farming Experience				
≤10	52	38.5	66	57.4
11-20	43	31.9	39	33.9
21-30	3	2.2	7	6.1
31-40	31	23.0	3	2.6
>40	6	4.4	-	-
Mean	18.3(11.101)		12.2(5.464)	
Years of formal education				
0	22	16.3	8	7.0
2-6	1	0.7	8	7.0
7-12	76	56.2	76	66.1
13-18	36	26.7	23	20.0
Mean	9.9(5.053)		10.2(3.545)	

Source: Field Survey, 2024

Table 2: Distribution According to the Adoption of Climate Smart Agricultural Practices

CSA practices	Frequency	Percentage	Rank
Use of Organic Fertilizer	156	62.40	1st
Integrated Pest Management	143	57.20	2nd
Diversified Cropping	142	56.80	3rd
Use of Improved Variety	106	42.40	4th
Irrigation	66	26.40	5th

Source: Field Survey, 2024

Table 3: Distribution of Respondents According to the Level of Adoption of CSA

Adoption Level	Frequency	Percentage (%)
Non-adopters	115	46
Adopters	135	54
Total	250	100

Source: Field Survey, 2024

Determinants of adoption of CSA practices

The diagnostic test results in Table 4 support the use of the endogenous switching regression model to evaluate the adoption of climate-smart agricultural (CSA) practices and their effects on cocoa yield. The rho values of 0.8112 and -0.1384 suggest that unobserved factors promoting CSA adoption are linked to higher cocoa yields for adopters, while non-adopters face lower yields due to factors that discourage CSA adoption. Key factors influencing farmers' decisions to adopt CSA practices include sex, years of education, land ownership, farm experience, farmers' organization membership, off-farm income, access to agricultural credit, and climate change awareness. Notably, male household heads are less likely to adopt CSA practices compared to females, consistent with findings of (Atta-Aidoo et al., 2022; Popoola et al., 2022). Additionally, farmers who are members of organizations and those aware of climate change are more likely to adopt CSA practices, as noted by(Ghimire et al., 2015; Rodríguez-Barillas et al., 2024). The awareness of the effect of climate change has a positive and significant effect on farmers' decisions to adopt Climate-Smart Agriculture (CSA) practices. This indicates that understanding climate change plays a crucial role in encouraging the adoption of CSA. This aligns with the findings of(Saadu et al., 2024), who suggest that raising awareness and providing information about climate change can be key in motivating farmers to implement CSA practices.

Table 4 also highlights factors affecting cocoa yields among adopters and non-adopters. Years of education positively influence yields, with a more significant effect for adopters (0.0320 for adopters and 0.0297 for non-adopters). Moreover, land ownership and access to agricultural credit improve yields for both groups, aligning with studies that support rural finance policies for adopting new CSA practices. This agrees with (Antwi-Agyei et al., 2021; Mujeyi et al., 2020; Teklu et al., 2023) that where policies that support rural finance programs exist, farmers have adopted new CSA practices.

Distribution of adopters and non-adopters by Cocoa yield

Table 5 shows that 33.34% of adopters achieved cocoa yields of 1001 to 1200 kg/ha, with an average yield of 1213.33 kg/ha. In contrast, 46.96% of non-adopters produced 1000 kg/ha or less, averaging 1040.61 kg/ha. Higher yields above 1200 kg/ha were more common among adopters; 3.70% of adopters reached yields over 1500 kg/ha, while none of the non-adopters did.

Table 4: Endogenous switching regression results for adoption of CSA practices and effect of CSA practices on cocoa yields

Variable	Selection Equation		Outcome Equation – cocoa yields			
	CSA adoption		Adopters		Non-adopters	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Age	0.0183	0.375	-0.0002	0.970	-0.0020	0.369
Sex	-1.0082*	0.077	-0.0354	0.800	-0.0183	0.748
Household size	0.1144	0.238	-0.0240*	0.098	-0.0121	0.344
Education	0.2176***	0.008	0.0320***	0.000	0.0297***	0.000

Farm size	-0.0396	0.784	-0.0112	0.407	0.0389*	0.056
Land ownership	0.0320***	0.000	0.2619***	0.000	0.5096***	0.000
Experience	0.0898***	0.002	0.2720*	0.084	0.0071	0.310
Membership organization	0.7125**	0.039	-0.0050*	0.067	0.0061	0.863
Off-farm income	4.83e-08***	0.003	1.98e-06**	0.031	-8.25e07**	0.017
Credit access	0.1599**	0.018	0.2828***	0.000	0.2515*	0.083
Extension	-0.2586	0.347	0.5096***	0.000	0.0013**	0.013
Climate information	1.7881***	0.000	-	-	-	-
Awareness of climate change	2.0206**	0.015	-	-	-	-
Constant	-3.1141	0.015	7.3197	0.000	6.7764	0.000
Diagnostic						
sigma_1			0.1330 (0.0210)			
sigma_2					0.1384 (0.0980)	
rho_1			0.8112 (0.4160)			
rho_2					-0.5723 (0.4890)	
Wald chi2(11)	81.19***					
Log likelihood	-319.028					
Wald test of indep. eqns.: χ^2(1)	3.93**					
Number of observations	250					

Note: The outcome variable is in log-transformed form. Standard errors are presented in parentheses; *, **, and *** represent significance level at 10,5,1 percent respectively.

Table 5: Distribution of adopters and non-adopters by Cocoa yield

Variable	Adopters		Non-adopters	
Cocoa yield (kg/ha)	**Frequency**	**Percentage (%)**	**Frequency**	**Percentage (%)**
≤1000	18	13.33	54	46.96
1001-1200	45	33.34	50	43.47
1201-1300	32	23.70	3	2.61
1301-1400	20	14.82	3	2.61
1401-1500	15	11.11	5	4.35
>1500	5	3.70	-	-
Mean	1213.33(180.253)		1040.61(165.144)	

Source: Field Survey, 2024

Effect of adoption of climate-smart agricultural practices on yield

To assess the effect of Climate Smart Agriculture (CSA) on crop yield, a log-linear regression was used to ensure observed yield increases are not influenced by farmer characteristics.

Table 6 reveals that CSA adopters have significantly higher cocoa yields, with actual yields of 1,205.124 kg/ha compared to predicted yields of 960.892 kg/ha without CSA adoption. This difference of 244.232 kg/ha is significant at the 1% level ($p < 0.01$), indicating that CSA practices boost yields directly. For non-adopters, the predicted yield if they adopted CSA is 1,079.715 kg/ha, while their actual yield is 864.462

kg/ha, showing a significant difference of 215.233 kg/ha ($p < 0.01$). Overall, CSA practices significantly enhance cocoa yields for both adopters and non-adopters, with adopters experiencing greater benefits due to factors like experience and resource access.

Estimation of cocoa yield effect from CSA adoption.

Table 6: Estimation of conditional expectations, treatment, and heterogeneity

Sub-samples	Decision stage		Treatment effects
	Adopters	Non-adopters	
Adopted cocoa farmers	1205.124 (373.121)	960.892 (401.557)	**TT (kg/ha) = 244.232*** (88.923)**
Non-adopted cocoa farmers	1079.715 (423.441)	864.462 (197.899)	**TU(kg/ha) = 215.233*** (98.401)**
Heterogeneity effects	BH_1 (kg/ha)= 125.409*** (47.387)	BH_2 (kg/ha)= 96.410*** (39.076)	

Source: Field Survey, 2024

Conclusion

Adoption of climate-smart agricultural (CSA) practices has a significant effect on cocoa yield. Farmers who are well-educated, land owners, are members of farmers' organizations, and more experienced are more likely to adopt these practices. However, CSA ***adoption remains moderate***, with barriers such as ***limited access to irrigation infrastructure, and lack of awareness*** hindering widespread adoption. Farmers who adopted CSA practices achieved ***higher yields compared to non-adopters***, demonstrating the effectiveness of these practices in enhancing cocoa output, and this highlights the potential of CSA adoption as a sustainable agricultural strategy for cocoa production. Addressing these barriers could enhance CSA adoption and ensure more farmers benefit from improved practices.

Recommendations

Based on the results, the following are recommended:

i. Farmers should also attend farmer training programs that focus on experiential learning rather than just formal education.
ii. Research institutes should establish demonstration farms for farmers to observe and learn CSA practices. Afterward, farmer groups could manage these farms.
iii. Awareness of the environmental and health benefits of Integrated pest management (IPM) over conventional pesticide use should be created regularly, thereby contributing to resilient and sustainable cocoa production system.

References

Adebisola, A., & Ayodeji, T. (2022). Factors influencing adoption of climate smart agricultural practices among maize farmers in ondo state, nigeria. *Journal of Economics and Allied Research*, *7*(4).

Agbenyo, W., Jiang, Y., Jia, X., Wang, J., Ntim-Amo, G., Dunya, R., Siaw, A., Asare, I., & Twumasi, M. A. (2022). Does the adoption of climate-smart agricultural practices impact farmers' income? Evidence from Ghana. *International Journal of Environmental Research and Public Health*, *19*(7). https://doi.org/10.3390/ijerph19073804

Antwi-Agyei, P., Abalo, E. M., Dougill, A. J., & Baffour-Ata, F. (2021). Motivations, enablers and barriers to the adoption of climate-smart agricultural practices by smallholder farmers: Evidence from the transitional and savannah agroecological zones of Ghana. *Regional Sustainability*, *2*(4), 375–386. https://doi.org/10.1016/j.regsus.2022.01.005

Atta-Aidoo, J., Antwi-Agyei, P., Dougill, A. J., Ogbanje, C. E., Akoto-Danso, E. K., & Eze, S. (2022). Adoption of climate-smart agricultural practices by smallholder farmers in rural Ghana: An application of the theory of planned behavior. *PLOS Climate*, *1*(10), e0000082. https://doi.org/10.1371/journal.pclm.0000082

Attiogbé, A. A. C., Abotsi, K. E., Adjossou, K., Parkoo, E. N., Adjonou, K., & Kokou, K. (2022). Climate vulnerability of coffee-cocoa agrosystems in the sub-humid mountain ecosystems in south-west Togo (West Africa). *Environmental Systems Research*, *11*(1). https://doi.org/10.1186/s40068-022-00274-4

Blessing, F., Kehinde, A., & Tijani, A. A. (2022). Economic Impact of Cocoa Farmers' Compliance to EU Pesticide Regulations in Osun State, Nigeria Kehinde Blessing FALONI Akeem Abiade TIJANI Ayodeji Damilola KEHINDE (🖂). In *Agric. conspec. sci* (Vol. 87, Issue 2). https://www.researchgate.net/publication/361425989

Bomdzele, E., & Molua, E. L. (2023). Assessment of the impact of climate and non-climatic parameters on cocoa production: a contextual analysis for Cameroon. *Frontiers in Climate*, *5*. https://doi.org/10.3389/fclim.2023.1069514

Bukola, O. O., Oluwadunsin, A. E., & Abimbola, F. O. (2021). Effects of Climate Variabilityon Cocoa Production in Ondo State, Nigeria. *American Journal of Climate Change*, *10*(04), 396–406. https://doi.org/10.4236/ajcc.2021.104020

Deborah Popoola, O., McGreevy Co-supervisor, S., & Lulofs, K. (2022). *A Nexus Approach to Solar Pumping Irrigation Systems in North Africa: Opportunities And Challenges A Case Study Of Egypt*.

Ghimire, R., Huang, W.-C., & Shrestha, R. B. (2015). *ScienceDirect Factors Affecting Adoption of Improved Rice Varieties among Rural Farm Households in Central Nepal*. https://doi.org/10.1016/S1672-6308(14)60278-X

Hussain, S., Amin, A., Mubeen, M., Khaliq, T., Shahid, M., Hammad, H. M., Sultana, S. R., Awais, M., Murtaza, B., Amjad, M., Fahad, S., Amanet, K., Ali, A., Ali, M., Ahmad, N., & Nasim, W. (2022). Climate Smart Agriculture (CSA) Technologies. In *Building Climate Resilience in Agriculture* (pp. 319–338). Springer International Publishing. https://doi.org/10.1007/978-3-030-79408-8_20

Intergovernmental Panel on Climate Change [IPCC]. (2022). *Climate Change: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* .

Jellason, N. P., Conway, J. S., & Baines, R. N. (2021). Understanding impacts and barriers to adoption of climate-smart agriculture (CSA) practices in North-Western Nigerian drylands. *The Journal of Agricultural Education and Extension*, *27*(1), 55–72. https://doi.org/10.1080/1389224X.2020.1793787

Kavita Shah, Vyomendra Chaturvedi, & Shalini Gupta. (2019). Climate change and abiotic stress-induced oxidative burst in rice. . *Advances in Rice Research for Abiotic Stress Tolerance*, *25*, 505–535.

Kongor, J. E., Owusu, M., & Oduro-Yeboah, C. (2024). Cocoa production in the 2020s: challenges and solutions. *CABI Agriculture and Bioscience*. https://doi.org/10.1186/s43170-024-00310-6

Lamidi, H. S. (n.d.). *COCOA PRODUCTION IN THE ERA OF CRUDE OIL ECONOMY: THE CASE STUDY OF ONDO STATE, NIGERIA*.

Mireille Dohmen, M., Noponen, M., Enomoto, R., Mensah, C., & Muilerman, S. (2018). *Climate-Smart Agriculture in Cocoa A Training Manual for Field Officers Climate-Smart Agriculture in Cocoa*. www.worldcocoafoundation.org

Morgan, M., & Werner, C. (n.d.). *Signature Page*.

Mujeyi, A., Mudhara, M., & Mutenje, M. J. (2020). Adoption determinants of multiple climate smart agricultural technologies in Zimbabwe: Considerations for scaling-up and out. *African Journal of Science, Technology, Innovation and Development*, *12*(6), 735–746. https://doi.org/10.1080/20421338.2019.1694780

Napogbong, L. A., Ahmed, A., & Derbile, E. K. (2021). Fulani herders and indigenous strategies of climate change adaptation in *Kpongu* community, North-Western Ghana: implications for adaptation planning. *Climate and Development*, *13*(3), 201–214. https://doi.org/10.1080/17565529.2020.1746231

Ojo, T. O., Kassem, H. S., Ismail, H., & Adebayo, D. S. (2023). Level of adoption of climate smart agriculture among smallholder rice farmers in Osun State: does financing matter? *Scientific African*, *21*. https://doi.org/10.1016/j.sciaf.2023.e01859

Ojoko, E., Akinwunmi, J., Yusuf, S., & Oni, O. (2017). Factors influencing the level of use of climate-smart agricultural practices (CSAPs) in Sokoto state, Nigeria. *Journal of Agricultural Sciences, Belgrade*, *62*(3), 315–327. https://doi.org/10.2298/jas1703315o

Okpokiri C.I., Agwu N.M., Onwusiribe N.C., & Igwe K.C. (2021). Analysis of usage and determinants of climate smart agriculture among farmers in Ebonyi state, Nigeria. *Journal of Community & Communication Research*, *6*(2), 220–228.

Oyawole, F. P., Shittu, A., Kehinde, M., Ogunnaike, G., & Akinjobi, L. T. (2021). Women empowerment and adoption of climate-smart agricultural practices in Nigeria. *African Journal of Economic and Management Studies*, *12*(1), 105–119. https://doi.org/10.1108/AJEMS-04-2020-0137

Q1 2024_GDP Report. (n.d.).

Rodríguez-Barillas, M., Poortvliet, P. M., & Klerkx, L. (2024). Unraveling farmers' interrelated adaptation and mitigation adoption decisions under perceived climate change risks. *Journal of Rural Studies*, *109*. https://doi.org/10.1016/j.jrurstud.2024.103329

Saadu, B., Ibrahim, H. Y., Nazifi, B., & Mudashiru, A. (2024). Adoption of climate-smart agricultural practices and its impact on smallholder farming households in some rural areas of North-Western Nigeria. *Agricultura Tropica et Subtropica*, *57*(1), 23–34. https://doi.org/10.2478/ats-2024-0003

Saliu Akinlabi Tiamiyu. (2018). Adoption of Climate Smart Agricultural Practices and Farmers' Willingness to Accept Incentives in Nigeria. *International Journal of Agricultural and Environmental Research*, *4*(4), 198–205.

Seleiman, M. F., Al-Suhaibani, N., Ali, N., Akmal, M., Alotaibi, M., Refay, Y., Dindaroglu, T., Abdul-Wajid, H. H., & Battaglia, M. L. (2021). Drought Stress Impacts on Plants and Different Approaches to Alleviate Its Adverse Effects. *Plants*, *10*(2), 259. https://doi.org/10.3390/plants10020259

Suh, N. N., & Molua, E. L. (2022). Cocoa production under climate variability and farm management challenges: Some farmers' perspective. *Journal of Agriculture and Food Research*, *8*. https://doi.org/10.1016/j.jafr.2022.100282

Teklu, A., Simane, B., & Bezabih, M. (2023). Multiple adoption of climate-smart agriculture innovation for agricultural sustainability: Empirical evidence from the Upper Blue Nile Highlands of Ethiopia. *Climate Risk Management*, *39*, 100477. https://doi.org/10.1016/j.crm.2023.100477

Trinh Thi, V. H., & Zhou, W. (2025). Investigating the Technical Efficiency and Balanced Development of Climate-Smart Agriculture in Northeast China. *Land*, *14*(3), 547. https://doi.org/10.3390/land14030547

Victory, G., Lizzie, O., & Olaitan, A. (2022). Climate-Smart Agricultural Practices at Oyo State-Nigeria. *South Asian Journal of Social Review*, 1–7. https://doi.org/10.57044/sajsr.2022.1.1.2201