

Beyond The Rains: Impact of Irrigation on Production Efficiency of Small-Scale Rice Farmers in Benue State, Nigeria

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ABSTRACT

Food is essential to the human body's metabolism, yet remains scarce due to climate variability that manifests as floods, rising temperatures, drought, intermittent rainfall, and water stress. This calls for effective resilience strategies, such as irrigation, to enhance food production in Benue State, which is strategic to Nigeria's food self-sufficiency. Against this background, with limited empirical attention on the impact of irrigation on rice production, a common staple food in Benue State, this study was motivated. The survey research design was relied upon with primary data collected through structured questionnaires administered to 150 small-scale rice farmers in the state. Data collected were analyzed using descriptive statistics and the stochastic frontier model, with the paired-samples t-test as a robustness check. Results indicated a positive but insignificant impact of irrigation ($\beta = 4.44\%$; $p = 0.559$) on rice yield in Benue State, as rice irrigated farmers in the state operate at 50.28% level of efficiency, leaving about 49.72% room for improvement when inefficiency variables such as experience, education, and access to credit are improved upon. For robustness check, the paired sample t-test showed a significant negative mean difference between output before and output under irrigation, implying that output under irrigation remains higher than rainfed rice production, but the overall impact of irrigation is insignificantly positive due to technical inefficiency. In line with the results, the study recommended that IFAD and the state government should intensify efforts on extension services and farmers' training on global best practices to enhance the experience level of farmers and rice yield under irrigation in the state.

Keywords: Irrigation, Rice Production, Production Efficiency, Stochastic Frontier Model

INTRODUCTION

Food crops have become highly susceptible to climate stress, particularly water scarcity (Geo et al., 2024), in contemporary times. One of the most affected food crops is rice (*Oryza sativa L.*), a staple food most consumed in Nigeria (Ogunwande, 2023). Given its importance to household food security in Nigeria, about 218,541,291 tons of rice are cultivated in the country per annum, making Nigeria the largest producer in Africa and the sixth globally. Regardless, Nigeria still relies heavily on rice imports and smuggling (Ugalahi et al., 2016) through porous land borders to bridge the demand-supply gap, underscoring the need for effective irrigation systems to deepen food availability and stability in the country. The relevance of irrigation to rice production (Ai et al., 2024) is that sufficient water is required, especially during the grain-filling period (Dong et al., 2011), to optimize rice yield. Although rice production is most crucial in Nigeria, its high-water demand (Muscolo et al., 2015), which may exacerbate water stress for future generations, calls for sustainable irrigation practices and practical measures such as water footprint and virtual water trade utilized in Israel, Spain, Mexico, and Turkey (Adamo et al., 2023; Martinez-Alvarez et al., 2016).

In places like Benue State, where the temperature rises to 37°C with falling mean rainfall up to 1200 mm (Idoko et al., 2023), and recurrent flooding, manifesting in crop loss in Agatu, Makurdi, Guma, and Katsina-Ala LGAs, irrigation, primarily in the dry season, becomes a valuable alternative to meet the zero-hunger target by 2030 in line with SDG two. Yet, irrigation in the state and across Nigeria is mainly small-scale, with traditional practices such as basin irrigation, hand watering, and tube wells, characterized by excessive water withdrawal and salinization. Nigeria has 12 River Basin Development Authorities (RBDA) with about 37.46 billion cubic meters

(BCM) of water to enhance irrigation, but only 11.66 BCM is utilized for irrigation due to an undue reliance on rainfed agriculture, which is highly susceptible to climate change (USAID, ND). Rain-fed agriculture is not only predominant in Benue State, Nigeria but constitute about 97% of staple food production in Africa (Ogunwande, 2023), resulting in low cereal yield of less than 1.5 ton/ha instead of its potential of >5tons/ha (Bidzakin et al., 2018) and food insecurity among 868 million people in the continent in 2022 (Omar, 2024). This, of course, may also be due to climate variability, poor resilience strategies, and limited agricultural funding despite the 10% benchmark proposed by the Maputo and Malabo declarations of 2003 and 2014, respectively, to enhance production and food security in Africa (AU, 2014).

Benue is an agrarian state with over 80% of its population relying on farming for livelihood (IFRC, 2025), making it the Food Basket of the Nation. Agricultural funding, however, remained low in the state. Despite its 33,955 square kilometers of landmass (Benue ACREsAL, nd), which is primarily suitable for irrigation, and the availability of sufficient water outlets such as the River Benue, the Katsina-Ala River, the Mua River, and other tributaries, irrigation remains at a small scale. In addition to adequate water outlets suitable for irrigation (Nwakonobi & Gwaza, 2012), about 1,225 tube wells were constructed during the FADAMA I program to deepen irrigation farming in the State. However, Moro and Onoja (2006) observed that tube wells remained underutilized in crop production in Agatu LGA, despite the 25,000-ha floodplain that supports irrigation farming.

The transmission effect of poor irrigation practices with undue reliance on rainfed agriculture is rising food inflation up to 23% in September 2023, excessive dependence on food imports, and food insecurity among 30 million people in 2024 in Nigeria, while Benue State has about 50% of its population experiencing malnutrition (Shiaondo, 2024). This suggests a paradigm shift towards irrigation, which accounts for 40% of global food production (FAO, 2018) and 61% of global rice production (Ai & Hanasaki, 2023). While irrigation remains essential, a paradigm shift towards innovative methods, such as drip irrigation, is paramount. This is because traditional irrigation practices characterized by waterlogging, water depletion, toxicity, unproductive water outflows, seepage, percolation, and evaporation (Wudil et al., 2023) may impede effective food yield. Suriyan et al. (2010) underscored the importance of innovative irrigation techniques by showing that drip irrigation delivers 50% of the water directly to crops, resulting in a 29% higher rice yield than conventional irrigation methods.

Beyond irrigation, Aigner, Lovell and Schmidt (1977) offered a compelling approach to production efficiency in what is termed the Stochastic Frontier Model (SFM), an improvement over the Cobb-Douglas production function. Through its composite error term, the SFM suggests that deviations from the deterministic output in the production process are not solely random but due to technical inefficiencies. In other words, small-scale rice farmers in Benue State can operate at the maximum or potential output by improving inefficiency variables such as experience level, education, and access to credit as production transcends the traditional Cobb-Douglas input factors of capital and labor. Bhehibi et al. (2017) applied the SFM in Tunisia, demonstrating that citrus farmers can deepen production by leveraging inefficiency variables. Accordingly, Donkoh, Ayambila, and Abdulai (2013) assessed the technical efficiency of rice production at the Tono Irrigation Scheme in Northern Ghana, while Seidu, Sarpong, and Al-Hassan (2004) revealed that small-scale rice farmers operate 34% below the deterministic output in the Upper East Region of Ghana. In Benue State, however, research embracing the SFM and its influence on rice production under irrigation remained inadequate. This suggests a nuanced empirical investigation, thus, the need for this study, which assessed the impact of irrigation on the production efficiency of rice farmers in Benue State, Nigeria.

LITERATURE REVIEW

Irrigation is the process of abstraction of water from surface and sub-surface sources, with application as supplemental in rain-fed farming or as a full water supply in arid areas or during dry-season farming, to enhance food yield and security. Earlier irrigation practice dates back to 2,000 -5,000 BCE (Before the Christian Era) (Bassa, 2006), of which, the canal method in Iraq, basin irrigation along the Nile River in ancient Egypt, the Qanats utilized in ancient Persia, the noira method in North Africa, and the reservoir method to irrigate paddy fields in Sri Lanka are typical examples (Thomas & Fulkerson, 2021; Flannery, 2017; Silva, 1988). As time progressed, with theoretical postulations such as the hydraulic society theory (Wittfogel, 1957) that explored the

benefits of irrigation to economic structures, particularly in ancient civilizations, irrigation began to gain global traction. However, the methods utilized were essentially water-demanding, which necessitated theoretical approaches such as agroecology theory and integrated hydrologic-agronomic-economic model that called for sustainable and innovative agricultural practices that are more respectful of the environment and its ecological specificities (YouMatter, 2019). This has led to improved irrigation practices such as drip irrigation, hydroponics, desalination, and wastewater recycling that have contributed to about 40% of global food production.

In view of the growing benefits of irrigation for food production and efficiency, attempts have been made to infer the causal relationship between irrigation and rice production. In China, Geo et al. (2024) conducted an experiment between June and October at Jiangsu Runguo Agricultural Development Co., Ltd., using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) entropy-weight method. Four irrigation treatments such as the control of local conventional irrigation [CK, without water stress], mild water-saving treatment [W1, 20% more water saved than CK], moderate water-saving treatment [W2, 30% more water saved than CK], and severe water-saving treatment [W3, 40% more water saved than CK] were used for the study. The result indicated that the W1 20% saving method is most suitable, as it significantly increases rice yield and quality compared to CK. Similarly, Merza et al. (2023) experimented in 2020 at the Directorate of Agriculture in the Al-Hashimiya area, Hilla City, Iraq. The study prioritized the subsurface drip irrigation system (SDIS) and flood irrigation system (FIS). It was found that FIS and SDIS both positively impacted rice productivity in Iraq. However, the sub-surface system contributes a higher yield due to its adequate water supply to enhance rice yield and water sustainability.

Similarly, Zhang, Rasool, Wang, Guo, Zhao, Zhang, Wei & Xia (2024) evaluated the effect of irrigation and cultivation modes on growth, physiology, rice yield parameters, and water footprints in Jiangsu, China. The method involves four treatments, such as transplanted rice with frequent shallow irrigation (T-FSI), transplanted rice with rain-catching and controlled irrigation (T-RCCI), direct-seeded rice with frequent shallow irrigation (D-FSI), and direct-seeded rice with rain-catching and controlled irrigation (D-RCCI), employed in a randomized complete block design with three replications. The study found that the D-RCCI treatment significantly improved growth and physiological parameters, making it optimal for rice cultivation in Jiangsu province due to its positive impact on yield, water savings, and environmental benefits.

In northcentral Nigeria, Ogunwande (2023) assessed the inextricably linked relationship between rice production and irrigation using primary data collected from 196 rice farmers through structured questionnaires and interviews. Analytical techniques, including descriptive statistics, multinomial logit, and switching regression, were used to analyze field information collected for the study. Results from the study indicated a significant relationship between the monthly quantity of water to rice farms and the quantity of rice output realized in north-central Nigeria. To address the rising supply-demand gap in rice in Nigeria, the study calls for irrigation farmers to shift towards high-yielding, early-maturing, and drought-resistant rice varieties to optimize yield and profitability in Northcentral Nigeria. Tuan, Lee, and Thach (2020) in Vietnam relied on the quasi-experimental method and the difference in difference (DID) method with household panel data from the Vietnam Access to Resources Household Survey (VARHS) in 2016 and 2018 to estimate the effects of irrigation system improvement on the rice productivity of farmers in Vietnam. The study found a significant 4.5% increase in rice productivity due to improvements in the irrigation system, and a substantial increase in household income per capita of nearly 115%.

Ai et al. (2023) systematically quantified the contribution of irrigation to the national production of three major crops (maize, wheat, and rice) in 20 major producing countries under irrigation and rainfed conditions using a global hydrological model with an enhanced crop yield simulation function driven by the latest meteorological data from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP). Results indicated that irrigation accounts for 40% of maize yield in Egypt, Italy, China, and France, more than 40% of wheat production in Egypt, Pakistan, India, China, and Iran, while in China and Egypt, irrigation accounts for more than 50% for all three crops. The study concluded that irrigation is crucial to achieving food self-sufficiency and food security, underscoring the need for efficient irrigation to address global food insecurity. Wudil, Ali, Usman, Radulescu, Sass, Prus and Musa (2023) investigated the effects of inequitable access to irrigation on paddy yield among rice farmers in the Kano River Irrigation Project. Primary data were collected from 225 farming households spanning

January to June 2021, and the Kruskal-Wallis's test, Tukey-Kramer post hoc test, physical water productivity, and Logit model were used for data analysis. The results indicated that upstream farmers had three times higher predicted probability of higher yields than downstream farmers because better access to irrigation water could increase yields by 3.3-fold. Drawing on the results, the study calls for adequate sensitization of irrigation farmers on water efficiency to enhance equitable water distribution between upstream and downstream farmers and to optimize paddy output in the Kano irrigation project.

Ugalahi, Adeoye and Agbonlahor (2016) reviewed irrigation potentials and rice self-sufficiency in Nigeria. The review showed that, despite abundant arable land suitable for irrigation and sufficient water resources in Nigeria, the supply-demand gap for rice continues to escalate due to an undue emphasis on rain-fed agriculture and underutilization of irrigation potential to deepen rice yields. While the burgeoning population has contributed to increasing demand for rice in the country, other challenges, such as climatic variations, high inputs and labor costs, limited access to capital, high operating costs, and institutional challenges, have undermined adequate irrigation with rising supply-demand gaps and an uptick in the price of rice in the country. It was recommended, in line with the results, that the government, as a matter of urgency, support farmers with relevant irrigation inputs and effective credit access to enhance the efficiency of rice production in the country.

Similarly, Suleiman, Yunusa and Emigilati (2020) examined the impact of the Tungan-Kawo Irrigation Scheme on rice production in Wushishi Local Government Area, Niger State, Nigeria. A structured questionnaire was used to collect field data from a sample of 400, determined using the Taro Yamane sampling formula, while data analysis was conducted using descriptive statistics, Pearson's product-moment correlation, and regression analysis. A moderate and positive correlation between irrigation in the Tungan-Kawo Scheme and rice yield was established. Sustainable management of irrigation infrastructures with industrialized processing mills, and patronage of domestic rice are suggested to deepen irrigation and food self-sufficiency in the country. Bidzakin, Fialor, Awunyo-Vitor and Yahaya (2018) examined the impact of irrigation ecology on rice production efficiency in Ghana by using cross-sectional data from 350 small-scale rice farmers (both rain-fed and irrigated). The stochastic frontier model and the endogenous treatment effect regression model formed the analytical techniques for the study. The study found that irrigation farmers are technically more efficient in rice production than rain-fed farmers, and that, as a result, farmers should be encouraged to produce more under irrigation to increase yields and profits in Ghana.

Also in Ghana, Owusu, Nyantakyi, and Borkloe (2013) assessed the performance of rice irrigation across irrigation schemes in the country by reviewing the extant literature and GIDA periodicals and conducting key informant interviews for field data collection. The study indicated that the three types of rice production, such as lowland rain-fed, upland rain-fed, and irrigated rice cultivation, accounted for 78%, 6%, and 16%, respectively, of domestic rice production. This accounts for 30% of the annual demand of 600,000 metric tons, suggesting a wider demand-supply gap for rice in Ghana. The gap results from increasing attacks of birds and rodents on rice farms, climate variability, limited farm equipment, low technology, low soil fertility, and energy constraints that have impeded rice self-sufficiency and food security in Ghana. The study suggested that the government build a planned, adequate local production capacity rather than imposing an inadequate tariff on rice imports to address the country's supply bottlenecks.

Nonvide in 2017 evaluated the effect of irrigation adoption on rice yield in the municipality of Malanville, Benin. The data collected were analyzed using the Heckman selectivity model, probit regression, and propensity score matching for robustness checks. From the results, the factors influencing irrigation adoption included farmers' age, gender, extension services, access to credit, market participation, distance to irrigation scheme, use of tractor, and fertilizer, while the results from Heckman's second-stage estimates showed a significant 57% improvement in rice yield due to irrigation adoption in Benin. Accordingly, the robustness checks indicated a significant increase in rice yield of 55%-60% due to irrigation adoption. The study recommended the need for complementary services, in addition to irrigation adoption, to deepen rice yields in Benin.

Abdul-Ganiyu, Agyare, Kyei-Baffour and Dogbe (2015) also conducted two experiments using a randomized complete block design with four replications at On-Station (SARI) and On-Farm (Bontanga Irrigation Scheme) in 2012/2013 and 2013/2014 dry seasons to assess the effects of irrigation regimes on irrigated rice production in the Northern Region of Ghana. The study revealed that maintaining saturated soil throughout the growing

season and meeting 10ETc irrigation requirements are more important for increasing rice yield than rice flooding to promote growth. This is because flooding often results in adverse effects such as toxicity, salinization, and reduced yields. Dhehibi, Ibrahim, El-Shahat, and Hassan (2016) looked at the influence of irrigation on crops such as cotton, berseem, maize, rice, and wheat by collecting farm-level data from 152 producers in South El Husainia Plain, Egypt, spanning from 2011-2012. For estimation, the Cobb-Douglas production function and isoquant curves were used, from which the study revealed a low marginal productivity of irrigation water for the crops, especially cotton. The implication is that irrigation farmers over the years have been applying excess water to crop farms, suggesting a paradigm shift in sustainable water use by applying the correct quantity of water for crops to enhance yield and water sustainability in Egypt.

METHODOLOGY

This study relied on a survey research design due to its relevance in gathering field information using observation, questionnaire, and interviews from a pool of participants to enable generalization in a cost-effective and timely manner, unlike an experimental design that requires a controlled environment or ethnography design that requires a longitudinal presence and interaction of the researcher with the elements and the environment. Benue State forms the study area. It lies between Longitude 7° 47' and 10° 0' East, and Latitude 6° 25' and 8° 8' North. The state is bounded to the North by Nasarawa State, to the West by Kogi State, to the East by Taraba State and the Cameroun Republic, and to the South by Cross River and Enugu States. It has a total landmass of 33,955 km² with a mean rainfall of 1200mm to 1500mm and a temperature of 16°C to 37°C (Idoko et al., 2023).

In terms of water capacity, the River Benue, the River Katsina-Ala, the Mau River, and other water tributaries across the state made the state suitable for irrigation farming. However, irrigation remains largely small-scale, with practices such as basin and tube well irrigation in Agatu LGA, rainwater harvesting through the reservoir method in Ogbadibo LGA, and hand watering in Makurdi LGA. Additionally, there are irrigation sites in Makurdi, Gwer-West, Katsina-Ala, Jato Aka, Otukpo, and Agatu LGAs (Igidi, 2024), but Agatu, Katsina-Ala, and Guma LGAs were purposively selected for this study. Across the three LGAs, 50 farmers were randomly selected using simple random sampling (balloting without replacement) for questionnaire administration to elicit relevant data on inputs, outputs, and inefficiency variables, such as experience level, educational qualifications, and access to credit. The reason for fewer respondents selected is due to the limited number of rice irrigated farmers in the state. Data collected were analyzed using descriptive statistics, the stochastic frontier model, and the paired sample t-test for robustness check.

Model Specification

A stochastic frontier model was adopted for this study because it improves the traditional Cobb-Douglas production function. The model was developed by Aigner et al. (1977) and elaborated upon by Meeusen and Van de Broeck (1977). It emphasized the composite error, implying that a farmer's inability to operate on the deterministic frontier is not only a result of random shocks but also technical inefficiency in the production process. The model follows;

$$Y_i = f(X_i, \beta) \cdot e^{v_i - u_i} \quad 1.1$$

Where

Y_i = Observed output of i-th farmer

X_i = Vector of inputs (labor and capital) of i.th farmers.

$f(X_i, \beta)$ = maximum output that can be produced by combining labor and capital

e is the composite error expressed as $v_i - u_i$ 1.2

v_i = random error term/ noise or random shocks

u_i = inefficiency term (how far the farmer is from the deterministic frontier $[f(X_i, \beta)]$)

The random shock which follows a normal distribution with constant variance is represented as $v_i \sim N(0, \sigma_u^2)$ 1.3

While the inefficiency term with a half-normal or truncated distribution is shown as

$u_i \sim N^+(0, \sigma_u^2)$ 1.4

The model hinges on the assumption that the inefficiency error and the random error are independent. While the random error follows a normal distribution, the inefficiency effect follows a half-normal distribution or exponential distribution (Guo, Li, McAleer & Wong, 2018; Arsad et al., 2022).

The model specified by Bhehibi et al. (2017) to assess irrigation water efficiency and citrus production in Tunisia was adopted for this study. The model follows; $Y_i = f(X_i, W_i; a) \exp(\varepsilon = v_i - u_i)$ 1.5

Where

W = irrigation water.

The inefficiency term was specified as;

$u_i = g(Z_i; \delta) + w_i$ 1.6

Where

Z = vector of variables used to explain efficiency differentials among farmers

δ = vector of parameters to be estimated (including an intercept term)

w_i = id random variable with zero mean and variance defined by the truncation of the normal distribution such that $w_i \geq -[g(z_i; \delta)]$ 1.7

Equation 1.5 was modified for this study by adding other costs (OTC) to existing input factors (labor and capital), while changing Y_i (citrus output under irrigation) to rice yield under irrigation (RiceYLD). Irrigation (w) remains unchanged. The current production function follows;

$RiceYLD = a + \beta_1 LBR_i + \beta_2 CPT_i + \beta_3 OTC_i + \beta_3 W_i + e_i$ 1.8

Where

RiceYLD = Rice yield (5 tons/ha when resources are fully efficient)

LBR = cost of labor (in Naira)

CPT = cost of capital (in Naira)

OTC = other costs such as fertilizer, seedling, and herbicide (in Naira)

W = Irrigation (small-scale irrigation practices in the state)

To account for technical inefficiency (inefficiency term/error) in the production process, equation 1.6 was modified as;

$TE_i = \lambda + \delta_1 EDU_i + \delta_2 FEX_i + \delta_3 ATC_i$ 1.9

Where

TE = Technical Efficiency

EDU = Farmer’s level of education

FEX = Farmer’s experience

ATC = Access to credit

$\delta_1 - \delta_3$ = parameters to be estimated

The idea is to first and foremost estimate equation 1.8 to infer whether the Cobb-Douglas production function or the SFM is most suitable for the data set. If the absolute Lambda value from equation 1.8 is greater than or equal to one, then the decision is to estimate the SFM that incorporates both equations 1.8 and 1.9 as shown below.

$$\text{RiceYLD} = a + \beta_1\text{LBR}_i + \beta_2\text{CPT}_i + \beta_3\text{OTC}_i + \beta_3\text{W}_i + \beta_4\text{EDU}_i + \beta_5\text{FEX}_i + \beta_6\text{ATC}_i + e_i \quad \dots \quad 1.10$$

Equation 1.10 encompasses the input variables (labor, capital, other costs, and irrigation methods) with inefficiency variables (education, experience level, and access to credit) as efficiency level in rice production (the potential 5tons/ha in SSA) does not dependent only on input variables but experience level of rice farmers, level of education, and access to credit in the state.

RESULTS AND DISCUSSION OF FINDINGS

From the 150 questionnaires administered, 148 responses, which represent 98.7% of the questionnaires, were returned. Data cleaning excluded two questionnaires, making 146 questionnaires (97.3%) eligible for analysis.

Table 1.1: Attributes of Respondents

| Gender | Freq. | Percentage |
|----------------------------|--------------|-------------------|
| Male | 113 | 77.4 |
| Female | 33 | 22.6 |
| Total | 146 | 1000 |
| Forms of Irrigation | Freq. | Percentage |
| Basin | 71 | 48.6 |
| Hand Watering | 9 | 6.2 |
| Tube well | 55 | 37.7 |
| Others | 11 | 7.5 |
| Total | 146 | 1000 |
| Rice yield/ha | Freq. | Percentage |
| Less than 1ton/ha | 56 | 38.4 |
| 1-2.5tons/ha | 80 | 54.8 |
| 2.6-5 tons/ha | 10 | 6.8 |

| | | |
|----------------|------------|-------------|
| Above 5tons/ha | 0 | 0 |
| Total | 146 | 1000 |

Source: Author’s Computation using STATA 15 (2025)

According to Table 1.1, rice irrigation farming is dominated by males (n = 113; 77.4%), with basin irrigation the most practiced irrigation method (n = 71; 48.6%) in Benue State. Osaulu and Ogbemhu (2019) also identified basin irrigation as the dominant irrigation practice for deepening crop production in Northern Nigeria. Despite its importance, excessive water withdrawal coupled with salinization has persistently undermined crop yields under basin irrigation. This could be the reason for a relatively low yield (1-2.5tons/ha) in the study, as an average rice irrigation farmer in the state produces below the 5 tons/ha cereal potential in SSA. This aligns with the findings of Bidzakin et al. (2018), who reported that cereal yields in most parts of SSA are below 1.5 t/ha.

Table 1.2: Inefficiency Test Result (Equation 1.8)

| Variables | Coef. | Std. Err. | Z | P-value | [95% Conf. Interval] |
|---------------|-----------|-----------|-------|---------|----------------------|
| LBR | -.1169748 | .0933994 | -1.25 | 0.210 | -.3000342 .0660846 |
| CPT | -.3005896 | .0878933 | -3.42 | 0.001 | -.4728574 -.1283218 |
| OTC | -.0286277 | .080863 | -0.35 | 0.723 | -.1871163 .1298608 |
| W | .045509 | .076969 | 0.59 | 0.554 | -.1053474 .1963654 |
| _cons | 4.550704 | .4330194 | 10.51 | 0.000 | 3.702002 .1963654 |
| /lnsig2v | -1.732881 | .3506385 | -4.94 | 0.000 | -2.42012 -1.045642 |
| /lnsig2u | .239922 | .2233449 | 1.07 | 0.283 | -.1978259 .6776699 |
| sigma_v | .4204454 | .0737122 | | | .2981794 .5928456 |
| sigma_u | 1.127453 | .1259054 | | | .9058215 1.403312 |
| sigma2 | 1.447924 | .2509849 | | | .9560029 1.939846 |
| Lambda | 2.681568 | .1805504 | | | 2.327695 3.03544 |
| Number of obs | = | 146 | | | |
| Wald chi2 (4) | = | 13.95 | | | |
| Prob > chi2 | = | 0.0075 | | | |

Source: Author’s Computation using STATA 15 (2025)

It suffices that the traditional Cobb-Douglas production function assumes a fully efficient production process. Any deviation from this efficiency level is due to random shocks. However, the result in Table 1.2 invalidates this assumption, given that the absolute Lambda (2.681568) is greater than one (1). This suggests that deviations from the potential output among small-scale rice irrigation farmers in Benue State are not limited to random shocks but technical inefficiencies in the production process. Because deviations in the model are not entirely random, the result in Table 1.2 suggests the need to collapse the models (equations 1.8 and 1.9) into a Stochastic Frontier Model (equation 1.10) to account for actual deviations from the deterministic output owing to technical inefficiency among irrigated rice farmers in the state.

Table 1.3: Stochastic Frontier Model Result (Equation 1.10)

| Variables | Coef. | Std. Err. | Z | P-value | [95% Conf. | Interval] |
|---------------|-----------|-----------|-------|---------|------------|-----------|
| LBR | -.1283539 | .0941116 | -1.36 | 0.173 | -.3128093 | .0561016 |
| CPT | -.2692884 | .0864087 | -3.12 | 0.002 | -.4386464 | -.0999304 |
| OTC | -.017 | .0795668 | -0.21 | 0.831 | -.1729481 | .138948 |
| W | .0444531 | .0760789 | 0.58 | 0.559 | -.1046588 | .193565 |
| _cons | 4.468701 | .4305204 | 10.38 | 0.000 | 3.624897 | 5.312506 |
| Insg2v_cons | -1.732758 | .336441 | -5.15 | 0.000 | -2.392171 | -1.073346 |
| Insig2u EDU | -.2051772 | .2599833 | -0.79 | 0.430 | -.7147351 | .3043807 |
| FEX | .0525903 | .2744032 | 0.19 | 0.848 | -.48523 | .5904106 |
| ATC | .3959599 | .2287295 | 1.73 | 0.083 | -.0523416 | .8442614 |
| _cons | -.486595 | 1.012445 | -0.48 | 0.631 | -2.470951 | 1.497761 |
| sigma_v | .4204712 | .0707319 | | | .3023756 | .5846902 |
| Number of obs | = | 146 | | | | |
| Wald chi2(4) | = | 12.13 | | | | |
| Prob > chi2 | = | 0.0164 | | | | |

Source: Author’s Computation using STATA 15 (2025)

Drawing from the result in Table 1.3, input factors LBR ($\beta = -12.83\%$; $s.e = .0941116$; $p = 0.173$), CPT ($\beta = -.26.92\%$; $s.e = .0864087$; $p = 0.002$), OTC ($\beta = -.1.7\%$; $s.e = .0795668$; $p = 0.831$) exerted a negative impact on rice yield among irrigation farmers, with CPT exerting a significant negative effect. This lies in the output-oriented approach, which suggests increasing output without necessarily increasing the input factors. Output-oriented production focusses on enhancing efficiency level and productivity by keeping input factors stable or constant. Farmers under this system prioritize efficiency by improving experience level, education, and access to credit without necessarily improving labor and capital. While this remains important, the inverse relationship between input factors and RiceYLD is attributed largely to the rising security challenges, primarily farmer-herder conflict often manifesting in hinterlands and around water points suitable for irrigation farming in the state. The implication is that aggressive investment in input factors in the face of rising insecurity might lead to poor returns on investment and lower rice yield under irrigation in the state.

The result of irrigation (W) with a positive coefficient ($\beta = 4.44\%$; $s.e = .0760789$; $p = 0.559$), however, indicated a non-significant positive impact on rice yield among rice irrigation farmers in Benue State. This means that a percentage increase in irrigation practices will increase rice yield by 4.44% in the state. While the impact is positive, it remains statistically insignificant as output remains marginally below the deterministic level owing to technical inefficiency in the production process. Put differently, irrigation impacts positively but insignificantly on rice yield among small-scale rice irrigation farmers in the state, suggesting the need for improvement in technical efficiency to maximize the benefits of irrigation in rice production in Benue State, Nigeria.

In terms of inefficiency variables, farmers’ experience level and access to credit impacted positively on rice yield, while education level had a no significant negative impact on rice yield. The reason for an inverse relationship between EDU and RiceYLD could be that educated people often favor white-collar jobs over small-scale irrigation practices in the state. This means that when education level improves in the state, farmers will shift their labor services to formal sector rather than engaging in small-scale irrigation farming. On the other hand, an increase in experience level and access to credit will contribute positively to rice yield in the state.

Overall, the Chi-square result (12.13; $p = 0.0164$) indicates a fit model for the data set, as irrigation has a positive but insignificant impact on rice yield of small-scale farmers in the state, because a percentage increase in irrigation practices will improve rice yield positively (but insignificantly) by 4.44%. In a nutshell, irrigation enhances rice production positively, although the impact remains insignificant in the state. This result confirms the earlier findings of Merza et al. (2023), Ogunwande (2023), and Suleiman et al. (2020), which showed that irrigation positively impacts rice production.

Table 1.4: Technical Efficiency Result

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|----------|-----|--------|-----------|----------|----------|
| Tef | 146 | .50286 | .213013 | .0983212 | .8539113 |

Source: Author’s Computation using STATA 15 (2025)

In terms of efficiency level, Table 1.4 revealed that an average irrigation farmer in Benue State operates at 50.28% efficiency level, leaving a sizeable 49.72% room for improvement. Impliedly, irrigation farmers in the state can optimize yield or operate at the deterministic output by holding input factors (labor and capital) constant, while improving inefficiency variables such as experience level, access to credit, and education. In earlier studies, Seidu, Sarpong and Al-Hassan (2004) revealed that small-scale rice farmers in the Upper East Region, Ghana operate at an efficiency level of 66%, leaving about 34% room for improvement to optimize the potential output of >5 tons/ha in SSA. In a nutshell, the result in Table 1.4 revealed that rice irrigated farmers in the state can maximize output and efficiency of production by improving inefficiency variables, majorly experience level and access to credit.

Table 1.5: Robustness Check Using Paired Sample T-test

| Variable | Obs | Mean | Std. Err. | Std. Dev. | [95% Conf. Interval] |
|--------------------|-----|-----------|-----------|-----------|----------------------|
| YIELDB4 | 146 | 1.452055 | .0496394 | .5997953 | 1.353945 1.550165 |
| YIELDu~G | 146 | 2.657534 | .0405889 | .4904376 | 2.577312 2.737757 |
| Diff | 146 | -1.205479 | .0606358 | .7326646 | -1.325324 -1.085635 |
| t | = | -18.8556 | | | |
| Degrees of freedom | = | 145 | | | |
| P-value | = | 0.0000 | | | |

Source: Author’s Computation using STATA 15 (2025)

From Table 1.5, the paired sample t-test results showed that the mean rice yield before irrigation ($M = 1.452055$) and the mean yield during irrigation ($M = 2.657534$) are statistically different from zero ($P = 0.0000$). Accordingly, the resultant mean difference (-1.205479) is negative, implying that rice yield under irrigation is statistically different from output before irrigation. What the result means is that irrigation as a climate resilient strategy increases rice yield significantly more than rain-fed rice production. However, the overall rice yield

under irrigation in the state remains insignificantly positive ($\beta = 4.44\%$; $s.e = .0760789$; $p = 0.559$) due to technical inefficiency in the production process. This suggests that while rice yield under irrigation remains significantly higher than rain-fed yield, the overall rice output under irrigation is positive but insignificant because of limited experience level and inadequate access to credit by rice irrigated farmers in the state. This result aligns with the result of Nonvide (2017) that irrigation improves rice yield positively by 57% in the municipality of Malanville, Benin. Similarly, Bidzakin et al. (2018) found a significant improvement of rice yield under irrigation over rain-fed agriculture, suggesting irrigation as a resilience measure to enhance food productivity and food security in the face of rising climate change.

CONCLUSION AND RECOMMENDATIONS

The results from this study revealed a positive but insignificant impact of irrigation on rice yield among small-scale farmers in Benue State, Nigeria, as a percentage increase in rice farming under irrigation improves yield by 4.44%. This impact remains statistically insignificant because of technical inefficiency in the production process, as small-scale irrigated rice farmers are characterized by limited experience with poor access to credit, which undermines efficiency of production in the state. Also, rice farmers in the state depend primarily on traditional irrigation practices, such as basin and tube well, with high water demand and low yield due to salinization. Because of this setback, the average 1-2.5 tons/ha among irrigated rice farmers in the study falls significantly below the potential 5tons/ha yield in SSA. Regardless, rice yield under irrigation is considerably higher than rice production under rain-fed agriculture in the state because of the debilitating impact of climate variability, such as flooding, intermittent rainfall, and rising temperatures, which are most frequent under rain-fed agriculture. This makes irrigation a suitable climate change resilient strategy to achieve the goal two of SDG in Benue State, Nigeria.

As rice farmers shift towards climate-resilient rice production presented by irrigation in the state, there is an urgent need to embrace approaches such as drip irrigation, hydroponics, wastewater recycling, and rainwater harvesting that are more environmentally friendly to achieve a win-win situation of improved rice yields and water sustainability in the state. Additionally, the study recommended that;

- i. Relevant stakeholders, such as International Fund for Agricultural Development (IFAD), should deepen extension services and training of irrigation farmers on global best practices to enhance experience in planting techniques, spacing, manure application, weed control, improved varieties, and input mix to optimize rice yield and food security in the state.
- ii. The negative impact of CPT, LBR, and OTC on rice yield in the study underscore the need for effective security measures by the government to create a suitable and secure environment so that aggressive investment in irrigation can yield the needed returns and the potential 5tons/ha of rice production. This is because irrigation farming, notably basin irrigation, often takes place in the hinterlands, where farmer-herder conflicts are most common in the state. As a result, an uptake in investment by engaging more labor force, larger farm size, more machines, and more farm implements in the face of rising farmer-herder conflict in areas suitable for irrigation might be counterproductive. Thus, the inverse relationship between inputs and irrigation in the study calls for proactive security measures by the state to create an enabling environment for aggressive investment in irrigation in the state.

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APPENDICES

Estimation Result without Inefficiency Term (equation 1.8)

| | | | |
|---|---------------|---|--------|
| Stoc. frontier normal/half-normal model | Number of obs | = | 146 |
| | Wald chi2(4) | = | 13.95 |
| Log likelihood = -169.68728 | Prob > chi2 | = | 0.0075 |

| RiceYLD | Coef. | Std. Err. | z | P> z | [95% Conf. Interval] | |
|----------|-----------|-----------|-------|-------|----------------------|-----------|
| LBR | -.1169748 | .0933994 | -1.25 | 0.210 | -.3000342 | .0660846 |
| CPT | -.3005896 | .0878933 | -3.42 | 0.001 | -.4728574 | -.1283218 |
| OTC | -.0286277 | .080863 | -0.35 | 0.723 | -.1871163 | .1298608 |
| W | .045509 | .076969 | 0.59 | 0.554 | -.1053474 | .1963654 |
| _cons | 4.550704 | .4330194 | 10.51 | 0.000 | 3.702002 | 5.399407 |
| /lnsig2v | -1.732881 | .3506385 | -4.94 | 0.000 | -2.42012 | -1.045642 |
| /lnsig2u | .239922 | .2233449 | 1.07 | 0.283 | -.1978259 | .6776699 |
| sigma_v | .4204454 | .0737122 | | | .2981794 | .5928456 |
| sigma_u | 1.127453 | .1259054 | | | .9058215 | 1.403312 |
| sigma2 | 1.447924 | .2509849 | | | .9560029 | 1.939846 |
| lambda | 2.681568 | .1805504 | | | 2.327695 | 3.03544 |

LR test of sigma_u=0: chibar2(01) = 7.65 Prob >= chibar2 = 0.003

Source: Author's Computation using STATA 15 (2025)

Estimation Result with Inefficiency Term (Equation 1.10)



```
Stoc. frontier normal/half-normal model      Number of obs      =      146
                                             Wald chi2(4)       =      12.13
Log likelihood = -167.30405                  Prob > chi2        =      0.0164
```

| RiceYLD | Coef. | Std. Err. | z | P> z | [95% Conf. Interval] | |
|---------|-----------|-----------|-------|-------|----------------------|-----------|
| RiceYLD | | | | | | |
| LBR | -.1283539 | .0941116 | -1.36 | 0.173 | -.3128093 | .0561016 |
| CPT | -.2692884 | .0864087 | -3.12 | 0.002 | -.4386464 | -.0999304 |
| OTC | -.017 | .0795668 | -0.21 | 0.831 | -.1729481 | .138948 |
| W | .0444531 | .0760789 | 0.58 | 0.559 | -.1046588 | .193565 |
| _cons | 4.468701 | .4305204 | 10.38 | 0.000 | 3.624897 | 5.312506 |
| lnsig2v | | | | | | |
| _cons | -1.732758 | .336441 | -5.15 | 0.000 | -2.392171 | -1.073346 |
| lnsig2u | | | | | | |
| EDU | -.2051772 | .2599833 | -0.79 | 0.430 | -.7147351 | .3043807 |
| FEX | .0525903 | .2744032 | 0.19 | 0.848 | -.48523 | .5904106 |
| ATC | .3959599 | .2287295 | 1.73 | 0.083 | -.0523416 | .8442614 |
| _cons | -.486595 | 1.012445 | -0.48 | 0.631 | -2.470951 | 1.497761 |
| sigma_v | .4204712 | .0707319 | | | .3023756 | .5846902 |

Source: Author's Computation using STATA 15 (2025)

Technical Efficiency Result

```
. predict tef, te

. sum te
```

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|----------|-----|---------|-----------|----------|----------|
| tef | 146 | .502861 | .213013 | .0983212 | .8539113 |

Source: Author's Computation using STATA 15 (2025)

Paired Sample t-test

```
. ttest YIELDB4= YIELDunderIRRIG

Paired t test
```

| Variable | Obs | Mean | Std. Err. | Std. Dev. | [95% Conf. Interval] | |
|----------|-----|-----------|-----------|-----------|----------------------|-----------|
| YIELDB4 | 146 | 1.452055 | .0496394 | .5997953 | 1.353945 | 1.550165 |
| YIELDu~G | 146 | 2.657534 | .0405889 | .4904376 | 2.577312 | 2.737757 |
| diff | 146 | -1.205479 | .0606358 | .7326646 | -1.325324 | -1.085635 |

```
mean(diff) = mean(YIELDB4 - YIELDunderIRRIG)          t = -19.8807
Ho: mean(diff) = 0                                   degrees of freedom = 145

Ha: mean(diff) < 0          Ha: mean(diff) != 0          Ha: mean(diff) > 0
Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000         Pr(T > t) = 1.0000
```

Source: Author's Computation using STATA 15 (2025)