ARTICLE | **OPEN ACCESS**

Climate Change

Determinants of Adoption of Climate-Smart Agricultural (CSA) Practices among Arable Crop Farmers in Bayelsa State, Nigeria

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To Cite:
Edaba MIE, Aroyehun AR, Ologidi PO. Determinants of Adoption of Climate-Smart Agricultural (CSA) Practices among Arable Crop Farmers in Bayelsa State, Nigeria. *Climate Change* 2025; 11: e9cc3119
doi:

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Peer-Review History
Received: 01 March 2025
Reviewed & Revised: 09/March/2025 to 18/July/2025
Accepted: 29 July 2025
Published: 07 August 2025

Peer-Review Model
External peer-review was done through double-blind method.

Climate Change
pISSN 2394-8558; eISSN 2394-8566

URL: http://www.discoveryjournals.org/climate_change

DISCOVERY SCIENTIFIC SOCIETY

ABSTRACT

This research examines the elements influencing the adoption of climate-smart agricultural (CSA) techniques among arable crop farmers in Bayelsa State, Nigeria. Using a multistage sample strategy, data were obtained from one hundred twenty (120) and ninety-six (96) arable crop producers using structured questionnaires and analyzed using descriptive statistics and logistic regression models. According to descriptive statistics, the farmers' average age was 51.67 years, 77.1% were married, with a mean household size of six people and a mean agricultural experience of 20.1 years. The majority (89.6%) were aware that climate change has an influence on arable farming, and a majority (72.9%) also used CSA methods such as mulching, crop rotation, water management, etc. Using Tolerance and Variance Inflation Factor settings, the results show no indication of multicollinearity. The result of logit regression model shows that marital status (0.844, p = 0.000), education level (-0.065, p = 0.000), access to extension services (0.458, p = 0.001), farm size (0.664, p = 0.000), association membership (0.543, p = 0.000), cost of CSA (-0.541, p = 0.000), flooding (0.494, p = 0.000), and drought (0.721, p = 0.000). In addition, about 61.4% of the arable crop farmers agreed that adoption of CSA practices enhances farming output. Regardless of an extensive awareness and comprehension, the level of adoption remain subjacent as a result of financial limitations, insufficient high-tech provision, and infrastructure impediments. In order to boost the adoption of CSA approaches, the research recommends extension services delivery should be improved, financial accessibility should be enhanced, rural infrastructure should be improved, and farmer education should be increased. These actions are essential for furthering arable crop sustainability, fostering farmers' resistance to climate change, and guarantees food security.

Keywords: Arable crops, climate change, CSA, food security, logit model, VIF

1. INTRODUCTION

The production of arable crops and fishing along the coastline dominate the source of livelihood for the people of Bayelsa State (Edaba et al., 2024). More than 70% of the state's population depends on agriculture, either directly or indirectly, for their livelihood, making it the primary source of employment, income generation, food supply, and clothing for the rapidly increasing population (Saadu et al., 2024). Agriculture also provides raw materials for agro-based industries in the state. Elum and Snidjer (2024) proved that farmers in the area depend on rain-fed agriculture, as only a minimal proportion of the land in the state is irrigated. The common arable crops grown in the area include sweet potato, pepper, okra, pumpkin, yam, cassava, cowpeas, rice, and cocoyam, among others. These farmers, however, face daunting challenges in their efforts to ensure sustainable livelihoods, with a majority of them earning less than two Dollars ($2) daily (World Bank, 2023).

Arable crop farmers are especially vulnerable to the effects of climate change because they have limited access to high-quality irrigation infrastructure and lack experience in the agricultural production sector (Mthethwa et al., 2022). For example, rising temperatures have produced catastrophic droughts and floods in the Bayelsa State, reducing people's capacity to be productive. As a result, soil fertility, agricultural inputs, investment, and infrastructure have all declined (Oyawole et al., 2019). Because farming is mostly rainfed and climate dependent, peasant farming systems are particularly vulnerable to climate change and variability (Cohn et al., 2017). Because of this, regions like Sub-Saharan Africa that rely heavily on small-scale farming systems are among those most impacted by climate change (IPCC, 2022).

Gabriel et al. (2023) found that agriculture is vulnerable to climate change, particularly in developing nations like Nigeria that experience the burden of food insecurity, an alarming population growth, and heightened susceptibility to the adverse effects of global warming. The goal of climate-smart agriculture (CSA) is to increase food crop output while reducing the influence of climate change on agriculture and fostering resilience and adaptation to its effects (Onoja et al., 2019). Deforestation, methane emissions from animal dung, rice fields, landfills, agricultural chemicals, and pesticides, as well as the incomplete burning of fossil fuels, which releases carbon dioxide and carbon monoxide into the atmosphere, are some of the human activities that contribute to the long-term variability in climate (Eneji et al., 2020).

Climate change is closely linked with agriculture and its influences on means of livelihood and economies have been recorded in many parts of the world (Ullah et al., 2018; Abraham, 2018). Thus, a long-term change in global temperature, precipitation, wind patterns, and other climate indicators that takes place throughout time can be summed up as climate change (Onoja et al., 2019). The effects of these changes on crop output and food security are substantial. When combined with other weather variability indicators like rising temperatures and decreasing rainfall, its effects, such as reduced agricultural yield, high evaporation rates, decreased soil nutrients, and low income, could lead to a decline in agricultural productivity (Adebayo, 2010).

Changing in climatic factors is one of the extremely considerable threats to global agricultural activities, which could pose a significant consequence on food production. These factor comprises of rainfall patterns, increase in global mean temperatures, pest and disease invasions, and dietary changes in some crops (Victory et al., 2022). The average world temperature has increased steadily at a rate of 0.15 to 0.20 degrees Celsius every ten years since 1975 (NASA, 2020). Farmers in Africa are being forced to adopt mitigation and adaptation strategies due to the significant effects of climate change on agricultural output. Therefore, in light of the impacts of climate change, the adoption of the climate-smart agricultural (CSA) approach by arable crop farmers is essential to sustainable food production (Kalu and Mbanasor, 2023). In light of a changing climate and rising food demand, there is an imminent demand to better integrate agricultural production outcomes and climate responsiveness to achieve food security and ensure a more even development goals (Matemilola et al., 2019).

It is against this background that this study assessed the determinants of the adoption of climate-smart agricultural practices among rural arable farmers in Bayelsa State. The specific objectives are to identify the socio-economic characteristics of the farmers in the study area, identify the climate-smart agricultural practices in the area, determine the level of adoption of climate-smart agriculture by farmers in the study area, analyze the determinants of climate-smart agriculture by rural arable crop farmers in the area, and identify the constraints to the adoption of CSA practices in the area.

2. MATERIALS AND METHODS

The study was conducted in Bayelsa State, Nigeria. The State is located between Latitudes 4º15' and 5º23' north and Longitudes 5º15' and 6º45' east. The state is surrounded by Delta State to the north, Rivers State to the east, and the Atlantic Ocean to the south and west. The State has an area of approximately 21,100 km² (National Population Census 2006). Bayelsa State is located in Nigeria's wettest region, with dense rainforests and a brief dry season from November to March (Okringbo et al., 2017). Cassava, maize, yam, cocoyam, melon, rice, and vegetables are among the most widely produced arable crops. Plantain, banana, and African pear are some of the area's dominant perennial crops.

The arable crop farmers were selected using a multistage sampling technique. First, two (2) agricultural zones were chosen at random from the three agricultural zones. Second, two Local Government Areas (LGAs) were chosen at random, for a total of four (4) LGAs. Third, five communities were selected at random from each LGA, for a total of twenty (20) communities. Finally, ten (10) arable crop growers were picked at random from each community, totalling one hundred twenty (120) samples for the research; however, only ninety-six (96) were retrieved for analysis. The primary data were gathered via a questionnaire. The collected data were examined using descriptive statistics and inferential statistics with a logit regression model. Eviews and SPSS were utilised.

Model Specification

Let Pj denote the probability that the j-th arable crop farmer is adopting climate-smart agriculture (CSA) practices. Let's P_j be the random variable that has two values (1 and 0) according to Bernoulli as cited by Piech (2017), and its distribution depends on the vector of predictors X, so that:

$$P_j(X) = \frac{e^{\alpha+\beta X}}{1+e^{\alpha+\beta X}} \quad (1)$$

The logit function to be estimated is then written as:

$$Ln\{P_j/(1-P_j)\} = \alpha + \sum 1\beta_i X_{ij} \quad (2)$$

The logit variable $Ln\{P_j/(1-P_j)\}$ is the natural log of the odds in favour of an arable crop farmer adopting data CSA practices. The coefficient estimates of β give the change in the log-odds (logarithm of relative probabilities) of the outcome; here = 1, for a one unit increase in the independent variable, holding all other independent variables constant. Logit regressions are estimated using Maximum Likelihood (ML) rather than OLS. ML calculates coefficient estimates that maximize the likelihood of the sample data set being observed.

Logit regression model was used following Mbanasor et al. (2024), and Shaibu et al. (2025) to estimate the probability of arable crop farmers adopting CSA practices. This is represented by a dichotomous dependent variable (Y1), where Y1 equals one (1) if the farmer adopts CSA and zero (0) otherwise.

The binary logit model to be estimated is specified as follows:

$$CA_{ij} = \beta_0 + \beta_1 AG_1 + \beta_2 GD_2 + \beta_3 MS_3 + \beta_4 LE_4 + \beta_5 HS_5 + \beta_6 AM_6 + \beta_7 FE_7 + \beta_8 EC_8 + \beta_9 AC_9 + \beta_{10} FS_{10} + \beta_{11} CT_{11} + \beta_{12} CC_{12} + \beta_{13} ER_{13} + \beta_{14} FD_{14} + \beta_{15} DT_{15} + \beta_{16} CI_{16} + u \quad (3)$$

Where;

CA_{ij} = Dummy = 1 if the arable crop farmer is adopting CSA practices, and zero (0) otherwise.

AG_1 = Age (in years)

GD_2 = Gender (dummy; male = 1, female = 0)

MS_3 = Marital status (categorical; single = 1, married = 2, widow/widower = 3, divorced = 4)

LE_4 = Level of education (years spent in schooling)

HS_5 = Household size (in number)

AM_6 = Association membership (dummy; yes =1, and 0 otherwise)

FE_7 = Farming experience (in years)

EC_8 = Extension contact (dummy; yes =1, and 0 otherwise)

AC_9 = Access to credit (dummy; yes =1, and 0 otherwise)

FS_{10} = Farm size (in ha)
CT_{11} = CSA training (dummy; yes =1, and 0 otherwise)
CC_{12} = Cost of CSA (dummy; yes =1, and 0 otherwise)
ER_{13} = Erratic rainfall pattern (dummy; yes =1, and 0 otherwise)
FD_{14} = Flooding experience (dummy; yes =1, and 0 otherwise)
DT_{15} = drought experience (dummy; yes =1, and 0 otherwise)
CI_{16} = Climate change impact on arable farming practices (categorical; strongly disagree = 1, disagree = 2, neutral = 3, agree =4, strongly agree = 5)
β_0 = Intercept
β_1-β_{16} = Coefficient measurement of the estimated factors
u = stochastic error term.

Variance Inflating Factor (VIF) as used by Aroyehun et al. (2025) was used to evaluate the multicollinearity of the regression model, and specified as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + +\beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16} \quad (4)$$

$$VIF = \frac{1}{1-R^2} \quad (5)$$

$$TOL = 1 - R^2 \quad (6)$$

3. RESULTS AND DISCUSSION

Table 1 displays the socioeconomic characteristics of arable crop producers in the research region. The majority of farmers were between the ages of 41 and 60 (about 71%), indicating that arable farming is primarily done by middle-aged adults. Only around 11% are under the age of 40, showing that youth participation is limited. Farmers have an average age of 51.67 years, showing that they are relatively mature and experienced. This result is similar to Ayeni et al. (2023) study, which found a mean age of 54 years among crop producers in North Central Nigeria. Arable crop farming was predominantly male (63.5%), although a considerable 36.5% were female, indicating some gender diversity. This conclusion is consistent with Ayeni et al.'s (2023), who found that 84% of crop producers in North Central Nigeria were male. The vast majority (77.1%) are married, indicating that farming is a key source of income for family heads, approximately 79% of the population finished school or tertiary education, which fosters enthusiasm for adopting better farming practices. The average education level (mean = 3.19, most likely classified from 1 to 5) shows a relatively high level of education. The average household size stood approximately six (6) people, together with about 58.3% arable crop farmers with 4-6 people's household, this implies that a sizeable labour force for the farmers.

Table 1: Socioeconomic characteristics of the arable crop farmers in the study area

Variable	Frequency	Percentage	Mean
Age (in years)			51.67
40 and below	11	11.4	
41-50	35	36.5	
51-60	33	34.4	
61 and above	17	17.7	
Gender			
Male	61	63.5	
Female	35	36.5	
Marital status			
Single	10	10.4	
Married	74	77.1	
Widow/widower	12	12.5	

Level education			3.19
No formal education	6	6.3	
Primary completed	13	13.5	
Secondary completed	35	36.5	
Tertiary completed	41	42.7	
Others	1	1.0	
Household size (in number)			6
3 and below	3	3.1	
4-6	56	58.3	
7 and above	37	38.6	
Membership association			
Yes	31	32.3	
No	65	67.7	
Farming experience (in years)			20.1
10 and below	11	11.5	
11-20	41	42.7	
21-30	37	38.5	
30 and above	7	7.3	
Extension officer contact (within a year)			
Yes	36	37.5	
No	60	62.5	
Land ownership			
Yes	36	37.5	
No	60	62.5	
Amount spent on rent/ lease (₦)			76,552.08
50,000 and below	39	40.6	
50,001-100,000	46	47.9	
100,001-150,000	6	6.3	
150,001-200,000	1	1.0	
200,000 and above	4	4.2	
Access to credit			
Yes	32	33.3	
No	64	66.7	
Amount of credit received last year (₦)			94,333.33
100,000 and below	65	67.7	
100,001-200,000	10	10.4	
200,001-300,000	11	11.5	
300,001-400,000	7	7.3	
400,000 and above	3	3.1	
Arable crop farm size (ha)			1.3
1.0 and below	47	49.0	
1.1-2.0	42	43.7	
2.1 and above	7	7.3	
Total	**96**	**100.0**	

Source: Field Survey, 2025

About 32.3% of the arable crop farmers belong to at least one farmers association, this indicates poor partnership and rendezvous among the farmers. The majority (81%) of farmers have being planting arable crops for more than ten (10) years, with a mean of 20.1 years' experience in agriculture, this indicate that the farmers were well-versed in arable farming. Only 37.5% contacted an extension officer throughout the year, indicating a lack of access to agricultural advisory services. Only 37.5% own land, while 62.5% rent or lease it, indicating that many farmers are insecure about their land tenure. The average rent expenditure was ₦76,552.08, with most households spending between ₦50,000 and ₦100,000 per year. This demonstrates that land renting was a significant monetary burden. Only 33.3% used credit facilities, showing insufficient financial support for farming activity. Among those who obtained credit, the average amount was roughly ₦94,333.33, and the majority (67.7%) received ₦100,000 or less, reflecting small-scale funding. The average arable crop farm size was 1.3 hectares, with the majority of farmers (49%) owning 1 ha or less, indicating that they run smallholder farms.

Table 2: Agricultural practices adopted by arable crop farmers in the study area

Agricultural Practices	Frequency	Percentage
Solely traditional	48	50.0
Predominantly modern	30	31.3
Mixture of traditional and contemporary	18	18.8
Total	**96**	**100.0**

Source: Field Survey, 2025

Table 2 shows the predominant agricultural methods utilized by the arable crop producers in the research region. Approximately 50% of arable crop farmers used only traditional farming methods, which means that half of the farmers continue to rely on indigenous tools and techniques such as hoes, cutlasses, manual planting, and natural pest management. Approximately 31.3% of arable crop farmers employed mostly contemporary agriculture, implying that one-third had accepted technology such as tractors, better seeds, fertilizers, herbicides, and irrigation systems. While approximately 18.8% used a combination of traditional and modern methods, this indicates a gradual transition among some arable crop farmers towards modernization. Therefore, the farming system in the study area was still largely traditional, with limited adoption of modern agricultural practices. This suggests poorer production, poor mechanization, and diminished competitiveness until more farmers adopt new techniques (Oyawole et al., 2019).

Table 3: Awareness of the impact of climate change on arable farming in the study area

Awareness of the impact of climate change	Frequency	Percentage
Neutral	10	10.4
Agree	33	34.4
Strongly agree	53	55.2
Total	**96**	**100.0**

Source: Field Survey, 2025

Table 3 shows the awareness of the impact of climate change on arable farming in the study area. About 55.2% of the farmers strongly agree that they were aware of the effects of climate change on arable crop production, about 34.4% of the arable crop farmers agree that they were aware of the effects of climate change on arable crop farming, while the smallest portion (10.4%) were neutral and apathetic regards the awareness of the effects of climate change on arable crop farming. This implies that a small number of farmers were unaware or uncaring about climate change issues. Farmers in the study region were fully aware of the negative impact of climate change on their farming operations. If farmers receive the necessary support, this high level of knowledge may make them more willing to embrace climate-smart agriculture techniques (Mthethwa et al., 2022).

Table 4: Level of familiarity with climate-smart agricultural (CSA) practices by the arable crop farmers in the study area

Level of familiarity with CSA practices	Frequency	Percentage
Not familiar	4	4.2
Slightly familiar	10	10.4
Moderately familiar	47	49.0
Very familiar	35	36.5
Total	**96**	**100.0**

Source: Field Survey, 2025

Table 4 depicts the level of acquaintance among arable crop farmers with CSA practices. The majority (85.5%) of arable crop farmers, with approximately 49.0% of the farmers were moderately familiar with CSA practices, while about 36.5% of the farmers were very familiar with them. However, about 14.6% of the farmers were not familiar or slightly familiar with CSA systems. Therefore, the majority of arable crop farmers in the research region were familiar with climate-smart agriculture, which is a good indicator for encouraging sustainable farming. However, a small group still needs additional sensitisation and training to understand and apply these ideas fully.

Table 5: Adoption of CSA practices by the arable crop farmers in the study area

Adoption of CSA practices	Frequency	Percentage
Yes	70	72.9
No	26	27.1
Total	**96**	**100.0**

Source: Field Survey, 2025

Table 5 displays the adoption of CSA practices among arable crop farmers. The majority (72.9%) of the farmers had adopted CSA techniques, while about 27.1% did not follow these procedures. Most farmers in the study region were actively using climate-smart strategies to deal with climate change, indicating a high potential for enhancing farm resilience and sustainability. However, over 25% of farmers have yet to adapt, showing that constraints such as cost, lack of expertise, or restricted access to resources may remain. This finding is consistent with the results of Okringbo et al. (2017) and Victory et al. (2022), who stated that farmers in the nation were already creating measures to deal with the consequences of climate change.

Table 6: Climate-smart agricultural practices adopted by the arable crop farmers in the study area

Adopted climate-smart agricultural practices	Yes		No		Mean
	F	%	F	%	
Mixed cropping system	80	83.3	16	16.7	1.17
Water management	82	85.4	14	14.6	1.15
Integrated crop-livestock systems	74	77.1	22	22.9	1.23
Agroforestry	62	64.6	34	35.4	1.35
Planting of climate-resilient crop varieties	75	78.1	21	21.9	1.22
Use of heat-tolerant varieties	35	36.5	61	63.5	1.64
Crop rotation	85	88.5	11	11.5	1.11
Changing in planting date	55	57.3	41	42.7	1.43
Use of mulching	88	91.7	8	8.3	1.8
Early harvesting	82	85.4	14	14.6	1.15
Planting of early-maturing crops	76	79.2	20	20.8	1.21
Application of organic fertilizer	25	26.0	71	74.0	1.74

Source: Field Survey, 2025; multiple responses recorded

Table 6 outlines the climate-smart agriculture techniques used by the area's arable crop growers. Mulching (91.7% usage, mean = 1.08), crop rotation (88.5% usage, mean = 1.11), water management (85.4% usage, mean = 1.15), early harvesting (85.4% usage, mean = 1.11), and mixed cropping (83.3% usage, mean = 1.17) are the most widely used CSA techniques. These measures are extensively utilized, indicating that arable crop producers prioritized soil moisture conservation, soil fertility enhancement, and climate risk mitigation. Planting early-maturing crops (79.2%, mean = 1.21), integrated crop-livestock systems (77.1%, mean = 1.23), climate-resilient varieties (78.1%, mean = 1.22), and agroforestry (64.6%, mean = 1.35) are examples of moderately accepted CSA activities. These demonstrate high levels of acceptance, but there is still an opportunity for improvement, particularly in agroforestry. Lower adoption proportions for CSA methods consist of the use of heat-tolerant varieties (36.5%, mean = 1.64), changes in planting date (57.3%, mean = 1.43), and application of organic fertilizer (26.0%, mean = 1.74). This result agrees with Pelemo et al. (2024), and Mbanasor et al. (2024), who reported parallel ratio among farmers on CSA approaches in Kogi State, and the south-east region of Nigeria. As a result, it appears that more specialized or resource-intensive procedures were less widely adopted, most likely due to a lack of knowledge, expense, or technical expertise.

Lower mean values (near 1) suggest greater adoption, whereas higher means (closer to 2) imply less adoption. Mulching, crop rotation, water management, and early harvesting were the CSA practices with the lowest mean ratings, reflecting their popularity. CSA practices, including organic fertilizer usage and heat-tolerant cultivars, received higher mean ratings, indicating poor implementation. Thus, arable crop producers in the study region mostly use simple, low-cost, and successful climate-smart measures such as mulching, crop rotation, and water management. However, adoption of sophisticated or input-intensive approaches, such as heat-tolerant cultivars and organic fertilizer treatment, remains low, indicating a need for further education, incentives, and assistance. According to Elum and Snidjer (2024), the considerable impacts of climate change on agricultural productivity are compelling farmers in Bayelsa State to implement mitigation and adaptation measures such as early planting and the use of improved crop varieties.

Table 7: Collinearity diagnostics of the logit regression model used for the adoption of CSA practice in the study area

Variables	Tolerance	VIF
Age	0.867	1.153
Gender	0.877	1.140
MariStatu	0.869	1.151
LevEdu	0.839	1.192
HouseSize	0.888	1.127
AssMemb	0.887	1.127
FarmExp	0.821	1.218
ExtCont	0.892	1.121
AccessCrdt	0.819	1.221
FrmSiz	0.700	1.428
CSATraini	0.840	1.191
CostCSA	0.616	1.623
EratRain	0.856	1.169
Flood	0.713	1.403
Drought	0.728	1.374
ClimImpact	0.826	1.211

Source: Field Survey, 2025

Table 7 presents a study of collinearity statistics for Tolerance and Variance Inflation Factor (VIF) values. Tolerance is a measure of a variable's independence from others (values near one are desirable; values < 0.1 indicate a significant problem). VIF assesses how much a variable's variance is overstated owing to multicollinearity. The findings suggest that all variables had Tolerance values greater than 0.6 and VIF values between 1.1 and 1.6. There was no evidence of multicollinearity; all VIF values were far lower than the normal warning level of five. Cost of CSA (CostCSA) had the greatest VIF (1.623) and lowest Tolerance (0.616); however, this was far from a concern. Finally, there was no indication of multicollinearity among the independent variables examined in this study. As a consequence, we can safely proceed with logit regression analysis without encountering skewed findings due to multicollinearity.

Table 8: Parameter estimates of the logit regression model result showing arable crop farmers' decisions to adopt CSA practices and their determinants in the study area

Variable	Coefficient	Std. Error	Z	Sig.
Age	0.011	0.008	1.381	0.167
Gender	0.107	0.132	0.813	0.416
MariStatu	0.844***	0.144	5.847	0.000
LevEdu	-0.065***	0.016	-4.106	0.000
HouseSize	0.325***	0.062	5.285	0.000
AssMemb	0.543***	0.146	3.718	0.000
FarmExp	0.031***	0.010	3.237	0.001
ExtCont	0.458***	0.140	3.266	0.001
AccessCrdt	-0.033	0.135	-0.243	0.808
FrmSiz	0.664***	0.129	5.154	0.000
CSATraini	0.255*	0.153	1.664	0.096
CostCSA	-0.541***	0.152	-3.555	0.000
EratRain	-0.753***	0.150	-5.033	0.000
Flood	0.494***	0.151	3.276	0.001
Drought	0.721***	0.235	3.074	0.002
ClimImpact	-0.106	0.101	-1.042	0.297
Constant	-7.559***	0.899	-8.405	0.000
Wald	18.596***			
Pseudo R-square	0.13			
Chi-square	147030.554			
p-value	0.000			

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

Source: Field Survey, 2025

Table 8 depicts the factors influencing arable crop producers' decisions to use climate-smart agriculture (CSA) methods in the research region. The logit regression model performance demonstrates that the Wald statistic of 18.596 in the predicted value was statistically significant at 1%. Pseudo R-square of 0.13 indicates that the model explained around 13% of the variation in CSA adoption, which is appropriate for social science data. The model's chi-square value of 147030.554 with a p-value of 0.000 indicates a very significant overall result.

MariStatu (marital status), with a coefficient of 0.844, was positive and highly significant at 1% (p = 0.000), showing that being married improves the chance of adopting CSA behaviour. LevEdu (years spent achieving the degree of education) had a coefficient of -0.065, which was negatively and highly significant at 1% (p = 0.000), indicating that higher education somewhat lowers the chance of CSA adoption. Although it is expected that a positive relationship exists between education and CSA adoption, this negative sign may be because the majority of arable crop farmers continued to use traditional methods, as shown in Table 2, or that the farmers, despite being educated, were not open to innovative agricultural technologies. This conclusion contradicted Mbanasor et al. (2024), who found a favourable outcome among agricultural farmers in south-east Nigeria. HouseSize (household size) with a coefficient of 0.325 was statistically positive and highly significant at 1% (p = 0.000), implying that bigger households may be more likely to adopt CSA since they have adequate family labour to employ (Erokhin et al., 2020). AssMemb (association membership) had a coefficient of 0.543, which was statistically positive and highly significant at 1% (p = 0.000); hence, participation in an association encourages CSA adoption.

FarmExp (farming experience), with a coefficient of 0.031, was positive and significant at 1% (p = 0.001), indicating that more farming experience leads to increased CSA adoption. This conclusion was consistent with Khatri-Chhetri et al. (2017) and Mbanasor et al. (2024), who found comparable effects in studies of farmers in Rajasthan, India, and southeast Nigeria, respectively. ExtCont (extension contact), with a coefficient of 0.458, was statistically positive and significant at 1% (p = 0.001), implying that farmers who were able to receive extension officers' visitation could be more disposed to adopt CSA. Maize farmers in Uganda have adopted conservation of soil utilization, preservation of soil moisture, adequate extension service, and mulching, which are very vital fundamentals of CSA techniques (Ekyaligonza et al., 2022). Hence, adequate extension services delivery tailored guidance based on area circumstances, which can broaden the application of CSA approaches.

FrmSiz (arable crop farm size), with a coefficient of 0.664, was positive and highly significant at 1% (p = 0.000), indicating that higher farm sizes greatly promote CSA adoption. A greater farm size increases the likelihood that maize-producing households may invest in CSA methods. According to Shaibu et al. (2025), larger-scale farmers are more likely to incorporate new technologies, devote more time and resources to learning about agricultural practices, and place a higher value on employing productive rather than processing technology. CSATraini (CSA training) had a coefficient of 0.255, which was statistically positive and marginally significant at 10% (p = 0.096), implying that training obtained by arable crop producers modestly boosts adoption. CostCSA (cost of CSA), with a coefficient of 0.541, was statistically negative and highly significant at 1% (p = 0.000), indicating that greater prices diminish CSA adoption among arable crop producers. EratRain (erratic rainfall) had a coefficient of -0.753, which was statistically significant at 1% (p = 0.000). This means that more irregular rainfall prevents arable crop growers from adopting CSA practices. Flood (continuous flooding experience) had a coefficient of 0.494 that was positive and significant at 1% (p = 0.001), indicating that arable crop farmers who suffer flooding are more likely to embrace CSA. Drought (continuous drought experience) had a coefficient of 0.721 and was statistically significant at 1% (p = 0.002), implying that drought experience encourages arable crop producers to embrace CSA.

Finally, being married, larger household sizes, membership in associations, years of farming experience, receiving extension services, larger farm size, attending CSA training, and having experienced flooding and/or drought were all positive influences on arable crop farmers' adoption of CSA practices. The high expenses of CSA methods, as well as variable rains, deter arable crop growers from adopting it. Surprisingly, more years in school (degree of education) marginally reduce adoption. Age, gender, availability of financing, and anticipated climate impact all had no significant effect on arable crop producers' adoption. As a result, farmers' real-world experiences (such as floods, drought, and farm size) and practical assistance (such as training, association membership, and extension contact) are more significant for CSA adoption than personal factors like age, gender, or education.

Table 9: Residual diagnosis of the parameter estimates

Diagnosis	F-statistic	Prob.
Heteroskedasticity test: Breusch-Pagan-Godfrey	1.239	0.251
Correlation LM test: Breusch-Godfrey Serial	1.849	0.164
Ramsey RESET test	0.350	0.727

Source: Field Survey, 2025

Table 9 presents the residual diagnosis. Breusch-Pagan-Godfrey (F = 1.239, p = 0.251) was not significant, indicating that no heteroskedasticity was found and that the model errors had constant variance. Breusch-Godfrey Serial (F = 1.849, p = 0.164) proved not significant, indicating that there is no serial correlation and the residuals are independent. The Ramsey RESET test (F = 0.350, p = 0.727) was not significant, indicating that the model was accurately described with no indication of functional model and method error. Hence, the model was useful to examine the variables that influence the adoption of CSA systems were dependable and useable; the insignificant of heteroskedasticity, correlation, and specification error indicates that the logit regression model used in this study was strong and reliable to examine the adoption of CSA practices.

Figure 1 portraits a CUSUM graph showing the consistency of the parameters. The blue CUSUM line remains within the 5% significance boundaries throughout, indicating that there was no indication of structural instability in the model. Figure 2, which depicts a CUSUM of squares plot, was used to assess variance instability in the model. The blue line remains under the 5% significance boundaries, indicating that there was no indication of variance instability or structural fractures in the model. Both figures imply that the model remained stable across the sample period.

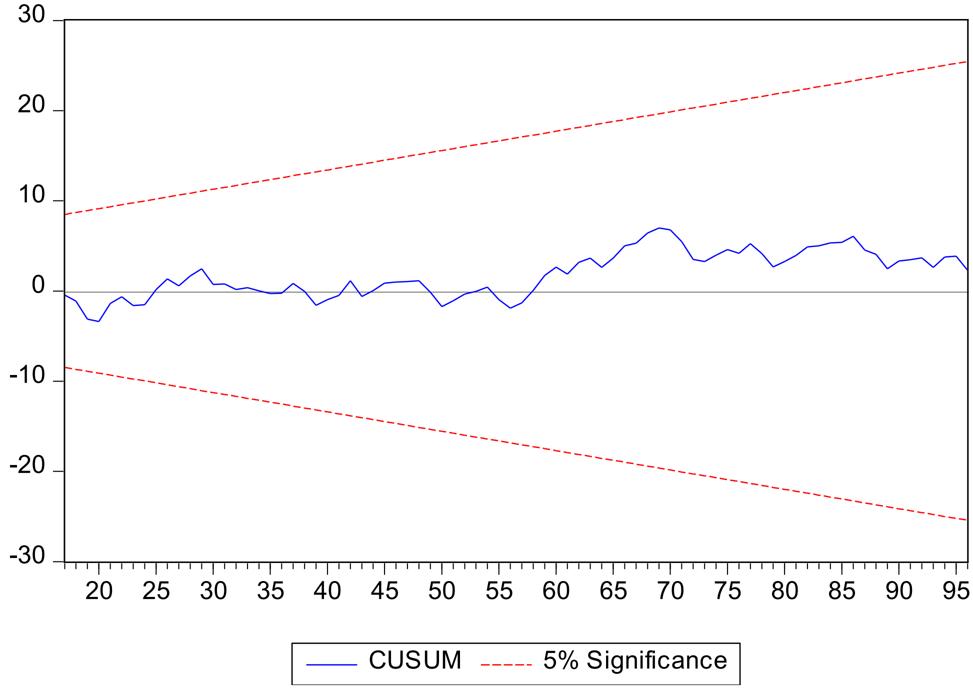

Figure 1: Cumulative sum (CUSUM) chart
Source: Field Survey, 2025

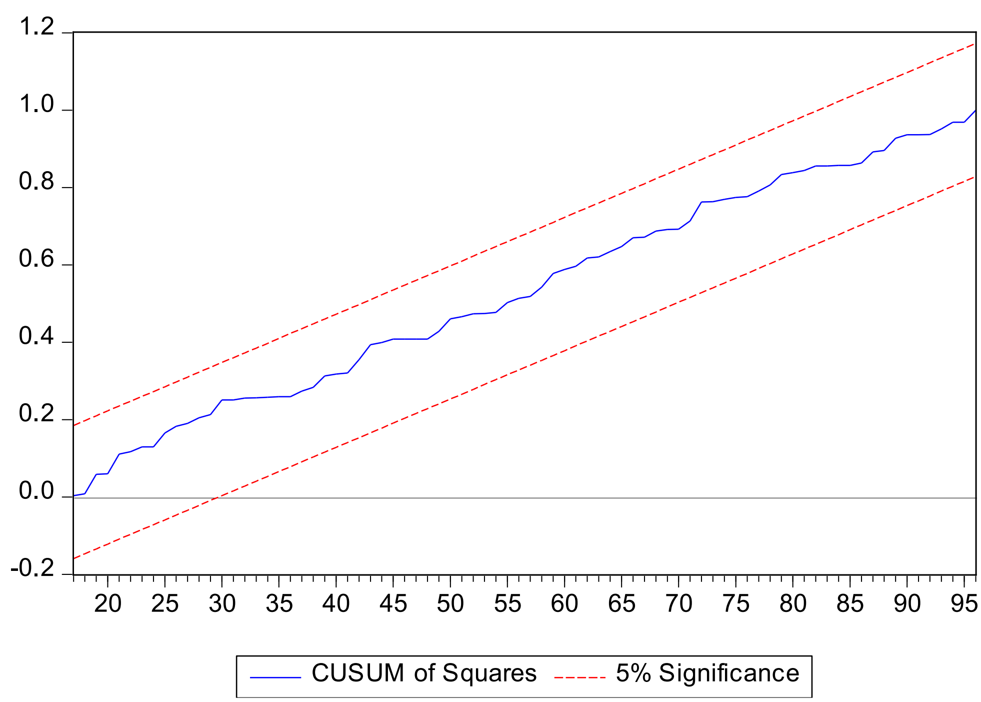

Figure 2: Cumulative sum of squares (CUSUM of squares) chart
Source: Field Survey, 2025

Table 10: Benefits of adopting CSA practices by the arable crop farmers in the study area

Perceived benefits of CSA practices	SD	D	N	A	SA	Mean
Adopting CSA practices increases crop yields	5 (5.2)	12 (12.5)	20 (20.8)	37 (38.5)	22 (22.9)	3.61
CSA practices enhance the resilience of the farming system to climate change	1 (1.0)	6 (6.3)	18 (18.8)	44 (45.8)	27 (28.1)	3.94
CSA practices contribute to long-term environmental sustainability	2 (2.1)	5 (5.2)	23 (24.0)	34 (35.4)	32 (33.3)	3.93

SD is strongly disagree; D is disagree; N is neutral; A is agree; SA is strongly agree; parentheses '( )' is the percentage
Source: Field Survey, 2025

Table 10 outlines the advantages of climate-smart agriculture (CSA) techniques. Approximately 61.4% of farmers (38.5% agree, 22.9% strongly agree) feel that implementing CSA techniques boosts agricultural yields, 20.8% are indifferent, while a tiny percentage disagrees (5.2% strongly disagree, 12.5% disagree). The mean score of 3.61 indicates positive perception, however, not as high as in other categories. A substantial majority (73.9% (45.8% agree, 28.1% strongly agree)) believe that CSA methods make their farming systems more adaptable to climate change, with only a small proportion (7.3%) disagreeing. The mean score of 3.94 shows a strong and unmistakably favourable evaluation. About 68.7% of farmers (35.4% agree and 33.3% strongly agree) believe that CSA methods contribute to long-term environmental sustainability, with only 7.3% disagreeing. A mean score of 3.93 indicates a very favourable evaluation. As a result, arable crop farmers had a significant, favourable impression of the benefits of CSA methods, particularly in terms of increased resilience and environmental sustainability. While they were significantly less convinced about yield gains, their overall acceptance and conviction in the advantages is quite strong. This conclusion is consistent with the findings of Lipper, McCarthy, Zilberman et al. (2018).

Table 11: Constraints facing arable crop farmers in adopting CSA practices in the study area

Constraints facing arable crop farmers in adopting CSA	Yes		No		Mean
	F	%	F	%	
High cost of inputs and technologies	77	80.2	19	19.8	1.20
Lack of technical knowledge and skill is a problem	67	69.8	29	30.2	1.30
Insufficient financial support	81	84.4	15	15.6	1.16
Inadequate access to extension services	80	83.3	16	16.7	1.17
Uncertain benefits	50	52.1	46	47.9	1.48
Cultural or traditional practices	76	79.2	20	20.8	1.21
Inadequate training on CSA practices	20	20.8	76	79.2	1.79
Lack of government support	82	85.4	14	14.6	1.15
Climate-smart practices are expensive	50	52.1	46	47.9	1.48
High labour cost	86	89.6	10	10.4	1.10
Land tenure system	81	84.4	15	15.6	1.16
Lack of access to high-quality seeds	71	74.0	25	26.0	1.26
Erratic rainfall	77	80.2	19	19.8	1.20
Constant flooding experience	54	56.3	42	43.8	1.44
Constant drought experience	86	89.6	10	10.4	1.10

Source: Field Survey, 2025; multiple responses recorded

Table 11 depicts the challenges that arable crop producers face in implementing climate-smart agriculture (CSA) in the research region. The top two difficulties, as reported by 89.6% of farmers, are high labour expenses and persistent drought. Lack of government assistance (85.4%), insufficient financial support (84.4%), land tenure difficulties (84.4%), and inadequate extension services (83.3%) are also significant obstacles. The mean ratings for these concerns range from 1.10 to 1.17, indicating a considerable consensus that they are severe difficulties. High input and technology costs (80.2%), variable rainfall (80.2%), cultural or traditional practices (79.2%), and deficiency of access to excellent seeds (74.0%). These factors comprises of financial and climate change constraining arable crop production. The reasonable limitations, comprising uncertain benefits (52.1%) and climate-smart practices expensive (52.1%), suggesting that approximately half of the farmers were concerned and nervous as regards the risk vs return of CSA implementation. 56.3% of respondents claimed having experienced constant floods. The least stated limitation was inadequate training on CSA techniques, which was identified as a constraint by just 20.8% of farmers (mean = 1.79), indicating that most farmers are sufficiently knowledgeable. According to Pelemo et al. (2024), most farmers in Southern Nigeria understand CSA and are actively implementing strategies including water retention, diversified cropping, and practical fertilizer usage. In contrast, many people in the country's northwest and northern areas remain uninformed, leading to reduction in adoption level (Shehu, 2024).

4. CONCLUSION AND RECOMMENDATIONS

This research on the factors that determines the adoption of CSA among arable crop farmers in Bayelsa State, Nigeria, revealed that some socioeconomic, utilitarian, and definite farming features influences the acceptability and adaptability of CSA technology. The main findings revealed that marital status of the farmers, educational level, extension services, size of the arable crop farm, household size, farmer's association membership, CSA training, CSA cost, rainfall unpredictability, flooding, and drought effect the adoption of CSA. Arable crop farmers' alacrity to adopt CSA technologies is furthermore influenced by the farmer's awareness and acuity of the aftermaths of climate change effects. However, many farmers were aware of the benefits accrue to the adoption of CSA usage, like increase in arable crop production, climate change and pest and disease resistance, and eco-friendly sustainability. Adoption of CSA is hampered by factors like inadequate financial resource, meagre technical support, and poor infrastructural development. Therefore, increasing extension service provision, enhancing financial accessibility, supporting farmer education, and investing in rural infrastructure are all critical strategies for growing CSA adoption. Promoting the broad adoption of CSA techniques among arable crop farmers in Bayelsa State is essential for maintaining long-term agricultural growth, food security, and resistance to the adverse effects of climate change. Policymakers, agrarian stakeholders, and development agencies must work together to create enabling environments that help farmers transition to climate-smart agriculture, resulting in a more secure and sustainable future. The study advises the following:

i. Farmers in the research region confront financial, technical, and climatic challenges while implementing CSA. The most pressing challenges are economic constraints (labour prices, input costs, and a lack of finance), government and extension service deficits, and growing climatic variability (drought, irregular rainfall). To increase CSA use, these barriers ought to tackle by means of focused and intended legislation, infrastructural improvement, and capacity-building dynamism.
ii. Government and other stakeholders could enhance extension services administration to intimate and armed farmers with adequate, timely and precise report and instruction regarding CSA practices.
iii. Education resourcefulness and knowledge efforts regarding the consequences of climate change and the advantages of CSA practices should be expanded, utilising local languages and community-based platforms to reach a larger audience.
iv. Financial institutions should offer farmer-friendly credit schemes with flexible repayment alternatives to help farmers access resources for CSA development. Farmers should be encouraged to join cooperatives and groups, which can provide better access to inputs, financing, training, and collective marketing possibilities, hence promoting CSA adoption.
v. To increase adoption rates, research institutions should focus on developing and disseminating CSA technologies tailored towards farmers' unique agro-ecological and socioeconomic characteristics. Providing farmers with accurate, real-time weather predictions and climate risk information will help them make educated decisions and improve their resilience through CSA practices.

Acknowledgement

The authors gratefully recognize the invaluable contributions of arable crop farmers in Bayelsa State, Nigeria, whose collaboration and willingness to contribute their time, experiences, and ideas enabled this research. We are also appreciative of community leaders and agricultural extension workers for facilitating access to rural communities and assisting with data collection. We thank the research assistants who helped with the fieldwork and data processing.

Authors contributions

Conceptualization: EMEI and ARA; Methodology: ARA; Data gathering and curation: EMEI and ARA; Formal analysis: ARA; Investigation and Supervision: EMEI, ARA, and OPO; Validation: EMEI, ARA, and OPO; Visualization: ARA and EMEI; Resources: EMEI and ARA; Writing original draft: EMEI, ARA, and OPO; Review: ARA, EMEI, and OPO; Editing of the manuscript: EMEI and ARA. All authors have read and agreed to the published version of the manuscript.

Informed consent

Oral informed consent was obtained from individual participants included in the study.

Ethical approval

The study was done in conformity with ethical guidelines. Participation was entirely voluntary, and all respondents provided informed consent. The participants' anonymity and confidentiality were ensured, and the data obtained were utilized purely for the study. The ethical guidelines for Human Subjects are followed in the study.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Funding

The study has not received any external funding.

Data and materials availability

All data associated with this study will be available based on the reasonable request to the corresponding author.

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