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Determinants of smallholder farmers' agronomic adaptation strategies to the effects of climate change: Evidence from rice farmers in Ekiti State, Nigeria

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ABSTRACT: Climate change through extreme temperatures, frequent flooding, drought, and increased water supply salinity constitute factors affecting rural households' livelihood and agricultural productivity, especially in sub-Saharan Africa. Thus, this study examines smallholder rice farmers' agronomic climate change adaptation strategies in Ekiti State, Nigeria. The study used five agronomic strategies: improved seed, monocropping, shifting cultivation, diversification, and afforestation. A multi-stage sampling technique was used to select 200 smallholder rice farmers across 4 Local Government Areas in Ekiti State, while descriptive statistics and a Multivariate Probit analysis regression model were used for data analysis. The results showed that about 65% of the respondents were males; the farmers' mean age and household size was 45 years and five members, with 93% being married. The multivariate probit regression shows that climate change agronomic adaptation strategies drivers are marital status, farm size, access to credit, age, education, sex, household size, risk, and livestock index. The study, therefore, recommends that smallholder rice farmers in the study area develop programs to address the specific needs and challenges faced by male and female farmers. Promoting sustainable livestock integration practices by expanding access to affordable credit and strengthening extension services to provide farmers with timely information on agronomic practices, climate-smart agriculture, and market trends is essential. Finally, facilitating market access for farmers' products through infrastructure development, value addition, and marketing support is crucial.

Keywords: Adaptation strategies, agronomic, climate change, smallholders, rice farmers.

INTRODUCTION

Agriculture is crucial for Nigeria's economy as it provides food and livelihood. The sector is also the source of raw materials used in several processing industries and foreign exchange earnings for the country (Mohamud *et al*., 2023; Sertoglu *et al*., 2017). Agriculture is the predominant occupation among rural dwellers, predominantly smallholder farmers in Nigeria (Begho and Begho, 2022); smallholder farmers constitute a significant portion of the world's population, with an estimated 500 million worldwide representing 85% of the world's farms (Kamara et al., 2019; Nagayet, 2005). In Nigeria, about 80% of the farmers are smallholders, and they are the heart of food production in the country, thereby contributing meaningfully to poverty reduction and food security (Mgbenka *et al.,* 2015; Akinsuyi, 2011). These smallholder farmers, who cultivate food crops such as rice, maize, cassava, cowpea, yam, millet, sorghum, etc., in small quantities, require support and investment. As policymakers, agricultural organisations, researchers, and stakeholders in the agricultural sector, your role in supporting these farmers is crucial and greatly valued (Adeagbo *et al.,* 2021; Komba and Muchapondwa, 2015; Chauvin *et al*., 2012)

Climate change is rapidly emerging as a critical global development issue affecting many sectors of the world. It is a non-random change in the average weather conditions of a place over time (Nigerian Meteorological Agency, 2017; Adejuwon, 2004) and is considered one of the most severe threats to sustainable development goals. Climate change through extreme temperatures, frequent flooding, drought, and increased salinity of water supply constitute factors that affect agricultural productivity (Manneh *et al.,* 2007). Studies revealed that climate change adversely affects African agricultural productivity (Mulwa *et al*., 2017). Studies by Sarka *et al*. (2017) and Knox *et al*. (2012) showed that a tolerable temperature increase would adversely impact the productivity of main staple crops such as rice, maize, wheat, etc. Likewise, the change in weather affects livestock, forestry, and fishery and decreases aquatic plant species (Niang *et al.,* 2014).

Rice is one of the staple food crops in Nigeria for over 90 per cent of the population and is associated with many technological, institutional, and climatic challenges. Extreme temperatures, floods, drought, and salt stress are the most common climatic issues related to rice production (Ayinde *et al.,* 2013), and all of these are likely to worsen as global climate changes increase rapidly (Ajetomobi *et al.,* 2011). Drastic changes in rainfall patterns and temperature increases usually introduce pests, diseases, and unfavourable conditions into the cropping calendar, reducing rice productivity (Wassmann *et al.,* 2007). Nigeria is currently the largest producer of rice in Africa, with a forecasted production of 8.7 million metric tons (MMT) in 2022, a 9 per cent increase compared to the previous year (United States Department of Agriculture [USDA], 2022). Despite this milestone in production, the yield per hectare of rice production has been consistently low; climate change is a significant contributing factor to this low yield. Hence, they are greatly hit by severe climate change effects. Also, smallholder farmers are likely to be more vulnerable to climate change because of compounding challenges of poverty, low infrastructural and technological development, high dependence on rain-fed agriculture, and environmental components, including soil and climatic components of the ecosystem (Harvey *et al.,* 2014).

To mitigate the impact of climate change on smallholder rice farming, farmers must adopt effective agronomic adaptation strategies. Adaptation is crucial in minimizing the long-term effects of climate change and variability (Akinnagbe and Irohibe, 2014; FAO, 2006). Agronomic adaptation strategies encompass the practices employed by smallholder farmers to either acclimate to or minimise the impacts of climate change and variability (Below *et al.,* 2010). Empirical evidence suggests that adopting such agronomic adaptation strategies is essential for mitigating the effects of climate change and addressing the associated challenges in crop production (Yakubu and Oladele, 2021; Seo and Mendelsohn, 2008). Therefore, implementing effective adaptation strategies will positively impact rice production in Ekiti State, Nigeria, offering hope for the future of rice farming in the region.

Most studies on climate change in Nigerian agriculture (Dutta *et al*., 2024; Grados *et al.,* 2024; Adeagbo *et al.,* 2023; Danso-Abbeam *et al.,* 2021; Onyeneke *et al.,* 2019; and Medugu *et al.*, 2011; Akpodiogaga and Odjugo, 2010) focus on the analysis of the monetary or yield impact of climate change and suggested adaptation strategies. However, there is a significant gap in the literature regarding understanding the drivers of agronomic adaptation strategies. This gap is crucial, as farmers' responses to climate change, or their adaptation strategies, are influenced by various agronomic practices and socio-economic factors. Our study takes a comprehensive approach, considering the agronomic strategies inherent in the study area and the rice farmers' socio-economic characteristics. This thorough approach will provide valuable insights to policymakers and practitioners, helping them strengthen local adaptation. Against this backdrop, our study investigates the determinants of smallholder rice farmers' agronomic adaptation strategies to the effects of climate change in Ekiti State, Nigeria.

Conceptual and theoretical framework

This study finds its strength in the Rational Choice Theory (RCT) and the theory of Utility Maximization. Smallholder farmers choose from several agronomic adaptation strategies by considering the available options and resources at their disposal, which is done to maximise their expected utility. The farmers' utility is a function of the expected costs and benefits of adoption and their preferences, which are influenced by various socio-economic factors. Agronomic adaptation strategies are a form of protective measure that reduces the farmers' risk exposure by reducing the marginal effect of climate change on their rice productivity (Fisher-Vanden and Wing, 2011). Higher yields do not define the utility of a farmer. In the context of adaptation, the utility derived from adopting a practice could yield stability and imply a risk reduction. A risk-averse farmer maximises utility by choosing an adaptation strategy with the benefits of adaptation (risk reduction) minus the cost of adaptation being higher than the benefits realised without adapting. Following Hazell and Norton (1986), a farmer's utility function is defined as follows:

$$U_y = E_y - \beta\omega_y \qquad (1)$$

Where U_y is the perceived utility of choosing an agronomic adaptation strategy y, E_y is the non-stochastic component, ω_y is the disturbance term indicating variation in yields, β is a coefficient that captures the risk aversion of individual rice farmers, which would affect the degree of the variability in the rice yields y ω_y.

Following Finger & Schmid (2007) as used by Ojo and Baiyegunhi (2018), the coefficient is expressed as.

$$\beta = \frac{-(\frac{\vartheta U}{\vartheta \omega y})}{(\frac{\vartheta U}{\vartheta y})} \qquad (2)$$

Where if $\beta < 0$, the farmer is risk-averse and thus more likely to adapt; $\beta = 0$ indicates a risk-neutral farmer and $\beta > 0$ indicates a risk-preferred. The utility of implementing an agronomic adaptation strategy y (Uy) is given by the revenue generated by the adopted strategy less the variable costs incurred in implementing the adaptation strategy. Given the choices of adaptation strategies, a risk-averse farmer will choose the strategy, say X, which yields higher expected utility than the alternatives, say Y, i.e.

$$E(U_x) - M_x > (U_y) - M_y \qquad (3)$$

Where the (U_x) is the expected utility of implementing agronomic adaptation strategy X and the associated costs M_y, while the second term (U_y) is the expected utility of implementing strategy Y and the associated cost M_Y. Assumptions about the relationship of disturbance terms of the adaptation equations, i.e. whether correlated or not, determine the type of qualitative choice model to use in the analysis.

METHODOLOGY

Study area

The study area is Ekiti State, Nigeria. The state is one of the six states in the Southwestern geopolitical zone of Nigeria. The state is within the tropics and was created on the 1st of October 1996 and comprises 16 Local Government Areas (LGAs) (Figure 1). Ekiti State occupies a land mass of approximately 8,6028 kmq2. Ekiti State is predominantly an agricultural area whose main cash crops are cocoa, timbers, oil palm, and kola nuts. The food crops grown are cassava, yam, cocoyam, and grain crops such as maize and rice. The state has two main seasons: the rainy and dry seasons. Ekiti state is renowned for producing local *Igbemo* rice, with an estimated production of 500MT (NBS, 2010). The state is also part of the staple crops processing zones (SCPZ) according to the agricultural transformation agenda (Agricultural Transformation Agenda (ATA), 2011-2014).

Primary data was used for the study. Data were collected from the rice farmers with the aid of well-structured questionnaires. The information that was obtained includes socio-economic and demographic characteristics of the rice farmers like sex, age, marital status, education level, household size, primary occupation access to credit, membership of a cooperative association, access to extension, distance to farm/market, climate change adaptation strategies adopted by the farmers such as mono-cropping, agroforestry, shifting cultivation, cropping pattern, improved seed, afforestation, and conservation of crop moisture. The data were collected through a multi-stage sampling technique. The first stage involved the purposive selection of four major rice-producing Local Government Areas from the state, and the selected local governments are Gbonyin, Ado, Irepodun/Ifelodun, and Ikole Local government areas. The second stage involved randomly selecting two communities from each local government area. The communities selected are Ode Ekiti and Agbado Ekiti from Gbonyin, Farm Settlement, Ago-Aduloju from Ado LGA, Igbemo Ekiti, Afao Ekiti from Irepodun/Ifelodun, and Ijesa-Isu Ekiti and Fatunla Village from Ikole LGA. In the final stage, 25 rice farmers were randomly selected from each community, making 50 rice farmers from each LGA, and 200 rice farmers were surveyed for the study.

Analytic framework

Various studies (Atube *et al*., 2021; Fadina and Barjolle, 2018) have used univariate modelling to analyse the determinants of climate change adaptation on farmers. Univariate modeling, such as simple logit or probit, treats the symptoms as mutually exclusive and excludes useful economic information about the interdependence and simultaneity of the climate agronomic adaptation strategies. In this sense, in adopting a particular climate agronomic adaptation strategy, a farmer may choose other strategies, and its adoption could be partly dependent on earlier adopted strategies informing decisions on subsequent practices in the future (Kassie *et al.*, 2013; Lin *et al*., 2005). The use of either multinomial logit or probit is not appropriate because of the difficulty in explaining the influence of the explanatory variable and unfeasibility in testing if the climate change agronomic strategies are complemented or substituted using the multinomial discrete choice model (Ndiritu *et al.,* 2012). Thus, this study adopted a multivariate probit (MVP) econometric technique, which concurrently models the influence of the set of explanatory variables on each of the agronomic adaptation strategies while allowing the unobserved

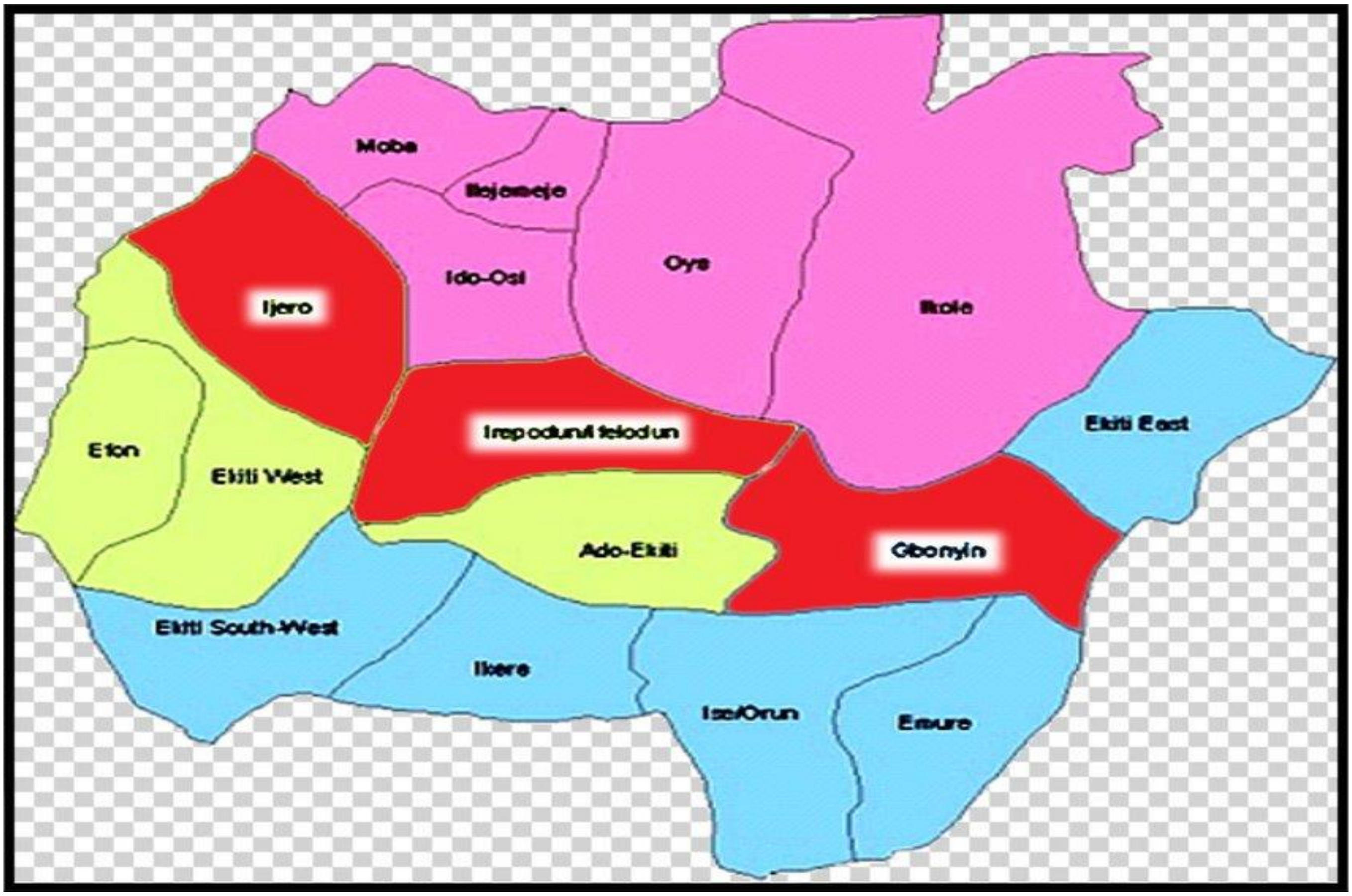

Figure 1. Map of Ekiti State (**Source:** Ekiti State gov.org).

systematic error terms to be freely correlated (Belderbos *et al*. 2004; Lin *et al*., 2005). The MVP specification overcomes the shortfalls of using separate probit equations and multinomial discrete choice estimators. MVP specification allows for systematic correlations between the modes of climate change adaptation strategies. One source of correlation may be complementarities (positive correlation) and substitutability (negative correlation) between different strategies (Teklewold *et al.,* 2013). Failure to capture unobserved factors and interrelationships among the strategies may lead to bias and inefficient estimates (Greene, 2008). Following Lin *et al*. (2005), five dependent variables were used in the model. They are Mono-cropping (M), Diversification (D), Shifting cultivation (S), Improved seed (I), and Afforestation (A). The general multivariate probit model is thus specified as follows.

$$Y_{ijk}^{*} = X_{ij}'\beta_k + U_{ij} \qquad \text{(k=M, D, S, I, and A)} \qquad (4)$$

Using the indicator function, the unobserved preferences in equation (4) translate into the observed binary outcome equation for each symptom as follows:

$$Y_k = \begin{cases} 1 \; if \; Y_{ijk}^{*} > 0 \\ 0 \; otherwise \end{cases} \qquad \text{(k=M, D, S, I, and A)} \; (5)$$

In the multivariate model, where the different climate change agronomic adaptation strategies adoption is possible, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalised to unity (for identification of the parameters) where (k=M, D, S, I, and A) $\sim MVN$ (0, Ω) and the symmetric covariance matrix Ω is given by

$$\text{II} = \begin{vmatrix} 1 & \rho_{12} & \rho_{13} & \dots & \rho_{1m} \\ \rho_{21} & 1 & \rho_{23} & \dots & \rho_{2m} \\ \rho_{31} & \rho_{32} & 1 & \dots & \rho_{3m} \\ \dots & \dots & \dots & 1 & \dots \\ \rho_{m1} & \rho_{m2} & \rho_{m3} & \dots & 1 \end{vmatrix} \qquad (6)$$

The interest or emphasis is on the off-diagonal elements in the covariance matrix, which represent the unobserved correlation between the stochastic components of the different agronomic adaptation strategies. This assumption means that equation (5) gives an MVP model that jointly represents the ability to experience a particular pesticide exposure route. This specification with non-zero

Table 1. Descriptive statistics of the dependent and independent variables.

Variable(s)	Obs.	Explanation	Mean	Std. Dev.
Dependent variables				
Improved seed	200	Use of the strategy 1=yes and 0 otherwise	0.19	0.39
Mono-cropping	200	Use of the strategy 1=yes and 0 otherwise	0.41	0.49
Shifting cultivation	200	Use of the strategy 1=yes and 0 otherwise	0.38	0.48
Afforestation	200	Use of the strategy 1=yes and 0 otherwise	0.65	0.48
Diversification	200	Use of the strategy 1=yes and 0 otherwise	0.32	0.47
Explanatory variables				
Sex	200	1=if sex of the head is male	0.36	0.48
Age	200	Age of the household head in years	47.01	11.47
Age Squared	200	Squared of the age	2340.43	1068.87
Marital Status	200	If household head Married =0, 1=otherwise)	0.93	0.26
Years of Education	200	Years the HH spent in school (Years)	8.65	5.88
Household size	200	No of the family	9.79	4.01
Farm size	200	Size of the HH farm in acres	18.72	9.96
Association membership	200	Yes =0, 1=otherwise	0.16	0.36
Access to credit	200	Yes=0, 1=otherwise	0.19	0.39
Risk index	200	Index of all risk	-0.21	0.99
Livestock index	200	Index of livestock owned	-0.082	1.075
Diversification index	200	Index of diversification activities	-.0766	2.15

Source: Survey Data, 2022.

off-diagonal elements allow for correlation across the error terms of several latent equations, representing unobserved characteristics that affect the experience of alternative agronomic adaptation strategies. The model is thus specified as:

$$Y_{ij} = \beta_o + \beta X_{ij} + \in \quad (7)$$

Y_{ij} (takes on values 1, 2…, 4, if individual i are financially inclusive j

$$Y_{ij} = \alpha + \beta_1 X_1 + \beta_2 X_2 \dots \dots \dots + \beta_{12} X_{13} + \cdots, \varepsilon \quad (8)$$

Where: Y'(is a binary dependent variable that takes the value of 1 if the ith farmer adopt jth agronomic climate change adaptation strategies and 0 otherwise, the jth determinants of financial inclusion are as stated below.

Variable definition

In Table 1; we present the definition of the variables of the study. The dependent variables and other independent variables of the study

Dependent variables are:

Y_1 = Improved seed (Yes=1, No=0); Y_2 = Mono-cropping (Yes=1, No=0); Y_3 = Shifting cultivation (Yes=1, No=0); Y_4 = Diversification (Yes=1, No=0); Y_5 = Afforestation (Yes=1, No=0)

The Independent variables are:

X_1 =Sex (Male=1, Female=0); X_2 =Age (Years); X_3 =Age Squared; X_4 =Marital Status (Married =0, 1=otherwise); X_5 =Years of Education (Years); X_6 =Household size (Numbers); X_7 =Farm size (Acres); X_8 =Association membership (Yes=0, 1=otherwise); X_9 = Access to credit (Yes=0, 1=otherwise); X_{10} = Risk Index; X_{11}= Livestock index; X_{12} = Diversification index

RESULTS AND DISCUSSION

Socio-economic characteristics of the rice farmers

The socioeconomic characteristics of the smallholder rice farmers are shown in Table 2. The table shows that 64% of the farmers were male, with 36% female. Of the farmers, 93% are married, with 7% not married. The mean household size of the farmers is five members, indicating that the household sizes are not large. The age distribution of the smallholder rice farmers shows that the majority, 34%, are within the age of 41-50 years, with the mean age being 45. This indicates that the farmers are active, are still

Table 2. Socio-economic characteristics of the smallholder rice farmers.

Variable	Frequency	Percentage	Mean/Median
Sex			
Male	128	64.00	
Female	072	36.00	
Marital status			
Married	186	93.00	
No-married	014	7.00	
Household size			
0-5	107	53.50	Mean = 5
6-10	87	43.50	
11-15	06	3.00	
Age			
21-30	21	10.50	Mean = 45
31-40	39	19.50	
41-50	68	34.00	
51-60	36	18.00	
61-70	36	18.00	
Education level			
No Education	50	25.00	
Primary	19	9.500	
Secondary	69	34.50	
Tertiary	62	31.00	
Access to credit			
Yes	037	18.50	
No	163	81.50	
Farm size			
0-5	139	67.50	Mean = 5
6-10	60	30.00	
11-15	01	0.50	
Association membership			
Yes	169	84.50	
No	031	15.50	

in their productive age, and can work effectively in their farm operations. A more significant percentage of the farmers, 34.5%, had secondary education, 31% had tertiary education, 25% had no education, and only 9.5% had primary education. The distribution of the farmers by access to credit shows that 18.50% had access to credit, with 81.50% having no access to credit, indicating an apparent credit shortage among the rice farmers. This agrees with Osanyinlusi and Adelegan (2017), who had a similar result. The mean farm size of the farmers was 5 acres, indicating that the farmers are smallholders, going by the small sizes of their farms. The cooperative association is very effective for the farmers, as 84.50% belong to one or more cooperative associations, while only 15.50% do not belong to any cooperative association members. Fasakin and Popoola's (2019) study emphasises the importance of cooperative associations as an institutional vehicle to boost the smallholder farm sector in Nigeria. Furthermore, the distribution of the farmers by the agronomic climate change adaptation strategies shows that about 81.50% of the farmers used improved seeds, compared to 18.50% that did not, while 59% of the farmers practised mono-cropping against 41% that embraced a mixed cropping system. Shifting cultivation

Table 2. Contd.

Variable	Frequency	Percentage	Mean/Median
Improved seed			
Yes	163	81.50	
No	037	18.50	
Monocropping			
Yes	118	59.00	
No	082	41.00	
Shifting cultivation			
Yes	127	63.50	
No	073	36.50	
Afforestation			
Yes	070	35.00	
No	130	65.00	
Diversification			
Yes	137	68.50	
No	063	31.50	

Source: Source: Survey Data, 2022.

practice is adopted by 63.50% of the rice farmers against 36.50%, while 35% embrace afforestation and a more significant percentage, 65% do not. This might be due to the demand for land in Ekiti. Lastly, 68.50% of the rice farmers embrace diversification into non-farm activities, against 31.5% that do not diversify. Some of the non-farm income adopted by the farmers include bricklayer, bike rider (Okada), taxi driver, tailoring, hairdressing, barbing salon, painter, photographer, etc.

Determinants of climate change agronomic adaptation strategies adopted by the smallholder rice farmers

The determinants of agronomic climate change adaptation strategies adopted by the smallholder rice farmers were examined using a Multivariate probit regression. The dependent variables used in this study are improved seed, mono-cropping, shifting cultivation, diversification, and afforestation. A probability Chi^2 94.0235 of 0.000 indicates that the model is statistically fit and can be used for econometric prediction. The rho (ρ) likelihood ratio test is highly significant (p-value=0.000), indicating that a multivariate probit specification fits the data well. A further explanation of the diagnostic statistics is presented in Table 3.

Improved seed

Marital status was significant at 1% ($p>0.01$) and negatively related to improved seed as an agronomic practice; this means that married smallholders' rice farming households have less likelihood of adopting improved rice seed as a strategy than unmarried farmers. This disagrees with (Gebre *et al.*, 2019), who indicated that marital status is highly related to household decision-making. Also, similar studies (Kaliba *et al*., 2018; Umar *et al*., 2014; Banful *et al*., 2010) opined that households with married heads are more likely to adopt improved crop varieties since they seem to have distinct agricultural contacts. Such as extension agents and agro-input dealers, compared to their unmarried counterparts who rely primarily on other farmers as their source of agricultural information. Access to credit was significant at 5% ($P<0.05$), with a positive relationship with improved rice seed. This implies that having access to credit by the farmers will enable them to invest in costlier but more rewarding farming practices, which could reduce the negative impact of climate change on food production. This finding is consistent with the results of previous studies (Atube *et al*., 2021; Fosu-Mensah *et al*., 2012; Deressa, 2007), respectively, which indicated a positive correlation between the adoption of climate change adaptation practices and access to credit.

Monocropping

Farm size was significant at 1% ($P<0.01$), with a negative coefficient or relationship driving monocropping practice as an agronomic strategy for climate change among smallholder rice farmers. This implies that monocropping

Table 3. Result of the Multivariate Probit Regression for the determinants of agronomic climate change adaptation strategies adopted by the smallholder rice farmers.

Variables	Improved seed	Mono-cropping	Shifting cultivation	Diversification	Afforestation
Sex	-0.000	0.183	-0.145	0.378	0.335
	(0.230)	(0.221)	(0.208)	(0.202)*	(0.232)
Age	0.083	-0.030	0.214	0.020	-0.122
	(0.105)	(0.083)	(0.087)**	(0.086)	(0.090)
Age Squared	-0.001	0.000	-0.002	-0.000	0.001
	(0.001)	(0.001)	(0.001)**	(0.001)	(0.001)
Marital Status	-1.390	-0.402	-0.707	-0.287	0.632
	(0.585)***	(0.515)	(0.497)	(0.491)	(0.523)
Years of Education	-0.010	-0.029	-0.035	0.003	-0.053
	(0.019)	(0.018)	(0.018)*	(0.018)	(0.020)***
Household size	0.036	0.032	-0.024	-0.078	0.016
	(0.032)	(0.032)	(0.029)	(0.029)**	(0.032)
Farm size	0.007	-0.045	-0.029	0.010	-0.025
	(0.011)	(0.012)***	(0.011)**	(0.010)	(0.011)**
Association membership	0.382	0.331	-0.068	-0.270	-0.292
	(0.308)	(0.294)	(0.297)	(0.277)	(0.277)
Access to credit	0.476	0.415	0.274	0.197	0.870
	(0.273)*	(0.249)**	(0.242)	(0.258)	(0.307)***
Risk index	0.129	0.332	0.301	-0.021	0.402
	(0.119)	(0.112)***	(0.106)***	(0.108)	(0.120)***
Livestock index	0.109	0.069	0.144	0.248	-0.004
	(0.117)	(0.102)	(0.100)	(0.100)**	(0.096)
Diversification index	-0.034	-0.091	-0.082	0.244	-0.061
	(0.044)	(0.219)	(0.199)	(0.000)	(0.246)
Constant	-2.491	1.686	-3.659	-0.716	3.309
	(2.091)	(1.629)	(1.695)	(1.671)	(1.753)
Chi2(10) =	94.0235				
Prob > chi2 =	0.0000				
Log likelihood =	-469.01583				

Source: Authors Computation, 2022 Note: *** p<0.01, ** p<0.05, * p<0.1.

reduces biodiversity and can lead to soil degradation among rice farmers. Also, smaller farms with diverse cropping systems are more resilient to market risks. Furthermore, cultivated large farm sizes could help adopt technology because the monocropping system will help the farmers track the technological progress in the farm plot, thus increasing their income. The results corroborate with (Atube *et al*., 2021; Amare and Simane 2017), who showed that the size of land cultivated by a household tends to influence the adoption of farming practices. Access to credit was significant at 5% as a driver of monocropping with a positive relationship. This could be that farmers practising monocropping will be able to invest enough finance in rice production alone. The farmers can use or apply other inputs, such as herbicides, fertilisers, etc., efficiently. This will enhance crop productivity, help lessen food scarcity, and increase income for rice farmers, as access to credit has been identified to contribute positively to the adoption of technologies. Lastly, one of the drivers of monocropping as an agronomic climate change strategy is the risk index, which was significant at 1% (p>0.01) with a positive coefficient. This might be because farmers adopting a monocropping strategy have enough wherewithal to cope with any risk from their production. In managing the chance, working on a sole cropping system will be easier than having multiple crops in a plot likely affected by different diseases, additional fertilizer and nutrient requirements, and active herbicide ingredients.

Shifting cultivation

The age of the rice farmers shows a positive relationship with shifting cultivation at a 5% (p>0.05) significant level. This means that aged farmers are more experienced in adopting shifting cultivation practices in dealing with climate change conditions. Shifting cultivation has been identified as an old and age-long strategy farmers use to curb climate change's effects. This disagrees with (Ojo and Baiyegulni, 2021), who suggested that younger farmers are more likely to adopt shifting cultivation than their older counterparts, possibly due to being innovative and keen to try new technology and methods to improve agriculture. The rice farmers' education years show a negative relationship with shifting cultivation at a 10% (p>0.1) significant level. This implies that the possibility of adopting shifting cultivation decreases as the years of education increase. This might be because educated farmers nowadays usually use fertiliser to improve land fertility, and the demand for land is due to the scarcity of land for agricultural production. Feinstein and Mach (2019) opined that appropriately conceived education could be a powerful tool for effective adaptation to climate change. The most fantastic value of education lies in the transformative potential of adaptation learning support: curricular, pedagogical, and technological resources that prepare people for complex adaptive decision-making and help them solidify learning during that work. The farm size of the rice farmers shows a negative relationship with shifting cultivation at a 5% (P>0.05) significant level. As the farm sizes increase, the likelihood of adopting shifting cultivation decreases. This is because farming rice requires a large land area and is likely mechanised; hence, moving from plot to plot might be difficult due to the lack of land in the study area and the high demand for it. This result agrees with a study by (Akters *et al*., 2024), that farmers with larger farm sizes or cultivating large acreages can diversify their agricultural practices. Therefore, they are more likely to engage in shifting cultivation practices. The risk index of the rice farmers shows a positive relationship with shifting cultivation at a 1% (0.01) significant level. This implies that as the index of risk increases, the possibility of adopting shifting cultivation increases. The reason for this might be the ability of the rice farmers to move across different plots in dealing with the climate change problem. This will help circumvent some diseases inherent in the previous field.

Diversification

The sex of the rice farmers shows a positive relationship with diversification at a 10% significant level. This means that the female farmers have a higher likelihood or chance of adopting a diversification strategy than the male households. This might be due to factors such as social and cultural norms, access to resources, knowledge and skills, financial strength, and economic empowerment of the female farmers that could help them diversify into other activities. This finding disagrees with the studies of (Atube *et al.*, 2021; Ndamani and Watanabe, 2016), who found that male household heads were likelier to adopt climate-related practices than female household heads. Female farmers have lower capacities to diversify their sources of income due to heavy domestic responsibilities than their male counterparts (Röhr and Saeur, 2018; Roehr, 2007). The household size of the rice farmers shows a negative relationship with diversification at a significant level of 5% (0.05). This implies that the likelihood of diversifying to other activities decreases as the household size increases. This might be due to the redundancy in the household members' creativity and the adoption of new skills to alleviate the effect of climate change. Such finding agrees with (Atube *et al*., 2021, and Ndamani and Watanabe, 2020) that adapting to climate change was higher with large household sizes than with small household sizes. The livestock index of the rice farmers shows a positive relationship with diversification at a significant level of 5% (0.05). This means that as the livestock owned by the rice farmers increases, the probability of adopting a diversification strategy increases. The finding is plausible because owning livestock is a critical diversification option, as the livestock can generate income and be used in farm operations, among other positivity in curtailing climate change effects. This is in concord with (Kakumanu *et al*., 2016), where livestock ownership has been successfully used in dealing with climate change in India.

Afforestation

Years of education of the rice farmers show a negative relationship with afforestation at a significant level of 1% (0.01). This implies that as the education level of the farmers increases, their chances of adopting an afforestation strategy as an agronomic option decrease. This might be due to the high demand for land, which inhibits afforestation practices. Also, afforestation practices impede the use of machinery on the farm if the farmers want to practice mechanisation. The finding disagrees with (Fadina and Barjolle, 2018; Kakumanu *et al*., 2016), who found a positive relationship between education and climate change adaptation strategies. The farm size of the rice farmers shows a negative association with afforestation at a significant level of 5% (0.05). The farmer's possibility of adopting afforestation decreases as the farm size increases. This might be because the farmers are rice farmers and may not prefer adopting such a practice since rice as a crop does not require coverage for productivity. The finding disagrees with (Atube *et al.,* 2021), who opined that large farm size allows for adopting newly introduced farming practices without running sort of land to practice the usual farming practices. Access to the credit of the rice farmers shows a positive

Table 4. Results of the Wald test of simultaneity of the drivers of smallholder rice farmers agronomic climate change adaptation strategies.

Parameters	Coeff.	St.Er	p-values
/atrho21	0.200	0.131	0.125
/atrho31	0.273	0.129	0.034**
/atrho41	0.416	0.161	0.009**
/atrho51	0.172	0.177	0.330
/atrho32	0.650	0.145	0.000***
/atrho42	-0.554	0.200	0.006**
/atrho52	1.160	0.185	0.000***
/atrho43	0.084	0.140	0.548
/atrho53	0.457	0.157	0.004***
/atrho54	-0.688	0.187	0.000***

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: Chi2(10) = 94.0235 Prob > chi2 = 0.0000.

relationship with afforestation at a significant level of 1% (0.01), implying that an increase in access to credit will lead to an increase in the adoption of the afforestation strategy. The afforestation strategy is capital intensive, and the proceeds from the economic trees planted by the farmers are a source of income for the farmers. Hence, afforestation might increase farmers' income levels.

Table 4 shows the results of the Wald test of the simultaneity of the drivers of climate change agronomic adaptation strategies among smallholder rice farmers. Rho refers to the correlation coefficient among the error terms of the climate change agronomic adaptation strategies. Rho21, for instance, is the correlation coefficient among the error terms of climate change strategies (1) and (2), and rho31 is the correlation coefficient among the error terms of climate change strategies (3) and (1) in that order. Furthermore, the correlation coefficients among the error terms are significant, indicating that climate change agronomic adaptation strategies are interdependent. Lastly, the simultaneous modelling was also justified by the highly significant off-diagonal values of the error covariance matrix (atrhoij)

Conclusion and policy recommendations

Using the multivariate probit model, the study analysed the determinants of climate change agronomic adaptation strategies among smallholder rice farmers in Ekiti State, Nigeria. The findings from the multivariate probit model revealed that the farmers' agronomic adaptation strategies were driven by socio-economic such as sex, marital status, age, years of education, household sizes, risk index, livestock index, access to credit, and farm size. Therefore, it is recommended that smallholder rice farmers in the study area develop programs to address the specific needs and challenges faced by male and female farmers. These programs should offer training that accommodates the diverse needs and learning styles of farmers of different ages. Additionally, strategies should be implemented to assist farmers in managing challenges associated with risk factors such as climate change and market volatility. Promoting sustainable livestock integration practices by expanding access to affordable credit. Strengthening extension services to provide farmers with timely and pertinent information on agronomic practices, climate-smart agriculture, and market trends is essential. Finally, facilitating market access for farmers' products through infrastructure development, value addition, and marketing support is crucial.

COMPETING INTERESTS

The authors declare that they have no conflict of interest.

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