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EFFECT OF CLIMATE CHANGE ADAPTATION STRATEGIES ON EFFICIENCY OF RICE (*ORYZA SATIVA* L.) PRODUCTION IN BENUE STATE, NIGERIA

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ABSTRACT

The study determined the effect of climate change adaptation strategies on efficiency of rice (*Oryza sativa* L.) production in Benue State, Nigeria. Multistage sampling technique was used to select 498 rice farmers across 24 rice farming communities, 6 Local Government Areas and 3 Agricultural Zones. Data were collected using structured questionnaires and analysed using descriptive statistics and stochastic frontier model. Results showed that fertilizer application (85.94%), multiple plots (69.28%) and improved rice varieties (68.27%) were the major climate change adaptation strategies used. The farmers operated with moderate levels of technical, allocative and economic efficiencies of 0.69, 0.73, and 0.53 respectively. Furthermore, fertilizer application (-0.113, P<0.01), irrigation (-0.102, P<0.01) and multiple planting dates (-0.114, P<0.01) significantly reduced technical inefficiency. Irrigation also reduced cost inefficiency (-0.081, P<0.01). Improved rice varieties (0.136, P<0.01) and multiple plots (0.055, P<0.05) had less impact on technical inefficiency. Trees planting increased cost inefficiency (0.028, P<0.01). The study concluded that climate change adaptation strategies had significant effect on efficiency of rice production in Benue State, Nigeria. The study recommended that, there is need for government to enhance the capacity of agricultural extension agents to provide targeted advisory services, training and demonstrations focused on climate-resilient practices that have proven to increase efficiency, such as effective fertilizer application, improved irrigation practices and optimal multiple planting date strategies.

Keywords: Climate Change, Adaptation Strategies, Efficiency, Production, Efficiency

INTRODUCTION

Rice is essential for food security in Nigeria (Hassan *et al*., 2022). The climatic environment in which rice grows is vital for attaining food security due to the growing importance of the crop as a staple food (Diagi *et al*., 2021). Climate has a direct impact on rainfed production of rice. Over the past few decades, rice production in Nigeria has been declining as a result of climate change and market forces. It is reported that a percent increase in temperature for instance is expected to result in a decrease in rice output of about 3.2 % (USDA, 2024). Despite progress made under National Rice Development Strategy II of Nigeria which aims to boost production and make the country a net exported by 2030, local production still falls short of demand due to climate change impacts and rapid population growth (Familusi and Oranu, 2021). Consequently, adaptation strategies are crucial to bridge this gap and achieve the goal. The importance of adaptation as key to adequately preparing for and responding to climate change impacts has been underscored by the Federal Government of Nigeria (FGN). The government has hence developed the National Adaptation Strategy and Action Plan on Climate Change for Nigeria (NASPA-CCN) in 2011, the National Adaptation Plan Framework developed in 2020, and the Nigeria Climate Change and Response Strategy, developed in 2012 (which was recently reviewed in 2021) (FGN, 2021).

Rice is a food commodity that is widely consumed in Nigeria (KPMG, 2023). The country is considered as the largest producer of rice in Africa and at the same time a huge importer of the commodity as the output of rice in the country has not been able to keep pace with increasing demand requirements (Orifah *et al*., 2020). There has been a mismatch in the amount of rice produced and the amount consumed in Nigeria as only about 57% of the 6.7 million metric tons of rice consumed in the country annually is locally produced, leading to a supply deficit of about 3 million metric tons (KPMG, 2023). Compounding this production shortfall, climate change threatens rice yields, both directly through changes in growth and production and indirectly through impacts on the crop diseases (Shahzad *et al*., 2021). The impacts of climate change on rice production systems are felt in the form of adverse effects of extreme weather events. Floods and other extreme weather events have severely impacted rice production in Benue State, Nigeria. The flood of 2022 for instance inundated 80 % of the floodplains leading to 88.7 % reduction in rice output and this was attributed to waterlogging, soil erosion, crop submersion and infestation of pest (Bello *et al*., 2023). Also, climate change is projected to reduce crop (mainly rice) by 3.4 to 10.9 % by 2100 as a result of heat stress affecting pollination (FAO, 2024). In 2024, about 33 % of Nigerians were reported to be food insured and this is projected to further increase with increasing extreme weather events. Climate change has resulted in significant reduction in income of farmers in Nigeria with projections of 6 to 30 % loss in GDP by 2050 due to flooding and desertification. This may lead to 30 % less average income mainly among farmers (NiMet, 2023).

Consequently, application of climate resilient varieties, schedule of planting date to coincide with shifting seasons, and improvement of soil water retention and nutrient availability are some of the available climate change adaptation strategies (Liang *et al*., 2019). Reducing environmental effects to increase food production necessitates formation of comprehensive policies on strategies that utilize modern technology, ancient wisdom, and scientific understanding (Amin *et al*., 2023). The IPCC of the United Nations refers to adaptation as the "process of

adjustment to actual or expected climate and its effects" (IPCC, 2022). Traditional agricultural adaptation strategies including diversification of incomes, use of forest products as a buffer against climate induced crop failure, soil fertility improvement techniques, soil moisture and water conservation practices and the manipulation of land use leading to land use conversion have been adopted to cope with climate variability and extreme events (Akinnagbe and Irohibe, 2014). Climate change adaptation strategies for rice production have taken a wide range of forms including irrigation, crop rotation, intercropping, cultivation calendar adjustment, planting improved drought-tolerant variety, early planting, crop diversification, rainwater harvesting, integrated soil fertility management, integrated pest and weed management, organic manuring, agroforestry and soil management and water conservation practices (Ali *et al*., 2023; Ogisi and Begho, 2023; Magesa *et al*., 2023). Climate change adaptation strategies are expected to abate the effect of climate change through increasing resilience capacity, increase productivity of farmers by introducing new or improved rice production practices and improving efficiency which will lead to an increase in rice yield and farm income, improved welfare of rice farming households as well as enhance adaptive capacity of farm firms (Asmare *et al*., 2022). Perceptions of farmers are key for adaptation in agriculture as well as in employing various adaptation strategies to reduce the risks associated with climate change in agricultural production (Desquith and Renault, 2021; Vo *et al*., 2021).

Several studies have investigated the efficiency of rice production, climate change and its impact on agricultural production as well as the effects of climate change adaptation strategies on agricultural production. For instance, research has been conducted on the effect of climate change adaptation strategies on production efficiency of chickpea and lentil in Rajshahi District (Morsalina *et al*., 2021). Another study examined the effects of climate change adaptation on technical efficiency of maize production in Northern Ghana (Adzawla and Alhassan, 2021). Oyita *et al*. (2023) conducted a study on the effect of rice production input variables and climate change variables on rice output in Nigeria. Obianefo *et al*. (2020) investigated the efficiency of rice farmers in Anambra State. Erekalo and Yadda (2023) studied climate-smart agriculture in Ethiopia, focusing on adoption of multiple crop production practices as a sustainable adaptation and mitigation strategy. Abiola (2021) examined the technical efficiency of rice production in North Central, Nigeria. Hassan *et al*. (2022) assessed the determinants of allocative efficiency among rainfed rice farmers in Ardo-Kola and Jalingo Local Government Areas of Taraba State, Nigeria. Onoja (2023) carried out an investigation on determinants of arable crop farmer's decisions to adapt to climate change risks in Nigeria. Asmare *et al*. (2022) studied climate change adaptation and productive efficiency of subsistence farming using a bias-corrected panel data stochastic frontier approach. Ivom (2020) examined the effects of climate change adaptation strategies on groundnut production in Benue State, Nigeria. Otitoju (2013) analysed the effects of climate change adaptation strategies on food crop production efficiency in Southwestern Nigeria. These studies were conducted in various locations that have different intensities of climate change and levels of climate change adaptation. The results of these studies may depend on factors such as the intensity of climate variation, types and varieties of crops, adaptive capacity and specific adaptation strategies implemented.

The potentials of traditional and modern climate change adaptation strategies have been advocated however, the impacts of the adaptation strategies on efficiency of rice production still remain unclear. There is largely a limited understanding of the effects of climate change adaptation strategies on efficiency of rice production especially in Benue State, Nigeria. Benue State is one of the major rice producing states in Nigeria (Ikpe and Omede, 2025). As a result of these gaps in quantitative assessments of efficiency of rice production under various climate change adaptation strategies and the inability to complement local practices with formal climate change adaptation strategies, there is need for more empirical research on the effects of climate change adaptation strategies on efficiency of rice production. Based on these, the study specifically identified climate change adaptation strategies among rice farmers, estimated the efficiency of rice production and determined the effects of climate change adaptation strategies on efficiency.

METHODOLOGY

Study Area

The study was carried out in Benue State, which is located in the lower River Benue trough in the middle belt region of Nigeria. It lies within Longitude 7°47' and 10°0' East and Latitude 6°25' and 8°8' North (Ogbe, 2015). The total area covered by Benue State is 34,059 Km^2. The estimated population of Benue State for 2024 is 6,523,551 people based on NPC (2006) census record of 4,253,641 people. The state comprises 23 local government areas which are divided into three agricultural zones - Northeast, Northwest and Southern Agricultural Zones. The State shares boundaries with Nasarawa State to the North, Taraba State to the East, Kogi State to the West, Enugu State to the South-West, Ebonyi and Cross River States to the South and an international border with Cameroon to the South-East (Adebayo, 2018).

Benue State possesses a tropical climate with two distinct seasons- wet and dry seasons. The rainy season lasts from April to October with annual rainfall in the range of 900-1,500mm. The dry season begins in November and ends in March (Ocholi, 2020). Temperatures fluctuate between 21°C and 37°C. The south-eastern part of the State adjoining the Obudu-Cameroun Mountain range has a cooler climate similar to that of Plateau State. Benue State has high drainage density but many of the streams are seasonal. Hence, there is an acute water shortage in the dry season in Local Government Areas such as Guma, Okpokwu, Ogbadibo, Gwer West and Oju.

Agriculture is the mainstay of the economy of Benue State, engaging over 75% of the state's workforce. Soil types in the

state vary but the dominant ones are sandy loam, clay loam and alluvial soils which support the production of a wide range of crops including yam, rice, beans, cassava, sweet potato, maize, soybean, sorghum, millet, sesame and cocoyam (Adebayo, 2018). The vegetation of the southern parts of the state is characterised by forests, which yield trees for timber and provide a suitable habitat for various animals' types and species. The state thus possesses potential for the development of viable forest and wildlife reserves.

The topography of Benue State is characterized by low-lying plains, rolling hills and river valleys, which makes the state vulnerable to environmental challenges such as flooding, soil erosion and desertification (Ijaiya, 2017; Ademiluyi, 2019;). The location of the state in the Niger-Benue River basin makes it prone to flooding which can have devastating effects on agricultural production and human settlements (Odjugo, 2018). Benue State has high potentials for rice production with suitable land and water resources. The state is one the major rice producing areas in Nigeria (Adebayo, 2018). Efforts to improve rice production Benue State include the use of improved varieties, irrigation and mechanization. Despite the potential, rice production in Benue State is constrained by inadequate infrastructure, limited access to credit and climate change (FMARD, 2020).

Sampling Procedure and Data Collection

This study used a multi-stage sampling procedure; thus, Benue State was divided into four (3) Agricultural Zones namely: North West, North East, and Southern Agricultural Zones. The second stage involved the selection of Local Government Areas (LGAs). Simple random sampling was used to select two (2) LGAs from each Agricultural Zone, namely; Logo and Konshisha from North East, Guma and Buruku from North West and Agatu and Apa from Southern Agricultural Zone. The third stage involved the selection of rice farming communities. Four (4) communities were selected from each of the selected LGAs purposively based on; accessibility, level of rice production activities, political unrest, conflict and/or instability. The fourth stage involved randomly selecting five hundred and five (505) rice farmers who were used for this study. The farmers were selected from the four (4) communities. Taro Yamane formula with precision error term of 4.1% was used to determine the sample size. The formula is given as:

$$n = \frac{N}{(1+Ne^2)}$$

Where:
n = sample size
N = population of registered rice farmers
e = error term.

Data were collected using questionnaire. The questionnaire focused on climate change adaptation strategies and production resources as well as output. The questionnaires were administered by well-trained enumerators and four hundred and ninety-eight (498) of questionnaires were returned and used in analysis. The questionnaire was tested for validity and reliability using content validity and test-retest reliability respectively.

Table 1: Sample Size Selection Procedure

Agricultural Zone	Local Government Area	Community	Registered Rice Farmers	Sample Size
North East	Konshisha	Mbaikyase	284	43
		Mbaiwarnyam	91	14
		Mbatsen	143	22
		Mbatser/Mbagusa	99	15
	Logo	Mbagber	239	36
		Mbayam	192	29
		Tombo	135	20
		Yonov	177	27
North West	Buruku	Binev	84	13
		Etulo	222	34
		Mbaapen	229	35
		Mbaya	99	15
	Guma	Mbawa	207	31
		Nyiev	201	30
		Nzorov	215	33
		Uvir	192	29
Southern	Agatu	Egba	61	9
		Obagaji	53	8
		Odugbeho	40	6
		Okokolo	45	7
	Apa	Iga	91	14
		Igoro	80	12
		Ikobi	80	12
		Ugbokpo	72	11
Total			**3331**	**505**

Source: BNARDA, 2024

Analytical Technique

The data collected for this study were analysed using both descriptive and inferential statistical techniques. Descriptive statistics, specifically frequencies and percentages, were employed to identify and summarize the climate change adaptation strategies adopted by respondents. To estimate the efficiency of the farmers and assess the influence of climate change adaptation strategies on efficiency, the Cobb–Douglas stochastic frontier model was utilized.

The study data were fitted into Cobb–Douglas stochastic frontier model, which is widely applied in efficiency analysis because it permits the simultaneous estimation of efficiency levels and the determinants of inefficiency (Aigner *et al*., 1977; Battese & Coelli, 1995). This approach provides a comprehensive framework for examining variations in production performance among the farmers while accounting for random shocks beyond their control. The stochastic frontier production model employed in this study was specified as follows:

$$\ln Y = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + \beta_6 \ln X_6 + \beta_7 \ln X_7 + \beta_8 \ln X_8 + \beta_9 \ln X_9 + v_i - u_i \quad \ldots (1)$$

where;

Y = rice output (kg).
X_1 = farm size (ha).
X_2 = quantity of rice seed (kg).
X_3 = hired labour (man-day).
X_4 = family labour was (man-day).
X_5 = quantity of inorganic fertilizer (kg).
X_6 = quantity of organic fertilizer (kg).
X_7 = volume of pre-emergent herbicides (litres).
X_8 = volume of post-emergent herbicide (litres).
X_9 = volume of pesticides (litres).
ln = natural logarithm.
β_0 = intercept.
$\beta_1 - \beta_9$ = parameter estimates.
v_i = random error that assumes an independent and identical distribution as $N(0,\sigma v^2)$.
u_i = inefficiency effect that assumes an independent distribution that is defined by the truncation of $N(u_i,\sigma)$ distribution.

The stochastic frontier cost model employed is specified as follows:

$$\ln C = \beta_0 + \beta_1 \ln P_1 + \beta_2 \ln P_2 + \beta_3 \ln P_3 + \beta_4 \ln P_4 + \beta_5 \ln P_5 + \beta_6 \ln P_6 + \beta_7 \ln P_7 + \beta_8 \ln P_8 + \beta_9 \ln P_9 + \beta_{10} \ln P_{10} + v_i + u_i \quad \ldots (2)$$

Where;

C = total cost of production (₦)
P_1 = depreciation of assets (₦)
P_2 = cost of seeds (₦)
P_2 = cost of land (₦)
P_2 = wages of hired labour (₦)
P_2 = wages of family labour (₦)
P_2 = cost of inorganic fertilizer (₦)
P_2 = cost of organic fertilizer (₦)
P_2 = cost of pre-emergence herbicide (₦)
P_2 = cost of post-emergence herbicide (₦)
P_2 = cost of pesticide (₦).

Inefficiency (u_i) was specified as:

$$u_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \delta_7 Z_7 + \delta_8 Z_8 \quad \ldots (3)$$

Where;

Z_1 = fertilizer (inorganic/organic) application (kg).
Z_2 = improved rice variety (kg).
Z_3 = irrigation (irrigation frequency).
Z_4 = trees planting (number of trees integrated/hectare).
Z_5 = integrated pest management (number of distinct pest management used).
Z_6 = crop diversification (number of other crops planted).
Z_7 = multiple planting dates (number of distinct planting dates).
Z_8 = multiple plots (number of plots or parcel of land cultivated).

RESULTS AND DISCUSSION

Climate Change Adaptation Strategies among Rice Farmers

Climate change adaptation strategies are the actions the respondents take to manage the risks and opportunities associated with climate change. The aim of using the strategies is to enable farmers cope with the impacts of climate change (Asmare *et al*., 2022).

Table 2 shows that 85.94% of farmers used fertilizer application as a climate change adaptation strategy. The widespread use indicates recognition of the role of soil fertility in buffering rice yields against climate stress such as erratic rainfall and high temperature. Optimal fertilizer use improves efficiency by ensuring that nutrient limitations do not constrain yield response to other inputs. When combined with climate adaptation practices, fertilizer increases output per unit of land and labour, reducing yield gaps caused by climate-induced soil nutrient depletion. This enhances resource-use efficiency and economic returns. This result agrees with Emmanuel *et al*. (2024), who observed that 83.0% of farmers in Jos-South, Plateau State applied fertilizer as a coping strategy to maintain yields under climate change. Also 68.27% of farmers used improved rice varieties that can withstand flooded conditions, resist drought, and/or mature early. Adoption of climate-resilient varieties improves efficiency by reducing crop failure and stabilizing yields under stress. Early-maturing varieties allow farmers to escape late-season drought, while flood- and drought-tolerant varieties maintain physiological performance under stress, increasing output per unit of input. This reduces risk and improves input productivity. This finding aligns with Gbemavo *et al*. (2022), who reported that 76.4% of rice farmers in Benin used flood-tolerant varieties to manage negative impacts of climate change. Similarly, 69.28% of farmers cultivated multiple plots in different locations to reduce risk and increase resilience to climate-related shocks. Multiple plots enhance efficiency by reducing total crop loss when one plot is affected by flood or drought. This risk-spreading strategy stabilizes farm output and improves average yield per unit of labour and input. It also allows farmers to exploit variations in soil moisture and fertility increasing overall resource-use efficiency across the farm holding. This result aligns with Adeagbo *et al*. (2023), who found that 70.1% of smallholder farmers in Southwestern Nigeria used multiple plots to adjust to

changes in climatic conditions. Also, 53.21% of respondents used integrated pest management including cultural, biological and chemical control methods to manage climate-related pest and disease pressures. Integrated pest management improves efficiency by minimizing crop losses to pests and diseases while reducing over-reliance on chemical pesticides. Targeted pesticide use lowers input cost and environmental damage, increasing output per unit cost. By maintaining plant health under changing climate conditions, integrated pest management stabilizes yields and improves efficiency of resource utilization. This result is consistent with Erekalo and Yadda (2023), who reported that 52.2% of farmers in Ethiopia applied integrated pest management to control pests associated with climate change.

Furthermore, Table 2 shows that 47.19% of respondents diversified to other crops to cope with adverse effects of climate change. Diversification to other crops improves efficiency by reducing dependence on a single crop whose yield may be depressed by climate shocks. It ensures income stability and allows better utilization of family labour across the cropping calendar. While rice remains the focus, intercropping or rotation with compatible crops can improve soil health and input-use efficiency, contributing to sustainable production efficiency. The result of this study similar to that of Erekalo and Yadda (2023) in a study on climate-smart agriculture: adoption of multiple crop production practices as sustainable adaptation and mitigation strategies in Ethiopia, that over 58.31 % of the farmers in Ethiopia used crop diversification to mitigate climate change related risks. Also, 42.17% of farmers used multiple planting dates to reduce risk of crop failure due to irregular rainfall patterns. Multiple planting date improves efficiency by increasing the probability that at least one planting date coincides with favourable moisture conditions. This reduces risk of total crop failure and stabilizes yield across seasons. It also allows better distribution of labour, reducing peak-load constraints and improving labour productivity. Farmers who monitor weather forecasts can capitalize on favourable conditions, increasing output per unit input. This result aligns with Diallo *et al*. (2020) who used percentage to identify farm-level climate change coping strategies and soil management practices in southern Mali reported that close to half of the farmers adopted changes in planting dates across the planting season. Additionally, 12.65% of rice farmers used irrigation as climate change adaptation strategies to control insufficient water during periods of dry spells. The low adoption rate suggests resource constraints such as limited access to irrigation facilities, pumps and capital. Where used, irrigation improves efficiency by preventing yield losses moisture stress. It ensures optimal soil moisture for rice growth, increasing water productivity and output per unit input. Promoting low-cost irrigation practices can therefore yield significant efficiency gains in the study area. This result is in line with Zagre *et al*. (2024), who observed that 6.0% of rice farmers in Senegal's Semi-Arid Zone practiced irrigation to reduce climate impacts. Finally, 11.04% of rice farmers used trees planting to provide shade, improve soil health, and reduce erosion. Low adoption suggests limited awareness and technical knowledge. Where practiced, trees planting improves efficiency by enhancing soil organic matter, reducing erosion losses, and moderating microclimate. Trees also provide alternative income, reducing pressure on rice yields. Integrating trees planting with rice can improve long-term productivity per unit of land and input, contributing to sustainable efficiency. This result aligns with Okon *et al*. (2020), Mbow *et al*. (2019), and Nguyen *et al*. (2021), who reported 20.0% adoption in Southeast Nigeria, 5.0% in West Africa and 15.0% in Asia respectively, indicating that trees planting adoption remains low but beneficial for climate adaptation.

Table 2: Distribution of Respondents according to Climate Change Adaptation Strategies Used

Strategies	Frequency*	Percentage (%)
Fertilizer application	428	85.94
Multiple plots	345	69.28
Improved rice varieties	340	68.27
Integrated pest management	265	53.21
Crop diversification	235	47.19
Multiple planting dates	210	42.17
Irrigation	63	12.65
Trees planting	55	11.04

Source: Field Survey Data, 2025
*** = multiple responses**

Efficiency of Rice Production

Farm production efficiency is the optimal use of production inputs such as land, labour, seeds, fertilizers, pesticides, and herbicides to maximize output while minimizing waste and cost of production (Yusuf *et al*., 2022). Table 3 shows that technical efficiency ranges between 0.11 and 0.91 with a mean of 0.69. This implies that, on average, rice farmers in the study area are producing 69% of the maximum possible output given their current level of inputs and technology. There is potential to increase technical efficiency by 31% without additional inputs if farmers adopt best practices. It also shows that, 47.99% of farmers had technical efficiency of 0.61–0.80, 29.92% had 0.81 and above, 13.25% had 0.41–0.60, 7.23% had 0.21–0.40, and 1.61% had 0.01–0.20. The mean technical efficiency indicates substantial inefficiency in converting inputs to output, partly due to climate-related yield losses. Farmers with low technical efficiency can improve output by correctly implementing climate change adaptation strategies. These strategies help farmers produce more rice from the same land, labour, and capital, thereby closing the efficiency gap. This result is similar to Abiola *et al*. (2021), who reported technical efficiency of rice farmers in North Central Nigeria ranging

from 0.32 to 0.96 with a mean of 0.81, indicating that inefficiency exists but can be reduced through improved management. Also, the allocative efficiency ranges from 0.14 to 0.93 with a mean of 0.73. This suggests that farmers could reduce production costs by 27% or increase output by reallocating resources more efficiently, without changing technology. It also shows that, 42.57% of respondents had allocative efficiency of 0.61–0.80, 39.96% had at least 0.81, 12.45% had 0.41–0.60, 4.02% had 0.21–0.40, and 1.00% had 0.01–0.20. The mean allocative efficiency indicates that many farmers misallocate inputs such as fertilizer, labour and seeds relative to their prices, reducing profitability under climate stress. Climate change adaptation strategies can improve allocative efficiency by spreading risk and aligning input use with seasonal conditions. Training on optimal input combinations and access to price information can help farmers adjust input levels to climate conditions, thereby improving cost efficiency. This result is in line with Nwahia *et al*. (2020), who found allocative efficiency of rice farmers in Ebonyi State ranging from 0.11 to 0.99 with a mean of 0.63, confirming that resource misallocation is common among smallholder rice farmers.

Similarly, the economic efficiency ranges from 0.02 to 0.84 with a mean of 0.53. This moderate level suggests fairly decent use of resources and cost management, but significant room for improvement. It also shows that, 41.57% of farmers had economic efficiency 0.81 and above, 41.57% had 0.61–0.80, 11.85% had 0.41–0.60, 4.02% had 0.21–0.40, and 1.00% had 0.01–0.20. The mean economic efficiency implies that farmers are losing 47% of potential profit due to technical and allocative inefficiencies exacerbated by climate change. Adoption and proper application of climate change adaptation strategies can improve economic efficiency. Targeted interventions to improve adoption intensity among less efficient farmers will therefore enhance profitability and resilience of rice production in the study area. This result aligns with Alabi *et al*. (2024), who reported economic efficiency of small-scale women rice farmers in Federal Capital Territory, Nigeria ranging from 0.05 to 0.97 with a mean of 0.51. It is also consistent with Okello *et al*. (2019), who found economic efficiency of small-scale rice farmers in Northern Uganda between 0.127 and 0.873 with a mean of 0.588.

Table 3: Distribution of Respondents based on Technical, Allocative and Economic Efficiencies

Efficiency Index	Technical Efficiency		Allocative Efficiency		Economic Efficiency	
	Freq.	%	Freq.	%	Freq.	%
0.01-0.20	8	1.61	5	1.00	5	1.00
0.21-0.40	36	7.23	20	4.02	20	4.02
0.41-0.60	66	13.25	62	12.45	59	11.85
0.61-0.80	239	47.99	212	42.57	207	41.57
≥0.81	149	29.92	199	39.96	207	41.57
Total	**498**	**100.00**	**498**	**100.00**	**498**	**100.00**
Minimum	**0.11**		**0.14**		**0.02**	
Maximum	**0.91**		**0.93**		**0.84**	
Mean	**0.69**		**0.73**		**0.53**	
Standard deviation	**0.17**		**0.15**		**0.19**	

Source: Field Survey Data, 2025

Effect of Climate Change Adaptation Strategies on Efficiency

Maximum likelihood estimates of the stochastic production frontier are presented on Table 4. Farm size (0.348), hired labour (0.093), organic fertilizer (0.046) and post-emergence herbicide (0.200) had positive and significant relationships with output at P<0.01. Seed quantity (0.092) was positive and significant at P<0.10. This means that a 1% increase in farm size, seed quantity, hired labour, organic fertilizer and post-emergence herbicide will increase rice output by 0.348%, 0.092%, 0.093%, 0.046%, and 0.200% respectively, holding other inputs constant. The positive elasticities show that expanding farm size and increasing use of labour, improved seed and organic fertilizer are key input pathways to technical efficiency. These inputs are expected to become more productive when combined with climate change adaptation strategies that reduce yield loss from climate stress.

The estimated gamma ($\gamma = 0.920$) and sigma squared ($\sigma^2 = 0.272$) were both significant at P<0.01. Gamma of 0.920 implies that 92.0% of the deviation of actual output from the frontier was due to technical inefficiency, not random noise. This confirms that inefficiency is a major source of output loss and can be reduced through better management, including effective application of climate change adaptation strategies. Sigma squared of 0.272 captures total variation in output unexplained by inputs.

Fertilizer Application

The coefficient of fertilizer application (-0.113) in the inefficiency model was negative and significant at P<0.01. A negative coefficient means fertilizer application reduces technical inefficiency and increases technical efficiency. Fertilizer application directly addresses soil nutrient depletion caused by erratic rainfall and high temperature. As intensity of fertilizer use increases, farmers move closer to the production frontier by ensuring that other inputs such as seed and labour achieve their full yield potential. This improves technical efficiency by reducing output gaps attributable to nutrient stress under climate change. This result is in line with Diallo *et al*. (2020), who observed that increased fertilizer application raised productivity and efficiency of crop production under climate variability in southern Mali.

Improved Rice Varieties

Also, the coefficient of improved rice varieties (0.136) was positive and significant at P<0.01. A positive coefficient in the inefficiency model means use of improved rice varieties increases technical inefficiency and reduces technical efficiency in the study area. This counterintuitive result suggests that farmers are adopting improved rice varieties but are not achieving expected efficiency gains, likely due to inadequate knowledge of variety-specific management practices. Improved rice varieties require correct spacing, fertilizer timing and moisture control to express their climate-resilience traits. Without proper management, genetic potential is not realized, leading to suboptimal yields and technical inefficiency. This highlights the need for training and extension support to improve efficiency of improved variety adoption.

Irrigation

Furthermore, the coefficient of irrigation (-0.102) was negative and significant at P<0.01. The negative sign indicates that irrigation reduce technical inefficiency. Rice is water-sensitive and climate change increases risks of both drought and flooding. Effective irrigation ensures optimal soil moisture, which improves plant growth and nutrient uptake. This reduces yield loss from water stress and increases output per unit of land, labour and seed, thereby raising technical efficiency. Irrigation is therefore a critical climate change adaptation strategy for efficiency gains in rainfed rice systems. This result aligns with Liu *et al*. (2023), who found that irrigation as a water management practice is an important adaptation strategy for managing negative impacts of climate change on rice technical efficiency.

Multiple Planting Dates

Similarly, the coefficient of multiple planting dates (-0.114) was negative and significant at P<0.01. This suggests that farmers who use multiple planting dates are less technically inefficient. Multiple planting dates allow farmers to match crop growth stages with variable rainfall onset and cessation. This reduces risk of total crop failure and stabilizes yield across seasons. By spreading labour demand and reducing exposure to mid-season drought, farmers achieve higher output per unit of labour and input, improving technical efficiency. It is a low-cost adaptation strategy with direct efficiency benefits. This result confirms Khatun *et al*. (2021), who found that multiple planting dates had a negative and significant relationship with technical inefficiency of legume production under climate variability in Bangladesh.

Multiple Plots

The coefficient of multiple plots (0.055) was positive and significant at P<0.05. The positive coefficient in the inefficiency model means that cultivating multiple scattered plots increases technical inefficiency. Multiple scattered plots raise transaction costs of supervision, input application and adoption of scale-dependent strategies such as mechanization and irrigation. Farmers with many small, dispersed plots find it difficult to manage operations uniformly, leading to resource waste and lower output per unit input. While multiple plots reduce risk of total crop loss, the efficiency cost from poor management outweighs the risk benefit in this study area. Land consolidation or group farming could improve technical efficiency for fragmented farmers. This finding is consistent with Zhou *et al*. (2024), who reported that technical efficiency initially decreases with increasing number of plots due to management challenges associated with land fragmentation.

Table 4: Maximum Likelihood Estimates of the Stochastic Production Frontier Function

Explanatory Variables	Parameters	Coefficients	Standard error	T- values
Constant	β_0	7.125	0.273	26.11***
Farm size	β_1	0.348	0.055	6.34***
Seed	β_2	0.092	0.053	1.75*
Hired labour	β_3	0.093	0.029	3.26***
Family labour	β_4	0.019	0.027	0.69
Inorganic Fertilizer	β_5	-0.004	0.024	-0.17
Organic fertilizer	β_6	0.046	0.012	3.71***
Pre-emergence herbicide	β_7	0.075	0.046	1.63
Post-emergence herbicide	β_8	0.200	0.054	3.72***
Pesticide	β_9	-0.029	0.034	-0.86
Inefficiency Effects				
Constant	δ_0	1.092	0.152	7.19***
Fertilizer application	δ_1	-0.113	0.028	-4.10***
Improved varieties of rice	δ_2	0.136	0.026	5.23***
Irrigation	δ_3	-0.102	0.037	-2.79***
Trees planting	δ_4	-0.057	0.038	-1.49
Integrated pest management	δ_5	-0.023	0.033	-0.71
Crop diversification	δ_6	-0.023	0.031	-0.76
Multiple planting dates	δ_7	-0.114	0.036	-3.17***
Multiple plots	δ_8	0.055	0.023	2.37**
Diagnostic Parameters				
Sigma squared	σ^2	0 .272	0.028	12.40***

Gamma	γ	0.920	0.041	4.33***
Log likelihood		-294.558		

Source: Field Survey Data, 2025
****** P<0.01, ** P<0.05, * P<0.1***

Maximum Likelihood Estimate of cost frontier are presented on Table 5. Depreciation on assets (0.028), rent on land (0.234), cost of seeds (0.508), cost of inorganic fertilizer (0.035), cost of organic fertilizer (0.011), cost of pre-emergence herbicides (0.114), cost of post-emergence herbicides (0.018) and wages of hired labour (0.009) had positive and significant coefficients. This implies that a 1% increase in these costs will increase total cost of production by the respective elasticities. Input costs are major drivers of total production cost. Effective management of these costs through climate adaptation strategies that reduce input waste can improve cost efficiency. Effective management of these costs through climate change adaptation strategies that reduce input waste can improve cost efficiency. Gamma ($\gamma = 0.012$) was significant at $P<0.05$ and sigma squared ($\sigma^2 = 0.022$) at $P<0.01$. Gamma of 0.012 indicates that only 1.0% of deviation from the cost frontier was due to cost inefficiency, while 99% was random noise. This suggests that cost inefficiency is low among rice farmers and variation in total cost is mainly explained by input prices and quantities. However, the significance of climate change adaptation strategies in the inefficiency model shows that climate change adaptation strategies still have measurable effects on cost efficiency.

Irrigation

The coefficient of irrigation (-0.081) in the cost inefficiency model was negative and significant at $P<0.01$. This indicates that irrigation reduce cost inefficiency. Proper irrigation prevents losses from poor germination, weed proliferation and crop failure, which would otherwise require expensive corrective actions. By stabilizing yields, irrigation reduces unit cost of production and improves cost efficiency. It is one of the few adaptation strategies that simultaneously improves technical and cost efficiency.

Trees Planting

Furthermore, the coefficient of trees planting (0.028) was positive and significant at $P<0.01$. This means that higher intensity of trees planting increases cost inefficiency. Trees planting adds costs related to tree establishment, land allocation and management complexity in the short run. These costs raise total cost of production per unit of rice output, reducing cost efficiency. However, the long-term benefits of soil fertility improvement, erosion control and diversified income are not captured in single-season cost efficiency. From a sustainability perspective, trees planting remains valuable despite short-term cost inefficiency.

Table 5: Maximum Likelihood Estimates of the Stochastic Cost Frontier Function

Explanatory Variables	**Parameters**	**Coefficients**	**Standard error**	**T- values**
Constant	β_0	2.398	0.173	13.89***
Rent on land	β_1	0.234	0.013	17.37***
Cost of seeds	β_2	0.508	0.023	22.16***
Wage of hired labour	β_3	0.009	0.004	2.16**
Cost of family labour	β_4	-0.007	0.005	-1.37
Cost of inorganic Fertilizer	β_5	0.035	0.004	9.70***
Cost of organic fertilizer	β_6	0.011	0.004	2.92***
Cost of pre-emergence herbicide	β_7	0.114	0.012	9.13***
Cost of post-emergence herbicide	β_8	0.018	0.007	2.74***
Cost of pesticide	β_9	-0.004	0.022	-1.86*
Depreciation on assets	β_{10}	0.028	0.008	3.34***
Inefficiency Effect				
Constant	δ_0	0.139	0.041	3.34***
Fertilizer application	δ_1	0.001	0.007	0.12
Improved varieties of rice	δ_2	0.003	0.006	0.54
Irrigation	δ_3	-0.081	0.015	-5.31***
Trees planting	δ_4	0.028	0.010	2.75***
Integrated pest management	δ_5	-0.024	0.823	-0.03
Crop diversification	δ_6	0.003	0.007	0.36
Multiple planting dates	δ_7	-0.010	0.009	-1.11
Multiple plots	δ_8	.011	.006	1.58
Diagnostic Parameters				
Sigma squared	σ^2	0.022	0.001	79.21***
Gamma	γ	0.012	0.004	2.36**
Log likelihood		-255.609		

Source: Field Survey Data, 2025
***** P<0.01, ** P<0.05, * P<0.1**

CONCLUSION AND RECOMMENDATIONS

Conclusion

The study concludes that rice farmers in Benue State are actively engaged in adapting to climate change. The adoption of climate change adaptation strategies such as fertilizer application, irrigation and multiple planting dates demonstrably contributed to increased efficiency of rice production, indicating their effectiveness in optimizing resource use and output. Conversely, while improved rice varieties, multiple plots and trees planting are widely adopted, the current application appears to be associated with a decrease in overall production efficiency. Also, the farmers operate with moderate levels of technical, allocative and economic efficiency, indicating room for improvement.

Recommendations

Based on the findings of the study, the following recommendations are made to enhance climate change adaptation and improve the efficiency of rice production in Benue State:

i. There is need for government to enhance the capacity of agricultural extension agents to provide targeted advisory services, training and demonstrations focused on climate-resilient practices that have proven to increase efficiency, such as effective fertilizer application, improved water irrigation practices and optimal multiple planting date strategies.

ii. Farmers should be encouraged and supported by government through extension services to the adopt and optimize fertilizer application, irrigation and multiple planting date strategies, which demonstrated positive impacts on efficiency.

iii. Researchers should further explore why improved rice varieties and multiple plots currently show a negative efficiency relationship to guide their optimal use.

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