

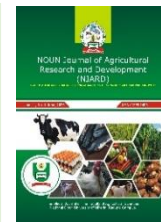


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Original Article

Impact of Irrigation Reform on Rice Yield: Evidence from Trimming Project Participants in North-West Nigeria

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ABSTRACT

This study investigates the impact of the TRIMING (Transforming Irrigation Management in Nigeria) project on rice yields of farmers in North-West Nigeria. Using a multistage sampling procedure a total of 666 respondents were randomly selected. Primary data were collected from project participants and non-participants using the KoboCollect tool, and were analyzed using Propensity Score Matching (PSM) and an Endogenous Switching Regression (ESR) model to rigorously estimate the project's effect on rice yield while addressing selection bias and endogeneity. The result shows a statistically significant and positive impact of the TRIMING Project on rice yield. The participants rice yield had increased by 1,468 kg/ha compared to if they didn't participate in the project, especially in Zamfara State, non-participating households, had a potential for substantial gains if they were to join (Average Treatment Effect on the Untreated, ATU = 1409kg/ha), consequently, the overall Average Treatment Effect (ATE = 1439) on the entire population is considerable. The ESR model confirms the presence of selection bias, with both observable and unobservable factors influencing participation and outcomes. However, the project's impact is heterogeneous, with effects varying significantly between Jigawa and Zamfara states, and between participants and non-participants in certain contexts. These findings support the need for region-specific implementation strategies, enhanced extension services, and improved input access. The study provides strong evidence of the effectiveness of targeted irrigation interventions and offers critical policy guidance for scaling agricultural productivity in Nigeria.

Keywords: Irrigation, Rice, yield, Northwest Nigeria, TRIMING Project, Impact Evaluation

INTRODUCTION

Agricultural development remains central to poverty reduction, food security, and rural livelihoods in Sub-Saharan Africa (SSA), where over 60% of the population depends on agriculture for their livelihoods (FAO, 2023). However, the sector is vulnerable to climatic variability, low productivity, and inadequate infrastructure, particularly in the rain-fed farming systems that dominate much of SSA. In response, irrigation development has emerged as a critical strategy to enhance agricultural productivity, stabilize incomes, and improve rural welfare (Gebre & Qaim, 2020; Adekoya & Kadir, 2021).

Across many SSA countries, irrigation reforms are being implemented to ensure equitable water use, improve

management efficiency, and boost agricultural transformation (Ngigi et al., 2021). Nigeria, despite its vast water resources, has historically underutilized its irrigation potential. To address this, the Transforming Irrigation Management in Nigeria (TRIMING) project was launched by the Federal Government, in collaboration with the World Bank, to rehabilitate major irrigation schemes, strengthen water user associations, and boost productivity and rural livelihoods (World Bank, 2023).

The North-West geopolitical zone of Nigeria – comprising Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara states is a strategic rice-producing area and a primary beneficiary of TRIMING interventions. The region's vulnerability to rainfall variability and seasonal



food insecurity makes irrigation reform particularly crucial for improving rural welfare outcomes such as income stability and food security (Aliyu & Ibrahim, 2023; Ogundeji & Yusuf, 2024).

Despite growing interest in irrigation reforms, empirical evidence on their impact on yields remains limited and context-specific. Thus, this study bridges that gap by evaluating the impact of irrigation reforms under the TRIMING project initiative on rice yield in North-West Nigeria. The findings are expected to inform policy design and enhance the effectiveness of future agricultural interventions in Nigeria and beyond.

Study Area

The study was conducted in selected communities North-West geopolitical zone. This region was chosen due to its strategic importance in national rice production and its inclusion among the major beneficiaries of the TRIMING project. Additionally, due to key irrigation schemes in the region; such as the Hadejia River Valley (HRV) in Jigawa State and the Bakolori Irrigation Scheme in Zamfara State, have undergone major rehabilitation under the TRIMING project. The region experiences a tropical savannah climate, with distinct wet and dry seasons, making it heavily reliant on irrigation for dry-season farming.

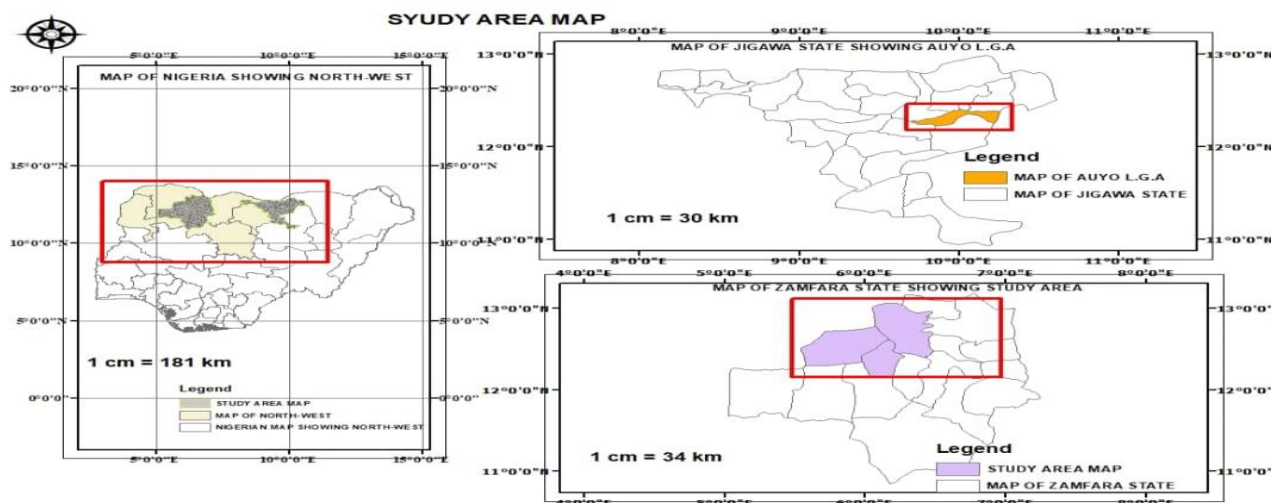


Figure 1: Map Nigeria Showing Jigawa and Zamfara State

Sampling Procedure

A multistage sampling technique was adopted for data collection. In the first stage, two TRIMING intervention states Jigawa and Zamfara were purposively selected based on the intensity of irrigation development and the concentration of rice farming activities. In the second stage, one rice-growing cluster (Auyo) was purposively selected in Jigawa State due to its exclusiveness in the project, and three clusters (Bakura, Maradun, and Talata Mafara) in Zamfara State. In the third stage, nine communities were randomly selected in the Auyo cluster, and three communities each from Bakura, Maradun, and Talata Mafara were randomly selected. In the fourth stage, farmers in each community were stratified into two groups: TRIMING participants (treatment group) and non-participants (control group).

A Raosoft sample size calculator was used using a 95% confidence level, 5% margin of error, and 50% response distribution, to come up with a total sample size of 666 rice farming households (333 participants and 333 non-participants). Structured questionnaires were administered to collect primary data on demographic characteristics, agricultural practices, input usage, income, and access to irrigation facilities.

Analytical Technique

To estimate the causal impact of TRIMING participation on rice yield while addressing selection bias, we employed an Endogenous Switching Regression (ESR) model and validated results using Propensity Score Matching (PSM). A

logistic regression (logit) model was used to estimate the probability of participation in the TRIMING project. The Average Treatment Effect on the Treated (ATT) was computed to measure the change in yield outcomes for participants.

PSM is a quasi-experimental technique that estimates causal effects by pairing treated and untreated units with similar characteristics. It involves calculating a propensity score (the probability of receiving treatment given observed covariates) for each unit and matching participants with non-participants on that score to reduce selection bias (Heckman, Ichimura, & Todd, 1997). The ESR model jointly estimates the participation decision and the outcome equations, accounting for non-random selection by allowing correlation between unobservables in the selection and outcome processes (Lokshin & Sajaia, 2004). In this way, ESR provides unbiased treatment effect estimates even when self-selection is present.

The Average Treatment Effect on the Treated (ATT) is defined as the mean impact of the intervention for those who actually received it;

$$E[Y_1 - Y_0 | D=1] E[Y_1 - Y_0 \mid D = 1]$$

The Average Treatment Effect on the Untreated (ATU) is which estimates the hypothetical gain for units that did not participate if they had been treated;

$$E[Y_1 - Y_0 | D=0] E[Y_1 - Y_0 \mid D = 0]$$

The overall Average Treatment Effect (ATE) is the mean difference in outcomes between treated and untreated units across the entire population;

$E[Y_1 - Y_0]E[Y_1 - Y_0]$.

Heterogeneous Treatment Effects (HTE) refer to variation in treatment effects across subgroups, which in this study we explore by comparing outcomes between participants group and non-participants.

Model Specification: We specify the following participation (selection) and outcome equations:

Selection equation (participation):

$$D_i = \alpha + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \mu_i \dots (1)$$

Where:

D_i : Binary variable (farmer i participates in TRIMING for $D_i = 1$ and $D_i = 0$ otherwise. The explanatory variables include farm size (ha), labor used (man-days), fertilizer used (kg), pesticides used (liters), number of technologies adopted, rice variety used (improved = 1), educational attainment (years), household size, farming experience (years), access to credit (1 = yes), distance to farm (km), and access to irrigation (1 = yes for canal access).

Outcome equation (yield): This equation models the outcome yield for each farmer, considering both participants and non-participants, accounting for the inverse Mills ratio derived from the selection equation.

$$Q_i = \alpha + \gamma_1 X_{1i} + \gamma_2 X_{2i} + \gamma_3 X_{3i} + \gamma_4 X_{4i} + \gamma_5 X_{5i} + \gamma_6 X_{6i} + \epsilon_i \dots (3)$$

Where:

Q_i : Quantity of rice yield of the i -th farmer (kilogram). Y_i : Farmer participation in TRIMING Project (participant = 1, non-participant = 0), $\gamma_1, \gamma_2, \dots, \gamma_6$: In the outcome equations,

these estimate the effect of variables included in the model on rice yield for participants and non-participants, respectively. The explanatory variables include; Farm size (ha), Labor Used (man-days), Fertilizer Used (kg), Pesticides Used (liters), Number of technologies adopted (Numbers), X_6 = Rice Variety used (Improved = 1, Otherwise = 0), ϵ_i is the error term.

RESULT AND DISCUSSION

Propensity Score Matching (PSM)

Table 1 presents the PSM-estimated treatment effects of the TRIMING project on rice yield. In Zamfara State, the estimated increase in yield (ATE) is 761.8 kg/ha, with an overall ATE of 770.9 kg/ha; both are significant at the 1% level ($p < 0.01$). In Jigawa State, the ATE is 573.0 kg/ha and the ATE is 565.5 kg/ha (both $p < 0.01$). The pooled (combined) sample shows an ATE of 864.3 kg/ha and an ATE of 841.3 kg/ha ($p < 0.001$). These results confirm a substantial and statistically significant positive impact of TRIMING participation on rice yield. The close correspondence between the ATE and ATET estimates in both states suggests that the gains observed among participants could be generalized to the broader rice farming population under similar intervention conditions.

These findings align with those of John et al. (2019), who reported an overall average gain of about 502 kg/ha in yield due to contract farming participation (using a PSM model), highlighting similar positive impacts from targeted agricultural interventions.

Table 1: Propensity score matching (PSM) Treatment Effects: impact of TRIMING project on the yield of rice farming households.

States		Coefficient	Std. err.	Z	P>z
Jigawa	ATE	565.4626	74.27238	7.61	0.000***
	ATET	572.9222	89.53788	6.40	0.000***
Zamfara	ATE	770.9333	155.9306	4.94	0.000***
	ATET	761.7667	152.4171	5.00	0.000***
Pooled	ATE	864.2984	65.29964	13.24	0.000***
	ATET	841.3036	80.86357	10.40	0.000***

Field Survey, 2024. Note: ***, ** & * significant at 1% level.

Endogenous Switching Regression (ESR) Results

The ESR model provides further insight by accounting for both observable and unobservable factors affecting participation and outcomes (Oyekale & Oyekale, 2019). Table 2 presents the estimated coefficients for the yield equations (for participants and non-participants) and the selection equation. Farm size positively and significantly affects yield for both groups ($p < 0.01$), with a larger marginal effect for participants. This suggests the TRIMING project complements land inputs to maximize returns. Fertilizer use also has a significant positive effect on yield for both groups; however, the coefficient is smaller for participants. This indicates that participants have adopted other nutrient management practices such as organic amendments, moderating the marginal effect of inorganic fertilizer.

The use of improved rice varieties significantly increases yield among participants ($p < 0.05$) but is not significant among non-participants. This suggests that TRIMING

participants were more effectively utilizing improved seed varieties. Furthermore, the number of technologies adopted has a negative and significant effect on yield for both groups. This unexpected result suggests potential challenges related to the complexity or compatibility of multiple interventions. Farmers may face information overload, financial burden, or difficulty integrating several new technologies simultaneously, which warrants further investigation into multi-technology package design. Pesticide use has a negative effect for both groups, significant for non-participants. For TRIMING participants, this negative coefficient may reflect a shift toward more sustainable pest management practices (such as integrated pest management) that reduce reliance on chemical pesticides while maintaining yields. For non-participants, the negative effect could indicate inefficient and or improper pesticide application. Labor use shows a small, insignificant negative effect for both groups, suggesting that labor was not a primary constraint to productivity and may indicate



some adoption of labor-saving innovations under the project.

In the selection equation, we find that having more available labor, using pesticides, higher education, larger household size, and access to credit all significantly increase the likelihood of participation in TRIMING. This indicates that farmers with more human capital and financial resources were more likely to join the project. Meanwhile, larger farm size, greater distance to the irrigation scheme, and prior adoption of improved rice varieties negatively influence participation. This could imply that small holder farmers or those located closer to the irrigation schemes were targeted, and farmers already using improved varieties felt less need to join. The likelihood ratio test of independence ($\chi^2 = 35.04$, $p < 0.001$) confirms the presence of selection bias, and the significant negative covariance terms ($\rho_1 = -0.32$, $\rho_2 = -0.90$) further validate the necessity for the use of ESR model.

The pooled ATT is 1,468 kg/ha ($p < 0.01$), indicating that participating households gained an additional 1,468 kg/ha of rice yield due to TRIMING. The pooled ATU is 1,409 kg/ha ($p < 0.01$), suggesting that non-participants would have gained an additional 1,409 kg/ha if they had participated. Consequently, the overall ATE is 1,439 kg/ha ($p < 0.01$). The Heterogeneous Treatment Effect (HTE) is about 102 kg/ha and is statistically significant at the 10% level, indicating

that participants gained slightly more from the project than a randomly selected non-participant would have.

When disaggregated by state, the impacts are consistently larger in Zamfara than Jigawa. For example, the ATT in Zamfara is 1,560 kg/ha ($p < 0.01$), considerably higher than the 1,362 kg/ha gain in Jigawa. Similar patterns hold for the ATU (1,530 vs. 1,277 kg/ha), ATE (1,546 vs. 1,321 kg/ha), and HTE (114 vs. 88 kg/ha). In all cases, ATT, ATU, and ATE are positive and significant at $p < 0.01$. These results indicate that the TRIMING project significantly increased rice yield for participants, and would likely have done so for non-participants as well. The consistently larger effects in Zamfara underscore the importance of context-sensitive approaches to irrigation development and productivity enhancement.

Overall, these findings corroborate other studies. The results align with Sarma and Rahman (2020), who reported positive and significant ATT and ATU treatment effects using ESRM and PSM in a different context. Similarly, Mtenga et al. (2024) found positive and significant ATT and ATU estimates for the effect of village savings and loans associations (VSLA) on crop productivity. These findings are also consistent with John et al. (2019), who reported that contract farming participation significantly increases yields of contract farmers and has the potential to raise yields of non-contract farmers.

Table 2: Endogenous Switching Regression Estimates for Rice Yield (Participants vs. Non-Participants)

	TRIMING Participation				Participants Yield Outcome				Non-Participants Yield Outcome			
	Coefficient	Std. err.	z	P>z	Coefficient	Std. err.	z	P>z	Coefficient	Std. err.	z	P>z
Farm size (ha)	-0.644	0.147	-4.37	0.000***	2055	101.106	20.33	0.000***	1401	90	15.55	0.000***
labour mandays	0.003	0.001	2.05	0.040**	-1.021	0.80872	-1.26	0.207	-1.336	0.982	-1.36	0.174
Fertilizer (kg)	0.001	0.001	0.91	0.363	1.291	0.34804	3.71	0.000***	2.089	0.46	4.54	0.000***
Pesticides (ltrs)	0.07	0.014	4.95	0.000***	-0.829	7.39293	-0.11	0.911	-29	14	-2.06	0.039**
No of technology adopted (No.)	0.047	0.047	0.99	0.321	-85	30.579	-2.77	0.006**	-50	29	-1.72	0.086*
Rice variety	-0.248	0.111	-2.23	0.025***	185	83.6165	2.22	0.027*	17	79	0.21	0.83
Education level	0.111	0.044	2.5	0.013***								
Household size (No.)	0.047	0.011	4.21	0.000***								
Experience (years)	0.006	0.005	1.19	0.234								
Access to credit	0.575	0.115	5.01	0.000***								
Distance to farm (km)	-0.037	0.02	-1.87	0.062*								
Access to irrig. Canals	0.122	0.138	0.88	0.376								
_cons	-1.106	0.314	-3.52	0.000***	804	156.137	5.15	0.000***	26	156	0.17	0.866
/lns1	6.444	0.046	138.95	0.000***								
/lns2	6.563	0.077	85.54	0.000***								
/r1	-0.336	0.144	-2.33	0.020*								
/r2	-1.481	0.286	-5.18	0.000***								
sigma_1	628.83	29.16										
sigma_2	708.18	54.33										
rho_1	-0.32	0.13										
rho_2	-0.9	0.05										

LR test of indep. eqns. : $\chi^2(1) = 35.04$ Prob > $\chi^2 = 0.0000***$

Field Survey, 2024. Note: ***, **, and * significant at 1%, 5% and 10% probability level.

Table 3: Average Treatment Effects (ESR Model)

States	Treatment	coefficient	std. err.	z	P> z
Jigawa	ATT	1361.668	23.90002	56.97	0.000***
	ATU	1276.713	28.1863	45.30	0.000***
	ATE	1320.655	17.48881	75.51	0.000***
	H.TE	87.96667	74.29048	1.18	0.236
Zamfara	ATT	1559.79	24.62484	63.34	0.000***
	ATU	1529.776	29.27065	52.26	0.000***
	ATE	1545.747	18.32537	84.35	0.000***
	H.TE	114.2131	87.1044	1.31	0.190
Pooled Sample	ATT	1468.067	16.92393	86.75	0.000***
	ATU	1408.859	20.11563	70.04	0.000***
	ATE	1439.95	14.74248	97.67	0.000***
	H.TE	101.8769	60.82617	1.67	0.094*

Notes: ATT = Average Treatment Effect on the Treated; ATU = Average Treatment Effect on the Untreated; ATE = overall effect; HTE (Heterogeneous Treatment Effect) is the difference ATT–ATU. Significance: *** ($p < 0.01$), ** ($p < 0.05$), * ($p < 0.10$).

Conclusion

This study rigorously evaluated the impact of the TRIMING project on rice yields of farming households in North-West Nigeria. The analysis consistently found that participation in TRIMING significantly improved rice yields. Both PSM and ESR models confirmed substantial positive effects: participating households had significantly higher yields, and non-participants would have also experienced large gains had they joined the project. The intervention's impact was notably greater in Zamfara State compared to Jigawa, indicating important regional heterogeneity in project effectiveness. The ESR results confirm that both observable and unobservable factors influenced participation and outcomes, underscoring the robustness of these findings. Notably, the observed negative effect of adopting multiple technologies on yield for both participant and non-participant groups' points to potential challenges in the design or management of complex intervention packages. This warrants further investigation into how farmers can be better supported when implementing multiple practices simultaneously.

Recommendations

Based on these findings, the following recommendations are proposed to enhance the effectiveness and sustainability of irrigation and agricultural development projects in Nigeria: Scale up irrigation interventions. Expand the TRIMING project to cover additional rice-growing regions, especially those with existing but underutilized irrigation infrastructure, to maximize national food security benefits. Customize interventions to local conditions. Conduct thorough baseline assessments and adapt project components to local agroecological, socio-economic, and cultural contexts. States like Jigawa, which showed relatively lower impact, require tailored strategies. Support multi-technology adoption. Develop integrated training programs to help farmers manage the complexity of adopting multiple technologies. This includes training on compatibility of practices and troubleshooting to prevent productivity losses from information overload or financial burden. Promote sustainable inputs. Encourage the use of organic fertilizers and Integrated Pest Management (IPM) through ongoing training and incentives. This will improve

environmental sustainability and long-term productivity by reducing reliance on harmful chemicals.

Strengthen monitoring and evaluation. The Federal Ministry of Water Resources should implement robust monitoring and evaluation frameworks to track the long-term sustainability of yield improvements. Monitoring should also assess broader impacts on household welfare, income diversification, and food security beyond just productivity gains.

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APPENDIX

Table A: Logit Factors influencing TRIMING Project participation

TRIMING Participation	Coefficient	std. err.	dy/dx	std. err.	Z	P> z
Age	-0.005	0.009	-0.001	0.002	-0.590	0.558
Gender	-0.336	0.194	-0.084	0.048	-1.740	0.082*
Household size	-0.001	0.017	0.000	0.004	-0.030	0.974
Education level	0.032	0.063	0.008	0.016	0.510	0.608
Farm size	-0.027	0.150	-0.007	0.037	-0.180	0.857
Cooperative membership	1.753	0.182	0.438	0.034	12.730	0.000***
Access to irrigation canals	-0.511	0.195	-0.128	0.048	-2.650	0.008***
Access to extension	0.574	0.159	0.143	0.038	3.730	0.000***
Distance to farm	-0.005	0.026	-0.001	0.007	-0.190	0.848
Household income	0.000	0.000	0.000	0.000	-0.020	0.980
Awareness of TRIMING project	1.550	0.384	0.387	0.094	4.120	0.000***



Willingness to adopt new tech.	-0.598	0.162	-0.149	0.039	-3.820	0.000***
_cons	-1.739	0.572			-3.040	0.002
LR chi2(12) = 301.69						
Prob > chi2 = 0.0000						
Pseudo R2 = 0.3534						
Log likelihood = -276.04834						

Field survey 2024, Note ***significant at 1%, ** significant at 5%, * significant at 10%

Table B: Covariate balance before and after matching

	Standardized differences		Variance ratio	
	Raw	Matched	Raw	Matched
Age	-0.070	0.127	0.799	1.051
Gender	0.007	-0.009	0.987	1.017
Household size	0.303	0.192	0.924	1.225
Education level	0.219	-0.071	0.938	1.447
Experience years	-0.112	-0.012	0.848	1.157
Farm size	0.024	0.088	0.698	1.094
Cooperative membership	1.419	0.118	0.231	0.677
Access to irrigation canals	0.163	-0.091	0.838	1.139
Access to extension	0.907	0.034	0.527	0.940
Distance to farm	-0.124	-0.037	1.257	1.270
Monthly household income	0.039	0.041	0.926	2.038
Awareness of TRIMING project	-0.190	-0.080	1.559	1.181
Willingness to adopt new tech.	-0.257	-0.062	1.138	1.019

Field survey, 2024. Note: Standard deviation < 0.1: Covariates are well-balanced between treated and control groups. Variance ratio close to 1: Variances of covariates are similar between treated and control groups.