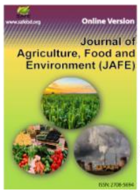
Vol 7 No 1 March 2026 Pages 49-58 e-ISSN 2708-5694

Journal of Agriculture, Food and Environment (JAFE)

Journal Homepage: https://journal.safebd.org/index.php/jafe

https://doi.org/10.47440/JAFE.2026.7106



Research Article

OPEN ACCESS

Irrigation as a Climate Adaptation Strategy: Evidence from Rice Farmers in the Volta Region of Ghana

Kavi FK[1], Lumorh PDD[1], Kavi LC[2*], Akaba S[3]

[1]Department of Agricultural Science Education, University of Education Winneba, Ghana
[2]Department of Mathematics and Information Technology, Concordia University of Edmonton, Canada
[3]Department of Agricultural Economics and Extension, University of Cape Coast

Article History

Received: 10 October 2025

Accepted: 26 December 2025

Published: 31 March 2026

***Corresponding Author**

Kavi LC, E-mail: lord.kavi@concordia.ab.ca

Keywords

Climate Change, Climate Information Services, Endogenous Switching Regression, Irrigation, Multiple Regression, Sustainable Food Production.

How to cite: Kavi FK, Lumorh PDD, Kavi LC, Akaba S 2026: Irrigation as a Climate Adaptation Strategy: Evidence from Rice Farmers in the Volta Region of Ghana. J. Agric. Food Environ. 7(1): 49-58.

ABSTRACT

In this era of climate change and variability, irrigation is essential for sustainable food production. This study examines the impact of irrigation use on rice production among 380 rice farmers in the Volta Region of Ghana. A multistage sampling procedure was employed, and data were analysed using multiple regression and an endogenous switching regression model to account for selection bias. The results show that irrigation use significantly and positively influences both rice yield and profitability. Other significant factors include farm size, access to credit, household size, membership in farmer-based organisations, agricultural extension services, and access to Climate Information Services (CIS). Irrigation increased yield by 0.85 units and profitability by 0.76 units. The models demonstrated good explanatory power, with R-squared values of 0.390 for yield and 0.521 for profitability. Greater yield variation was observed among irrigators than non-irrigators. The endogenous switching regression confirms the presence of selection bias and identifies irrigation cost and farmer-based organisation membership as key determinants of yields among non-irrigators, while household size and years of formal education drive yields among irrigators. The study concludes that improving access to irrigation and complementary services can significantly enhance rice production outcomes. It recommends increased investment in irrigation infrastructure, targeted credit schemes, strengthened farmer organisations, improved extension services, and enhanced access to climate information services to boost productivity, profitability, and resilience.

INTRODUCTION

Rice is a major staple in Ghana's food system, with consumption levels steadily increasing due to rapid urbanisation, population growth, rising incomes, and changing dietary preferences (Asiedu *et al.*, 2024). The crop has become very important in household food security, particularly in urban and peri-urban areas. However, domestic rice production continues to lag behind national demand, leading to substantial imports and exerting pressure on Ghana's foreign exchange reserves (Onumah *et al.*, 2022). This growing dependency on imported rice poses significant economic and food security risks, particularly in the context of climate change, global price volatility and trade disruptions (Hellegers, 2022).

Despite the strategic importance of rice in Ghana's agricultural development agenda, production remains heavily dependent on rain-fed systems (Issahaku *et al.*, 2022). This reliance exposes rice farmers to the adverse effects of climate variability, including irregular rainfall patterns, dry spells, and flooding, all of which contribute to unstable yields and production shortfalls (Hussain *et al.*, 2020, Kavi, 2026). The unpredictability of rain-fed rice cultivation discourages long-term investments and limits the capacity of rice farmers to adopt yield-enhancing technologies, thereby constraining productivity growth (Van Aalst *et al.*, 2023).

In response to these challenges, irrigation has been widely recommended as a critical strategy for enhancing and stabilising agricultural productivity in sub-Saharan Africa

(Darko *et al*., 2020). Irrigation not only reduces dependence on rainfall but also enables multiple cropping cycles, improved input efficiency, and higher yields per hectare (Zhang *et al*., 2023). In Ghana, various irrigation initiatives have been implemented over the years, particularly through institutions such as the Ghana Irrigation Development Authority (GIDA) and development programmes including the One Village One Dam (1V1D) initiative (Adams *et al*., 2024). These interventions have aimed to improve smallholder access to water and expand irrigable land, with rice identified as a key target crop.

The link between irrigation and crop productivity has long been established in agricultural economics literature. However, the actual impact of irrigation varies based on the type of irrigation system, water availability, farmer capacity, and maintenance of infrastructure (Gebru *et al*., 2025).

Studies by Owusu-Sekyere *et al*. (2021) have highlighted the positive effects of irrigation on rice yield, particularly in the Upper East and Northern Regions. Nonetheless, these studies also point to inefficiencies due to poorly maintained irrigation infrastructure and limited technical knowledge among farmers.

The Volta Region is one of the country's ecologically favourable zones for rice cultivation. In fact, it is by far the leading producer of rice in Ghana (MoFA, 2021). The region has abundant water resources, relatively well-developed infrastructure, and proximity to major markets. Consequently, irrigation schemes are easily established in the region to enhance rice productivity and contribute to national efforts to reduce rice import dependency.

However, the effectiveness of irrigation in improving rice productivity in the Volta Region remains mixed. While some irrigated farms report higher productivity and more consistent harvests, others face substantial constraints, including deteriorating infrastructure, inadequate water distribution, poor maintenance systems, and limited technical support. In some cases, irrigated farms produce yields comparable to or lower than those under rain-fed conditions, particularly in seasons with favourable rainfall (Lamptey, 2022). These inconsistencies raise critical questions about the real impact of irrigation on rice productivity and the factors that mediate its effectiveness.

Understanding the productivity implications of irrigation is therefore necessary for informing future investment and policy decisions. Although significant public resources have been allocated to irrigation development, empirical evidence assessing the productivity benefits of these investments, particularly at the regional level is scarce (Xie *et al*., 2021). Without rigorous analysis, there is a risk that irrigation policies may be poorly targeted, resulting in suboptimal outcomes and inefficient resource use (Bukhari *et al*., 2024).

This study seeks to fill this knowledge gap by examining the impact of irrigation on rice productivity in the Volta Region of Ghana. By comparing yield outcomes between irrigated and non-irrigated rice farmers within the same agroecological context, this research aims to provide robust evidence on whether and to what extent irrigation enhances rice productivity. The findings will enhance understanding of the role of irrigation in Ghana's rice sector and support the formulation of more effective strategies to achieve food self-sufficiency.

Generally, the study seeks to evaluate the impacts of irrigation on rice yields in the Volta Region of Ghana. The specific objectives were to examine the determinants of rice yields in the Volta Region of Ghana, to compare rice yields between irrigated and non-irrigated farms in the Volta Region, and to evaluate the impact of irrigation on the profitability of rice production

Theoretical underpinnings

This study is grounded in the theory of production economics, specifically the agricultural production function framework (Schultz, 1956) which posits that output (yield) is a function of various inputs including land, labour, capital, and technology. Within this framework, irrigation is conceptualised as a productivity-enhancing input that, when combined with complementary resources such as improved seed, fertilizer and labour can significantly increase crop output. The marginal productivity of irrigation is therefore central to this analysis, especially in comparing its effects across irrigated and non-irrigated rice farms.

In addition to production theory, the study draws on elements of the induced innovation theory (Ruttan, 1985), which suggests that technological and institutional changes in agriculture such as the adoption of irrigation infrastructure, are often responses to changing resource endowments and market pressures. In this context, the increasing demand for rice and growing water scarcity in Ghana have incentivised the expansion of irrigation as a strategy to intensify production and stabilise yields under climate variability.

By integrating these theoretical perspectives, the study provides a comprehensive lens for examining the complex and context-dependent relationship between irrigation and rice yield. This approach enables an analysis that goes beyond a simple input-output relationship to consider the broader institutional, environmental, and socio-economic factors that influence agricultural productivity in the Volta Region.

MATERIALS AND METHODS

The research was conducted in the Volta Region of Ghana, with a focus on key rice-producing districts and municipalities. The study purposively covered *Ketu* North, South *Tongu*, and *Hohoe* Municipalities which are the major rice growing areas in the region. In *Ketu* North, data were collected from the communities of *Avalavi*, *Weta*, and *Klenormadi*, whereas in South *Tongu*, the selected communities were *Fievie*, *Dabala*, and *Agbakofe*. In the *Hohoe* Municipality, the participating communities were *Fodome*, *Wli*, *Gbi Wegbe*. Fig. 1 presents a map of the selected study areas.

A sample size of 390 rice farmers was determined using the Krejcie and Morgan (1970) sample size determination table, from a population of 15000. Disproportionate sampling was used to select three communities from each municipality. Lastly, simple proportionate random sampling was conducted at the individual farmer level to finalise data collection.

Data collection for the study took place during the 2024/2025 cropping season across the selected study areas. To establish a comprehensive sampling frame of rice farmers in the selected areas, a visit was made to the Departments of Agriculture in the relevant Municipal and District

Assemblies. This preparatory visit occurred one month before the actual data collection commenced. The data collection process spanned from May 1, 2024, to June 15, 2024, during which efforts were made to ensure accuracy and reliability. Out of the 390 rice farmers initially sampled, 380 participated in the study, resulting in a response rate of 97.4%. This was made up of 231 irrigators and 149 non-irrigators.

The Multiple Regression and the Endogenous Switching Regression models; and the mean and the standard deviation were employed in data analysis. Data analysis was carried out using Stata version 15.1.

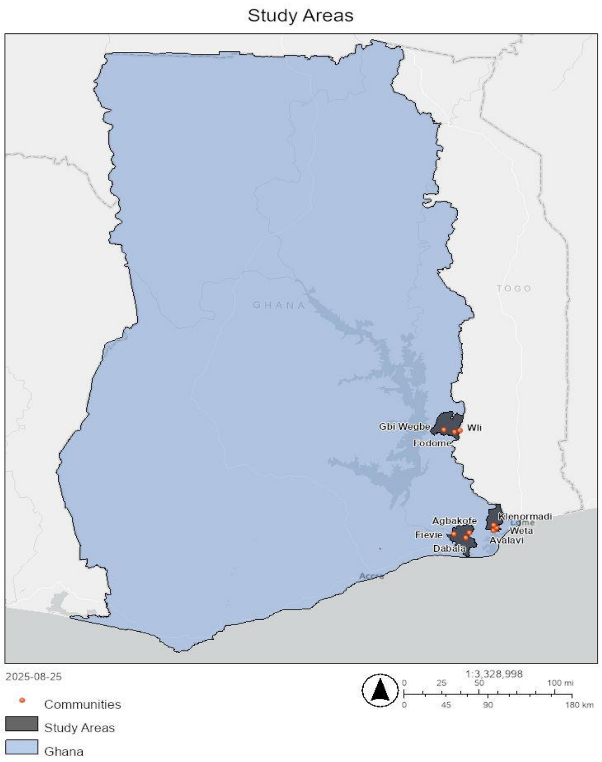


Figure 1: Map of selected study areas.

Model specifications

The multiple regression for the impact of irrigation on rice yields:

Let,

- YIELD =Rice yield (dependent variable)
- IRRIG = Use of irrigation (1 = Yes, 0 = No)
- FARMSIZE = Farm size (in acres or appropriate units)
- LABCOST = Cost of labour (in Ghana *cedis*)
- CREDIT = Access to credit (1 = Yes, 0 = No)
- FBO = Membership in Farmer-Based Organisation (1 = Yes, 0 = No)
- EDUYRS = Years of formal Education
- EXP = Years engaged in rice farming
- EXTENSION =Access to agricultural extension services (1 = Yes, 0 = No)
- CIS = Access to climate information services (1 = Yes, 0 = No)
- HHSIZE = Household size
- ε = Error term (captures unobserved factors)

$$YIELD_i = \beta_0 + \beta_1 \cdot IRRIG_i + \beta_2 \cdot FARMSIZE_i + \beta_3 \cdot LABCOST_i + \beta_4 \cdot CREDIT_i + \beta_5 \cdot FBO_i + \beta_6 \cdot EDUYRS_i + \beta_7 \cdot EXP_i + \beta_8 \cdot EXTENSION_i + \beta_9 \cdot CIS_i + \beta_{10} \cdot HHSIZE_i + \varepsilon_i \quad (1)$$

Where;

- β_0 is the intercept
- $\beta_1, \beta_2, \dots, \beta_{10}$ are the coefficients measuring the impact of each explanatory variable on rice yield
- i denotes the observation (individual farmer)

Since covariates are the same for both yield and profitability, the dependent variable, yield, in equation 1 is replaced with profitability to form equation 2 below:

$$\mathrm{PROFITABILITY} = \beta_0 + \beta_1 \cdot \mathrm{IRRIG_i} + \beta_2 \cdot \mathrm{FARMSIZE_i} + \beta_3 \cdot \mathrm{LABCOST_i} + \beta_4 \cdot \mathrm{CREDIT_i} + \beta_5 \cdot \mathrm{FBO_i} + \beta_6 \cdot \mathrm{EDUYRS_i} + \beta_7 \cdot \mathrm{EXP_i} + \beta_8 \cdot \mathrm{EXTENSION_i} + \beta_9 \cdot \mathrm{CIS_i} + \beta_{10} \cdot \mathrm{HHSIZE_i} + \varepsilon_i$$

In this study profitability was computed as the difference between total revenue from rice sales and the total cost of production, expressed in Ghana cedis per acre.

The Endogenous Switching Regression Model

Let I_i indicate irrigation adoption ($I_i = 1$ if farmer i irrigates, 0 otherwise).

- **Outcome covariate (both regimes):** X_i = [Household size, Labour cost, Access to credit, Access to CIS, Membership of FBO, Years of formal education, Access to extension]
- **Selection covariates**: Z_i = [Land ownership, Irrigation cost, Farm size, Membership of FBO]

Selection (irrigation decision),

$$I_i^* = Z_i'\gamma + u_i, \qquad I_i = I\{I_i^* > 0\} \quad (3)$$

Outcome (yield) regimes

Regime 1 (irrigators): $Y_{1i} = X_i'\beta_1 + \varepsilon_{1i}$, observed if $I_i = 0$ (4)

Regime 0 (non-irrigators): $Y_{0i} = X_i'\beta_0 + \varepsilon_{0i}$, observed if $I_i = 0$ (5)

Distributional assumptions:

$$\begin{pmatrix} \varepsilon_{0i} \\ \varepsilon_{0i} \\ u_i \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_1^2 & 0 & \sigma_{u1} \\ 0 & \sigma_0^2 & \sigma_{u0} \\ \sigma_{u1} & \sigma_{u0} & \sigma_u^2 \end{pmatrix} \right), \quad \rho 1 = \frac{\sigma_{u1}}{\sigma_1 \sigma_u}, \quad \rho_0 = \frac{\sigma_{u0}}{\sigma_0 \sigma_u} \quad (6)$$

Selectivity-corrected conditional means:

Let $\Phi(.)$ and $\phi(.)$ denote the standard normal Cumulative Distribution Function and Probability Density Function, defined as:

$$\lambda_1(Z_i'\gamma) = \frac{\phi(Z_i'\gamma)}{\Phi(Z_i'\gamma)}, \ \lambda_0(Z_i'\gamma) = \frac{\phi(Z_i'\gamma)}{1-\Phi(Z_i'\gamma)}$$
7

Then:

$$E[Y_{1i}\,|I_i = 1, X_i, Z_i] = X_i'\,\beta_1 + \left(\frac{\sigma_{u1}}{\sigma_u}\right)\lambda_1(Z_i'\gamma)$$
8

$$E[Y_{0i}\,|I_i = 0, X_i, Z_i] = X_i'\,\beta_0 - \left(\frac{\sigma_{u0}}{\sigma_u}\right)\lambda_0(Z_i'\gamma)$$
9

Counterfactuals:

$$E[Y_{0i}\,|I_i = 1, X_i, Z_i] = X_i'\,\beta_0 + \left(\frac{\sigma_{u0}}{\sigma_u}\right)\lambda_1(Z_i'\gamma)$$
10

$$E[Y_{1i}\,|I_i = 0, X_i, Z_i] = X_i'\,\beta_1 - \left(\frac{\sigma_{u1}}{\sigma_u}\right)\lambda_0(Z_i'\gamma)$$
11

Treatment effects

Average Treatment Effect on the Treated, $ATET = E[Y_{1i} - Y_{0i}\,|I_i = 1, X_i, Z_i] = X_i'(\beta_1 - \beta_0) + \frac{\sigma_{u1}-\sigma_{u0}}{\sigma_u}\lambda_1(Z_i'\gamma)$
12

Farm and Farmer-specific Characteristics

Variable	**Measurement**
Farm size	Continuous (acres)
Irrigation use	Dummy; yes =1, no = 0
Age	Continuous (years)
Fertiliser quantity	Continuous (kilogram)
Cost of labour	Continuous (Ghana Cedis)
Household size	Discrete (number)
Years engaged in rice farming	Continuous (years)
Membership of Farmer-Based Organisation	Dummy; yes =1, no = 0
Access to Extension	Dummy; yes =1, no = 0
Access to credit	Dummy; yes =1, no = 0
Years of formal education	Discrete (number)
Access to Climate Information Services (CIS)	Dummy; yes =1, no = 0
Use of CSA Innovations	Dummy; yes =1, no = 0

RESULTS AND DISCUSSIONS

Socioeconomic Characteristics of Rice Farmers

The socioeconomic characteristics of the rice farmers examined in this study include age, educational attainment, membership in farmer-based organisations, access to credit facilities, ownership of communication devices, farming experience, access to extension services, engagement in off-farm employment, land tenure arrangements, and irrigation use. Table 1 presents the age distribution of the respondents, indicating that 112 farmers (29.5%) were within the 40–49 years age group. The average age of 45.8 years suggests that the majority of the respondents fall within the economically active population, capable of making meaningful contributions to rice production in Ghana. This result is consistent with the findings of Tasila Konja *et al.* (2019), who reported that the average age of rice farmers in Ghana is approximately 45 years. Similarly, Kehinde (2021) observed that most rice producers in Northern Nigeria were between 31 and 50 years old, with a mean age of 43 years.

Table 1: Age distribution of respondents.

Age (Mean= 45.8)	Frequency	Percent (%)
<20	2	0.500
20-29	28	7.400
30-39	100	26.300
40-49	112	29.500
50-59	82	21.600
60-69	41	10.800
70-79	15	3.900
Minimum: 17		
Maximum: 78		
Total	380	100.000

Fig. 2 indicates that 62.4% of the rice farmers had attained some level of formal education, comprising primary, secondary, and tertiary education. Educational attainment is expected to enhance farmers' capacity for record-keeping and management of essential farm activities, thereby contributing to improved enterprise performance. This outcome contrasts with the findings of Ouedraogo *et al.* (2023), who reported that 52% of cowpea and sesame farmers in Burkina Faso had no formal education**.**

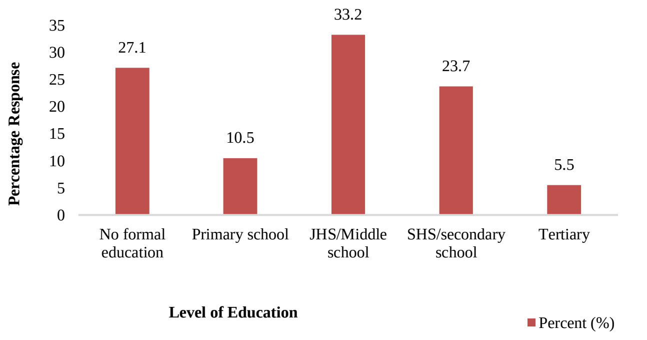


Figure 2: Percentage distribution of rice farmers by their level of education.

Fig. 3 shows that only 37.9% of the respondents belonged to farmer-based organizations (FBOs). This contrasts with the findings of Tasila Konja *et al*. (2019), who reported that 60% of rice farmers in Northern Ghana were affiliated with FBOs. Participation in off-farm activities, which are often an important source of supplementary income to support farming operations, was also assessed. The results reveal that 44.7% of the farmers engaged in off-farm work, implying that the majority were solely committed to rice farming.

The study found that only 48.4% of the farmers had access to credit, consistent with Hoang (2021), who observed that most rural rice farmers and processors lacked such access. Similarly, the results show that 54.7% of the farmers did not benefit from agricultural extension services, which restricted their access to technical information on rice production. This finding supports the work of Anwar *et al.* (2021), who reported limited access to extension services among rice farmers in Bangladesh. The absence of such services poses significant challenges to sectoral improvement, as innovations intended to enhance productivity may not reach the intended beneficiaries.

Regarding access to communication devices, the results indicate that a large majority (97.6%) of the farmers owned or had access to such devices. This aligns with Zossou *et al.* (2020), who found that most rice farmers in West Africa had access to communication tools that facilitated information flow. Finally, irrigation use was reported by 60.8% of the farmers, corroborating the findings of Hassan *et al.* (2022), who noted widespread use of irrigation among rice farmers in Egypt.

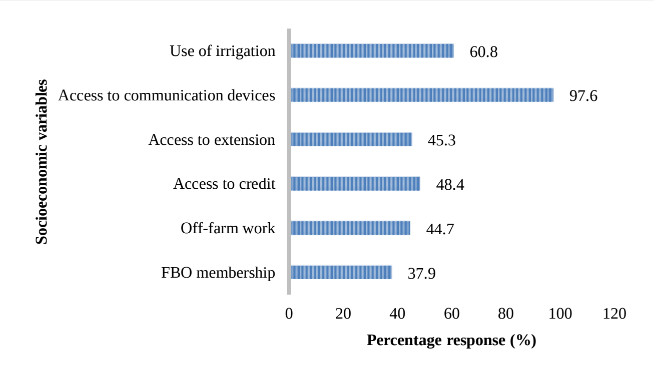


Figure 3: Percentage distribution of respondents on various socioeconomic variables

The study identified four rice varieties cultivated by the respondents, namely Jasmine, Togo Marshal, and AGRA. Fig. 4 presents the distribution of farmers according to the rice varieties grown. The results indicate that 35.8% of the farmers cultivated Jasmine, while 34.2% cultivated AGRA. This suggests that a majority (approximately 70%) of the farmers in the study area cultivated either Jasmine or AGRA. These findings are consistent with those of Diaka and Matsui (2023), who reported that Jasmine and AGRA were the predominant rice varieties cultivated in the *Asunafo* North Municipality of the *Ahafo* Region of Ghana.

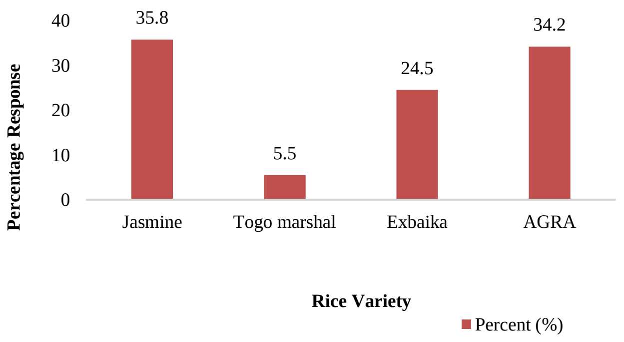


Figure 4: Distribution of rice farmers by the rice variety cultivated.

Fig. 5 shows that 42.4% of the rice farmers cultivated on family land, while 31.8% used their own land. Together, this accounts for 74.2% of farmers relying on either family or personally owned land for rice production. This result is consistent with Uhunamure *et al.* (2021), who reported that 72.2% of certified farmers in South Africa owned their farmland, and with Baffoe *et al.* (2021), who observed that most rice farmers in the Northern and Ashanti Regions of Ghana cultivated on either family or personal land. By contrast, only 25.8% of the respondents rented land or practised sharecropping. This suggests that the majority of rice farmers in the study area enjoy secure land tenure, a condition that is necessary for the adoption of major climate-smart agricultural innovations.

Figure 5: Percentage distribution of rice farmers by land ownership.

Determinants of Rice Yields

Table 2 presents the Multiple Regression analysis of the impact of irrigation use on rice yields, employing the Ordinary Least Squares estimation approach. The results reveal that approximately 39% of the variation in rice yield is explained by the model's independent variables (R-squared = 0.390). The F-statistic of 19.44 with a p-value of 0.000 indicates that the model is statistically significant, affirming that the explanatory variables collectively provide a robust explanation of variations in rice yield.

An important finding is that irrigation use has a statistically significant and positive effect on rice yield. Specifically, irrigation increases rice yield by 0.85 units, holding other variables constant. This supports the findings of Yu *et al.* (2024), who reported a 5.64% increase in early rice yields as a result of water-saving irrigation techniques in China.

Farm size is also found to have a positive and significant effect on rice yield, with a one-unit increase in farm size associated with a 0.96-unit increase in yield. This result contrasts with the findings of Kumar and Moharaj (2023), who observed an inverse relationship between farm size and rice productivity in India.

Furthermore, membership in a farmer-based organization (FBO) is associated with a 0.793-unit increase in rice yield. This effect is likely due to the enhanced access to information, resources, and collective action benefits that such groups provide. This finding aligns with Abdul-Rahaman and Abdulai (2020), who noted that group membership significantly improves crop productivity in rural Ghana.

Access to agricultural extension services also significantly boosts rice yield by 0.87 units. This is consistent with the work of Alam *et al.* (2024), which demonstrated the positive role of extension services in enhancing rice productivity and profitability in Bangladesh.

Lastly, household size shows a strong positive association with rice yield. A one-unit increase in household size results in a 1.21-unit increase in yield, suggesting that larger households may provide more labor for farming activities. This corroborates the findings of Song *et al.* (2024), who linked household size to improved farm productivity among rice farmers in China.

Table 2: Multiple regression analysis of the determinants of rice yields.

Variable	Parameter	Coefficient	Standard error	P-value
Intercept	β_0	0.514	0.019	0.001
Irrigation use	β_1	0.850***	0.016	0.000
Farm size	β_2	0.962***	0.019	0.000
Labour cost	β_3	-0.146	0.015	0.073
Access to credit	β_4	0.506	0.018	0.108
Membership of FBO	β_5	0.793**	0.021	0.004
Years of formal education	β_6	0.301	0.013	0.732
Years engaged in rice farming	β_7	0.169	0.094	0.072
Access to extension	β_8	0.866*	0.005	0.040
Access to CIS	B_9	0.273	0.157	0.320
Household size	β_{10}	1.214**	0.002	0.004
Model diagnostics				
F-statistic	19.440	Adj. R-squared	0.369	
P-value	0.000	R-squared	0.390	

*Significant at 5%, **Significant at 1%, ***Significant at < 0.1%

Rice yield differences between irrigators and non-irrigators

Table 3 presents the differences in rice yields between rice farmers who irrigated their farms and those who did not. The results indicate that rice farmers who irrigated their farms had higher yields (10735.820kg) than those who did not irrigate their farms (7121.436kg), with irrigators recording 3613.564kg higher than non-irrigators. This finding is consistent with that He *et al.* (2020) who found irrigation as a factor that increased significantly increased rice yields and contributed to sustainable rice production in China. The standard deviations of 659.34 and 511.71for irrigators and non-irrigators respectively indicate wide variations in rice yields across both categories of rice farmers in the Volta Region.

Table 3: Descriptive analysis of rice yield differences between irrigators and non-irrigators.

Farmer category	Mean yield (kg)	Standard deviation	N
Irrigators	10735.820	659.357	231
Non-irrigators	7121.436	511.706	149
Total			380

Table 4 gives the results of the Endogenous Switching Regression (ESR) on the effect of irrigation on rice yield, while accounting for selection bias, that is, the fact that farmers self-select into irrigation use based on certain observed (and unobserved) factors. The ESR model consists of a selection equation, that is what determines a farmer's decision to irrigate; and two outcome equations: one for non-irrigators (Yield0) and the other for irrigators (Yield1).

The sigma0 and sigma1 represent the standard deviation of errors for non-irrigators and irrigators respectively. The sigma0 value of 5279.46 indicates a moderate variation in yields among non-irrigators while the sigma1 value of 9436.73 shows larger variation in irrigators' yield relative to that of non-irrigators. The rho0 which shows the correlation between unobserved yield factors and selection for non-irrigators is significant and strongly negative (–0.862**)**, indicating the presence of strong selection bias. Also, the correlation between unobserved yield factors and selection for irrigators is significant (–0.304), and less strong bias compared to that of non-irrigators, but still important. Negative rho0 and rho1 imply that unobserved factors that make a farmer more likely to irrigate are negatively correlated with unobserved factors that affect yield. Therefore, not accounting for selection would yield bias estimates. The likelihood ratio test of independent equations (Chi^2 (2) = 10.88, with p = 0.004) shows that the observed chi square value is unlikely to occur under the null hypothesis of no selection bias. Hence the null hypothesis of no selection bias is rejected. This confirms the presence of endogeneity and the appropriateness of the ESR model.

The selection equation models the probability of irrigating. The results indicate that irrigation cost is positive and highly significant (p<0.001), implying that as irrigation cost increases, the probability of irrigating increases. This finding corroborates that of who found a significant positive effect of irrigation cost on the probability of irrigating. This indicates either a high value placed on irrigation or committed farmers self-select despite the high cost. Also, being a member of a farmer-based organisation increases the probability of irrigation adoption by 0.524. This finding supports that of Asravor (2023) who found membership of a farmer-based organisation to have significantly increased irrigation technology adoption in rural Ghana. The findings show that the decision to irrigate was not random, justifying the use of the ESR.

The outcome equations reveal that among non-irrigators (Yield0), higher labour cost increases yield, likely due to more intensive or specialised labour. This finding contradicts that of Mupaso *et al.* (2024) who found that lower labour costs contributed significantly to higher yields among non-irrigators in Zimbabwe. Also, access to Climate Information Services (CIS) is associated with lower yields for non-irrigators likely due to the fact that rice farmers do not benefit from CIS without irrigation. This finding is at variance with that of Asrat and Anteneh (2019) who found that pastoralist and agro-pastoralist who had access to CIS had higher income than those who had no access to CIS in Ethiopia. On the other hand, among irrigators (Yield1), household size and formal education are the key drivers of rice yield. Larger household sizes produce higher rice yields. This finding is in consonance with that of Anthony *et al.* (2021) who found that among irrigators, large household sizes produce higher yields in Abuja, Nigeria. This could be due to more family labour made available by larger household sizes. Also, more years of formal education enhances rice yields under irrigation. This finding confirms that of Anang (2019) who found years of formal education to have significantly enhanced rice yields among irrigators in Northern Ghana. This could be due to better use of irrigation technology, enhanced decision making and higher adoption of best practices and innovations, and better record keeping and planning among highly educated irrigators.

Table 4: Endogenous switching regression analysis of the determinants of rice yields.

Variable	Yield (Non-irrigators)		Yield1 (Irrigators)		Irrigation Selection decision		
	Coef.	P-value	Coef.	P-value	Variable	Coef.	P-value
Household size	-35.711	0.696	607.754***	0.000	Land ownership	-0.222	0.305
Labour cost	0.939***	0.000	0.044	0.696	Irrigation cost	0.008***	0.000
Access to credit	325.801	0.760	1646.467	0.224	Farm size	0.088	0.199
Access to CIS	-3660.492*	0.031	2535.498	0.519	Membership of FBO	0.524*	0.051
Membership of FBO	-1199.841	0.233	2507.241	0.177	Constant	-1.088	0.010
Years of formal education	75.012	0.397	331.081***	0.037	**Model diagnostics**		
Access to extension	53.717	0.954	2053.861	0.241	**Sigma0**	5279.463	
Constant	6475.089	0.000	-1434.126	0.757	**Sigma1**	9436.729	
					rho0	–0.862	
					rho1	–0.304	
					LR test	Chi2(2): 10.88	P-value:0.0043

*****Significant at 5%, **Significant at 1%, ***Significant at < 0.1%

The actual effect of irrigation on irrigators is presented in Table 5. The results indicate that among farmers who irrigated, irrigation increased rice yield by 1,990 kg/acre on average, compared to if they had not irrigated, holding other factors constant. This effect is statistically significant at the 5% level (p = 0.021). Furthermore, the predicted average rice yield for non-irrigators, controlling for covariates, is 8,745 kg/acre (POmean reports the expected yield for irrigators had they not irrigated). This implies that irrigators, had they not irrigated, would have produced about 8,745 kg/acre, but they actually produced on average 10,735 kg/acre (8745 + 1990) due to irrigation.

Table 5: Average treatment effect on the treated (atet): effect of irrigation on irrigators.

Variable	ATET		POmean	
	Coef.	P-value	Coef.	P-value
Irrigation use (1 vs 0)	1990.431	0.021	-	-
Irrigation use (0)	-	-	8745.392	0.000

Predictors of Profitability of Rice Production

The results of the multiple regression analysis examining the predictors of rice production profitability are presented in Table 6. The model explains 52.1% of the variation in profitability (R-squared = 0.521), indicating a moderately strong explanatory power. The F-statistic of 40.15 with a p-value of 0.000 confirms that the independent variables collectively account for a statistically significant portion of the variability in the dependent variable. This suggests that the model is well-specified and suitable for predicting or explaining profitability outcomes in rice farming.

A key finding is the statistically significant positive effect of irrigation use on profitability. The results show that, holding all other factors constant, the use of irrigation increases the profitability of rice production by 0.760 units. This finding supports that of Zakaria *et al.* (2021), who identified irrigation as a major determinant of profitability in rice farming in Northern Ghana.

Farm size also exhibits a significant and positive effect on profitability. Specifically, a one-unit increase in land area under cultivation leads to a 0.81-unit increase in profitability. This result is consistent with Kulyakwave *et al.* (2020), who reported a direct relationship between farm size and the profitability of small-scale rice production in Tanzania.

Access to credit emerges as another significant predictor. The findings reveal that increased access to credit enhances rice profitability by 1.21 units. This highlights the crucial role of financial capital in supporting agricultural investments and improving farm performance. The result aligns with the findings of Zakaria *et al.* (2021), who observed similar effects in Northern Ghana. However, it contrasts with Agboklou and Ozkan (2022), who reported that access to credit was not a significant determinant of profitability in rice production in Southern Togo. This divergence may reflect regional differences in credit accessibility, utilization, or repayment conditions.

Furthermore, the study finds that access to Climate Information Services (CIS) significantly increases rice production profitability by 0.14 units. This suggests that timely and reliable climate information enables farmers to make informed decisions regarding planting, irrigation scheduling, and risk management. The finding corroborates that of Onyeneke *et al.* (2022), who reported a significant positive relationship between CIS access and both yield and profitability in rice production.

Table 6: Multiple regression analysis of the predictors of profitability of rice production.

Variable	Parameter	Coefficient	Standard error	P-value
Intercept	β_0	0.214	0.026	0.000
Irrigation use	β_1	0.760***	0.037	0.000
Farm size	β_2	0.813***	0.046	0.000
Labour cost	β_3	-0.231	0.025	0.521
Access to credit	β_4	1.206***	0.012	0.000

Membership of FBO	β_5	0.653	0.125	0.489
Years of formal education	β_6	0.412	0.160	0.645
Years engaged in rice farming	β_7	0.984*	0.010	0.019
Access to extension	β_8	0.675	0.030	0.096
Access to CIS	B_9	0.136*	0.051	0.031
Household size	β_{10}	1.115	0.056	0.794
Model diagnostics				
F-statistic	40.15	Adj. R-squared	0.508	
P-value	0.000	R-squared	0.521	

***Significant at 5%, **Significant at 1%, ***Significant at < 0.1%

CONCLUSIONS

The analysis revealed that irrigation significantly enhances both rice yield and profitability. Specifically, irrigated farms recorded significantly higher yields compared to non-irrigated farms, with an average difference of 3,613.56 kg. The regression results further confirmed that irrigation use, farm size, access to credit, membership in farmer-based organisations, access to extension services, household size, and access to climate information services all positively and significantly influence rice yield and profitability.

While this research is specific to the Volta Region of Ghana, the findings are widely applicable to smallholder rice farming systems across sub-Saharan Africa. It was found that improved access to affordable irrigation, membership of farmer organisations, access to credit, and CIS enhance rice yield and profitability considerably. Similarly, in Ethiopia, smallholder irrigators recorded substantially higher yields, income, and resilience (Mume *et al*., 2023); as well as in Zimbabwe where production on the TISA project yielded stronger farming system resilience against extreme weather events (Moyo *et al*., 2025). These research findings imply that irrigation investments that combine water infrastructure with other services are potent adaptation measures across different smallholder farming systems. Policymakers and agricultural stakeholders beyond Ghana can therefore integrate agricultural extension and credit services with irrigation schemes to boost agricultural productivity and climate resilience.

The findings reinforce the critical role of irrigation and support services in enhancing agricultural productivity and profitability. However, the wide variation in yields among both irrigators and non-irrigators suggests that additional farm-level and institutional factors may be influencing outcomes, highlighting the need for targeted interventions.

Recommendations and policy implications

The study highlights the importance of strategic interventions to enhance rice productivity and profitability in Ghana's Volta Region. Irrigation significantly improves yield and profitability. This warrants public and private investment in smallholder-friendly, water-efficient systems, and the promotion of community-managed irrigation schemes. Landholding size was also a key determinant; thus, policies should aim to improve access to land, secure tenure, and encourage cooperative or cluster farming to enhance scale economies and land-use efficiency.

Access to credit emerged as necessary for profitability. This suggests tailored agricultural finance products, complemented by financial literacy programmes and government-backed credit guarantees. The positive impact of FBO membership and extension services calls for stronger support for farmer organisations and expanded extension delivery.

Additionally, access to CIS significantly enhanced profitability, and this underscores the need to integrate CIS into extension systems to support informed decision-making.

REFERENCES

Abdul-Rahaman A and Abdulai A 2020: Farmer groups, collective marketing and smallholder farm performance in rural Ghana. *Journal of Agribusiness in Developing and Emerging Economies* **10**(5):511–527. https://doi.org/10.1108/JADEE-07-2019-0095

Adams S, Martey M, Amoatey C, Taabazuing J, Otoo R and Abokyi E 2024: An exploratory study of the impact of the one-village-one-dam initiative in northern Ghana. *Sustainability* **16**(19).

Agboklou KE and Ozkan B 2022: Analysis of rice farmers' access to agricultural credit and profitability in South Togo. *Journal of Business Economics and Finance* **12**(1):1–14.

Alam MJ, Sarma PK, Begum IA, Crase L, Tama RAZ and Kader MA 2024: Impact of agricultural extension services on rice productivity and profitability in Bangladesh. *Outlook on Agriculture* **53**(4):376–389.

Anang BT 2019: Are adopters of improved rice varieties more productive than non-adopters? Empirical evidence from northern Ghana. *Ghana Journal of Development Studies* **16**(1):92–107.

Anthony L, Alabi OO, Ebukiba ES and Gamba V 2021: Factors influencing output of rice produced and choice of marketing outlets among smallholder farming households, Abuja, Nigeria. *Sarhad Journal of Agriculture* 37(1).

Anwar M, Zulfiqar F, Ferdous Z, Tsusaka TW and Datta A 2021: Productivity, profitability, efficiency, and land utilization scenarios of rice cultivation: an assessment of hybrid rice in Bangladesh. *Sustainable Production and Consumption* 26:752–758.

Asante BO, Frimpong BN, Asante MD, Prah S, Ayeh SJ, Sakyiamah B and Tufan HA 2023: Exploring gender differences in the role of trait preferences among stakeholders in the rice value chain in Ghana. *Sustainability* **15**(7):6026. https://doi.org/10.3390/su15076026

Asiedu CY, Opoku-Mensah S and Sarfo B 2024: Perception and attitude of consumer patronage of Ghana-grown rice: evidence from Kumasi, Ghana. *African Journal of Commercial Studies* **5**(4):233–247.

Asrat D and Anteneh A 2019: The determinants of irrigation participation and its impact on pastoralist and agro-pastoralists income in Ethiopia: a review study. *Cogent Food & Agriculture* **5**(1):1679700. https://doi.org/10.1080/23311932.2019.1679700

Asravor RK 2023: Factors influencing farm-level climate adaptation strategies of smallholder farmers in rural Ghana. *Journal of Land and Rural Studies* **11**(1):52–68. https://doi.org/10.1177/23210249221127490

Baffoe JD, Mizunoya T and Yabar H 2021: Determinants of rice farmers' willingness to pay for conservation and sustainable use of swampy wetlands in Ghana's northern and Ashanti regions. *Agriculture* 11(6):507. https://doi.org/10.3390/agriculture11060507

Bukhari SRH, Khan AU and Noreen S 2024: Optimizing water resource governance for sustainable agricultural and hydroelectric development in Pakistan: an in-depth examination and policy prescriptions. *Journal of Development and Social Sciences* **5**(2):280–293.

Darko RO, Liu J, Yuan S, Sam-Amoah LK and Yan H 2020: Irrigated agriculture for food self-sufficiency in the sub-Saharan African region. *International Journal of Agricultural and Biological Engineering* **13**(3):1–12. https://doi.org/10.25165/j.ijabe.20201303.4397

Diaka I and Matsui K 2023: Examining smallholder rice farmers' yield improvement needs in Asunafo North Municipality of Ghana. *Journal of Biology, Agriculture and Healthcare* **13**(8):20–29.

Gebru M, Tadesse T and Berhe M 2025: Reliability of irrigation water and farm-level productivity: evidence from semi-arid farming systems in northern Ethiopia. *Agricultural Systems* **223**:104193. https://doi.org/10.1016/j.agsy.2024.104193

Hassan HE, Farag RMA and Kamel Eid A 2022 Effect of irrigation water on production and cost technical efficiency of rice: empirical evidence from Egypt. *Life Science Journal* **19**(12).

He G, Wang Z and Cui Z 2020: Managing irrigation water for sustainable rice production in China. *Journal of Cleaner Production* **245**:118928. https://doi.org/10.1016/j.jclepro.2019.118928

Hellegers P 2022: Food security vulnerability due to trade dependencies on Russia and Ukraine. *Food Security* **14**(6):1503–1510. https://doi.org/10.1007/s12571-022-01306-8

Hoang HG 2021: Determinants of adoption of organic rice production: a case of smallholder farmers in Hai Lang district of Vietnam. *International Journal of Social Economics* **48**(10):1463–1475.

Hussain S, Huang J, Huang J, Ahmad S, Nanda S, Anwar S and Zhang J 2020: Rice production under climate change: adaptations and mitigating strategies. *Environment, Climate, Plant and Vegetation Growth* 659–686.

Issahaku A, Obeng FK and Yeboah RW 2022: Assessing the effects of training on rice farmers' yield: the case of JICA training on sustainable rain-fed lowland rice production technology in Ghana. *International Journal of Scientific Research in Science, Engineering and Technology* **9**(1):41–44.

Kavi FK 2026: Climate change and variability: an analysis of trends in rainfall and temperature in the Volta and Northern Regions of Ghana. *Theoretical and Applied Climatology* 157:214. https://doi.org/10.1007/s00704-026-06156-4

Kehinde MO, Shittu AM, Adewuyi SA, Osunsina IOO and Adeyonu AG 2021: Land tenure and property rights, and household food security among rice farmers in northern Nigeria. *Heliyon* **7**(2). https://doi.org/10.1016/j.heliyon.2021.e06110

Krejcie RV and Morgan DW 1970: Sample size determination table. *Educational and Psychological Measurement* **30**(3):607–610.

Kulyakwave PD, Xu S, Yu W, Sary S and Muyobozi S 2020: Profitability analysis of rice production, constraints and consumption shares by small-scale producers in Tanzania. *Asian Journal of Agricultural Extension, Economics & Sociology* **37**(4):1–12.

Kumar KK and Moharaj P 2023: Farm size and productivity relationship among the farming communities in India. *Outlook on Agriculture* **52**(2):212–227.

Lamptey S 2022: Agronomic practices in soil water management for sustainable crop production under rain fed agriculture of drylands in Sub-Sahara Africa. *African Journal of Agricultural Research* **18**(1):18–26.

Li J, Ma W, Renwick A and Zheng H 2020: The impact of access to irrigation on rural incomes and diversification: evidence from China. *China Agricultural Economic Review* **12**(4):705–725. https://doi.org/10.1108/CAER-09-2019-0172

Ministry of Food and Agriculture 2021: Agriculture in Ghana: Facts and Figures. Accra.

Moyo M, Dube T, van Rooyen A, Bjornlund H, Parry K, Wellington M and Pittock J 2025: Adapting smallholder irrigation systems to extreme events: a case of the transforming irrigation in Southern Africa (TISA) project in Zimbabwe. *International Journal of Water Resources Development* **41**(2):274–297. https://doi.org/10.1080/07900627.2024.2423733

Mume ID, Mohammed JH and Ogeto MA 2023: Impact of small-scale irrigation on the livelihood and resilience of smallholder farmers against climate change stresses: evidence from Kersa district, eastern Oromia, Ethiopia. *Heliyon* **9**(8). https://doi.org/10.1016/j.heliyon.2023.e18976

Mupaso N, Makombe G, Mugandani R and Mafongoya PL 2024: Assessing the contribution of smallholder irrigation to household food security in Zimbabwe. *Agriculture* **14**(4):617. https://doi.org/10.3390/agriculture14040617

Onumah EE, Addey Owusu P, Mensah-Bonsu A and Acquah Degraft H 2022: Rice price volatility and transmission: implications for food security in Ghana. *Cogent Economics & Finance* **10**(1):2085605. https://doi.org/10.1080/23322039.2022.2085605

Onyeneke CJ, Umeh GN and Onyeneke RU 2022: Impact of climate information services on crop yield in Ebonyi State, Nigeria. *Climate* **11**(1):7. https://doi.org/10.3390/cli11010007

Ouedraogo M, Barry S and Zougmoré RB 2023: How using weather and climate information services may impact farm productivity and technical efficiency: evidence from cowpea and sesame producers in Burkina Faso. *Climate Change Economics* **14**(02):2350011. https://doi.org/10.1142/S2010007823500112

Owusu-Sekyere E, Bibariwiah C, Owusu V and Donkor E 2021: Farming under irrigation management transfer scheme and its impact on yield and net returns in Ghana. *Land Use Policy* **102**:105266. https://doi.org/10.1016/j.landusepol.2020.105266

Ruttan VW 1985: Technical and institutional change in agricultural development: two lectures.

Schultz TW 1956: Reflections on agricultural production, output and supply. *Journal of Farm Economics* **38**(3):748–762.

Song D, Chen F and Ouyang X 2024: The impact of changes in rural family structure on agricultural productivity and efficiency: evidence from rice farmers in China. *Sustainability* **16**(10):3892. https://doi.org/10.3390/su16103892

Tasila Konja D, Mabe FN and Alhassan H 2019: Technical and resource-use-efficiency among smallholder rice farmers in northern Ghana. *Cogent Food & Agriculture* 5(1):1651473. https://doi.org/10.1080/23311932.2019.1651473

Uhunamure SE, Nethengwe NS, Shale K, Mudau V and Mokgoebo M 2021: Appraisal of households' knowledge and perception towards e-waste management in Limpopo province, South Africa. *Recycling* **6**(2):39. https://doi.org/10.3390/recycling6020039

Van Aalst MA, Koomen E, Tran DD, Hoang HM, Nguyen HQ and De Groot HL 2023: The economic sustainability of rice farming and its influence on farmer decision-making in the upper Mekong delta, Vietnam. *Agricultural Water Management* 276:108018. https://doi.org/10.1016/j.agwat.2022.108018

Xie H, You L, Dile YT, Worqlul AW, Bizimana JC, Srinivasan R and Clark N 2021: Mapping development potential of dry-season small-scale irrigation in Sub-Saharan African countries under joint biophysical and economic constraints: an agent-based modeling approach with an application to Ethiopia. *Agricultural Systems* 186:102987. https://doi.org/10.1016/j.agsy.2020.102987

Yu Q, Dai Y, Wei J, Wang J, Liao B and Cui Y 2024: Rice yield and water productivity in response to water-saving irrigation practices in China: a meta-analysis. *Agricultural Water Management* 302:109006. https://doi.org/10.1016/j.agwat.2024.109006

Zakaria A, Azumah SB, Dagunga G and Appiah-Twumasi M 2021: Profitability analysis of rice production: a microeconomic perspective from northern Ghana. *Agricultural Finance Review* 81(4):535–553. https://doi.org/10.1108/AFR-07-2020-0108

Zhang S, Huang G, Zhang Y, Lv X, Wan K, Liang J and Hu F 2023: Sustained productivity and agronomic potential of perennial rice. *Nature Sustainability* 6(1):28–38. https://doi.org/10.1038/s41893-022-00997-3

Zossou E, Arouna A, Diagne A and Agboh-Noameshie RA 2020: Learning agriculture in rural areas: the drivers of knowledge acquisition and farming practices by rice farmers in West Africa. *Journal of Agricultural Education and Extension* 26(3):291–306. https://doi.org/10.1080/1389224X.2019.1702066