Agriculture and Food

http://www.aimspress.com/journal/agriculture

AIMS Agriculture and Food, 3(2): 154–171.
DOI: 10.3934/agrfood.2018.2.154
Received date: 18 January 2018
Accepted date: 20 June 2018
Published date: 3 July 2018

Research article

Impact of irrigation technology use on crop yield, crop income and household food security in Nigeria: A treatment effect approach

Ogunniyi Adebayo[1,*], Omonona Bolarin[1], Abioye Oyewale[2,3] and Olagunju Kehinde[4]

[1] Department of Agricultural Economics, University of Ibadan, Ibadan
[2] Centre for Entrepreneurship and Innovation, University of Ibadan
[3] International Institute of Tropical Agriculture (IITA), Ibadan
[4] Agri-Food and Biosciences Institute(AFBI), 18a, Newforge Lane, Belfast, United Kingdom

* **Correspondence:** Email: bayogunniyiconsult@gmail.com; Tel: +2348032248847; Fax: +2348032248847.

Abstract: Using household survey data from a sample of about 2305 households selected from eighteen states in Nigeria, this paper analyses the impact of irrigation technology usage on crop yield, crop income and household food security in Nigeria among smallholder farmers. The logistic regression estimate revealed that years of education, household size, rainfall information, access to credit, regional dummies are the main drivers of usage decision. The results of the linear regression with endogenous treatment effects showed that irrigation technology use is positively related to crop yield, crop income and household food security. In consistence, the impact analysis using propensity score matching (PSM) also showed a significant and positive effect of irrigation technology use on crop yield, crop income and household food security. We suggest to policy makers, implementers, and any funding agencies with similar interest to further capitalize and scale up the irrigation technology facilities, especially for the poor households, and create more awareness to improve the livelihood of rural households. However, despite the positive impact of irrigation technology use, we contend that other sustainable irrigation sources, such as rainwater harvesting should be used due to possible environmental impact in the excessive use of irrigation technology. Moreover, rained agriculture can be improved with other farming techniques such as agroforestry and soil and water conservation practices.

Keywords: irrigation; food security; crop yield; treatment effect approach

1. Introduction

In sub-Saharan Africa (SSA), agriculture forms the backbone of livelihood for majority of the population [1] especially rural households [2]. A larger part of this region is rain-fed prone to drought and desertification [3]. According to the report from the international finance cooperation [4], it was revealed that growing population and changing food consumption patterns in SSA was estimated to necessitated doubling of food production in developing countries by 2050. Meanwhile, about 85% of the increase would need to come from higher crop yields and greater crop intensity given limited scope of agricultural land expansion [5]. However, the major bottleneck to further increase in agricultural production is the scarcity of agricultural water [6]. This has therefore informed and attracted the attention of national planners and policy makers to irrigation as a means of supporting future food production endeavors. As earlier stated, about 85% of the poor in SSA live in the rural areas and depend greatly on agriculture for their livelihoods. Yet agriculture in the region remains largely subsistence and production has not kept pace with population growth [7], food self-sufficiency has declined [8], farm families are locked in a low input low income system, with yields low and stagnating [9], the household income required for food purchase to enhance food security is consistently on the low [10]. Furthermore, the erratic rainfall pattern also creates uncertainty for agricultural production and this accentuates the need for irrigation [11].

In order to elucidate the concept of irrigation, we follow the definition of FAO [12] of irrigation as the supply of water to agricultural crops by artificial means, designed to permit farming in arid regions and to offset the effect of drought in semi-arid region. Van Averbeke et al. [13] also noted that irrigation water is applied to ensure that soil moisture is sufficient to meet crop water needs and thus reduce water deficit as a limiting factor in plant growth. The type of irrigation methods that majorly used by the irrigators in this study are divert stream, bucket, hand pump, treadle pump, motor pump and gravity. Historically, irrigation is a method for improving natural production by increasing the productivity of available land and thereby expanding total agricultural production especially in the arid and semi-arid regions of the world [14]. Availability and access to irrigation was considered essential for crop production, income generation, asset creation and expansion of development frontiers [15–17]. For instance, the success of the green revolution in Asia was achieved through rapid expansion of irrigated areas in the recent past, coupled with availability and access to new technology in form of high yielding varieties (HYV), fertilizers and tube-well and water extraction mechanisms [14]. Irrigated agriculture is one of the components of world food production, which has contributed significantly to maintaining world food security and to the reduction of income poverty[1] especially the rural households [15]. About 17% of global agricultural land is irrigated and accounts for up to 40% of the global production of cereal crops which is still on the increase [18]. In addition to food security, irrigated agriculture significantly contributes towards generating rural employment and maintaining rural livelihoods [14].

Smith [19] noted that irrigation enables the farmer to control the available water throughout the growing season, which boosts production and reduces exposure to water shortfalls or seasonal droughts. In many areas where rainfall is inadequate, unreliable, or incorrectly timed, reducing the

[1] Reducing income poverty enables households to achieve food security, accumulate assets, reduce vulnerability to external shocks, and provide for the future. Reduction of income poverty often also improves access to education, health services, and clean water.

farmer’s dependency on suitable weather patterns is important for the best production. However, concerns have been raised about the economic viability and social acceptability. World Commission on Dams in its report [20] on “Dams and Development” argued that irrigation dams have been less profitable in economic terms, destructive to ground water resources, displaced marginal and poor farmers and have made them landless laborers and ultimately driven them to become urban dwellers. However, the positive impacts of irrigation infrastructures could far outweigh some of these negative impacts, which can be potentially minimized or can be duly compensated through improved planning and management of irrigation systems [14].

Specifically, increasing adoption of irrigation technology in Nigeria is an important requirement for increasing Nigeria’s agricultural productivity [21]. However, Sani et al. [22] stated that despite the government’s effort to expand irrigated areas through largescale public irrigation schemes, a significant majority of Nigeria’s irrigated acreage is the result of small-scale private irrigation operations: “Small plots under the control of farmers using technology they can effectively operate and maintain”. He further stressed that private irrigation systems across Nigeria are more diverse than public irrigation systems, as farmers design systems that meet their diverse needs within their agroecological and socioeconomic environments. Such diversities include their capacity to access water and distribute it to their plots.

Nigeria been predominantly an agricultural country with an estimated 98.3 million hectares of productive land resources (but just 900,754 hectares are irrigated) of which about 75 per cent is arable, and an estimated human population of over 150 million [1]), which is predominantly agrarian [23]. Yet, Nigeria lags behind in its ability to grow enough food to feed its teeming population [24] which cannot be disconnected from low productivity [25]. Despite its importance, Nigerian agriculture has to a large extend not diverted itself from most of the characteristics of the peasant economy that was prominent in the pre-independence period [26]. Low yield, reduced income, food and fibre shortages resulting in under-nourishment of people and under-capacity utilization of industries have become the rule rather than exception. This couple with increasing populating pressure has resulted in food insecurity [27].

Dessalegn [28] suggests that, where rainfall is insufficient and unreliable, rain-fed agriculture cannot fully support food production, thus investment on irrigation can help stabilize agricultural production and promote food security. In Nigeria, where poverty is widespread, rain-fed agriculture is no longer reliable for sustainable agricultural production in the country. Hence, the development of irrigation is crucial for sustainable agricultural production and for enhancing the rural livelihoods in the country. Recognizing that the full potentials of Nigeria agriculture could not be realized without the development of her water resources for irrigation, governments in Nigeria have adopted various irrigation development policies. However, majority of the policies have not yielded the required results.

As earlier stated, improved access and use of irrigation infrastructure will increase crop yield, agricultural production and farm income of a farming households. However, the nexus between irrigation use and its impacts specifically on crop yield, crop income and food security are yet clearly understood or reported in irrigation literature. Therefore, this leaves a vacuum to be filled by this study. A number of studies [25,29,30] have treated irrigation impacts separately and individually without credence given to their linkages.

More importantly, Mendola [30] and Awotide [3] observed that one of the main drawbacks of many past empirical impact evaluation studies is the failure to point explicitly to a causal effect of the adoption of agricultural technology on outcomes of interest. Most studies failed to establish an appropriate counterfactual situation that could facilitate the true identification of the causes of change. This raises the concern that some of these studies might have overestimated, underestimated, or reported impact where in actual fact there was no impact at all. In this study, the ability to assess what the situation would be if the crop farmers had not use irrigation technology (the counterfactual scenario) is an important condition for us to be able to provide a consistent estimate of the impact of irrigation technology use on crop yield, crop income and food security. To achieve this objective, we adopted the two main methodologies that have been widely utilized in the literature: Propensity score matching (PSM) and the endogenous treatment regression model. Against this backdrop, this study therefore examined determinants and the impact of irrigation technology use on crop yield, crop income and household food security.

2. Analytical framework and estimation techniques

2.1. Propensity score matching (PSM) technique

The PSM method was adopted in this study, first to generate control group and then to tackle the problem of bias due to selection on observables (overt bias). The PSM method has been generally adopted in the impact evaluation literature for many years. Among many studies that have utilized the PSM in program impact evaluation [31–39]. The PSM essentially estimates crop farmer's propensity to use individually irrigation technology and it is commonly estimated using the Logit regression as a function of observable characteristics of the farmers and then matches each crop farmer with similar propensities. The PSM produces a variable called the propensity score which is the probability that a farmer would use irrigation technology which is based on the farmer's observable characteristics. The propensity score (P(x)) is written as:

$$P(x) = \Pr(T = 1 \mid X = x) \tag{1}$$

The obtained propensity score is usually used to create matched samples, uniform subgroups, and weight for balancing characteristics among the farmers and a variable for controlling or adjusting the data [40]. When farmers have similar scores (propensity), their assignment to the users is largely random with respect to relevant covariates, and thus takes the looks of a controlled experiment, thereby enabling us to accurately identify causal effects. The proficiency of the PSM is used to control for the variances in identified covariates that might influence the crop farmers' adoption decision. This is pivoted on the Conditional Independence Assumption (CIA)[2] which states that, conditional on observables characteristic of the crop farmers (X), yield, income and food security are independent of irrigation technology use written as: $TY_1Y_0 \cup T|X$. Another vital assumption is the common support or overlap condition: $0 < P(T = 1 \mid X) < 1$. According to Heckman et al. [40], this condition ensures that the treatment observations have comparison observations "nearby" in the propensity score distribution. Only in areas of common support can inferences be made about causality. A balancing test has been conducted, that is, to ascertain if:

[2]See Wooldridge 2002.

$$\hat{P}(X \mid T=1) = \hat{P}(X \mid T=0) \tag{2}$$

However, it is worthy of note that the estimation of the propensity score is a necessary but not sufficient condition to calculate the parameters of interest such as the average treatment effect (ATE), average treatment effect on the treated (ATT), and average treatment effect on the untreated (ATU). There is a need to search for the fit counterfactual(s) that match individual user depending on its propensity score. The nearest neighbour matching (NNM) and the kernel-based matching (KBM) approaches are the most commonly used matching methods. NNM pairs users and non-users with the same propensity scores, while the KBM measures treatment effects by subtracting from each outcome that is observed in the treatment group a weighted average of outcomes in the comparison group. The average treatment effect on the treated (ATT) is then estimated by the average of the within-match differences in the outcome variable between the users and non-users [41,42]. The examples are as follows:

$$\begin{aligned} & E(Y1-Y0 \mid T=1) = E\left[E(Y1-Y0 \mid T=1, P(x))\right] \\ & = E\left[E(Y1 \mid T=1, P(x)) - E(Y0 \mid T=0, P(x))\right] \end{aligned} \tag{3}$$

2.2. Linear regression with endogenous treatment effects

In order to deliver a consistent evaluation of the impact of irrigation technology use on our outcomes of interest, in addition to PSM presented above, the linear regression with endogenous treatment effect was used to account for endogeneity between use of irrigation technology and the outcomes. The reason owes to other bias related to unobservable characteristics of the farmers which cannot be controlled using ordinary least square (OLS) and PSM. As stated by Awotide et al., the endogenous treatment regression model is a linear potential outcome model that allows for a specific correlation structure between the unobservable that affects the treatment and the unobservable that affects the potential outcomes. Following the study by Heckman et al., we tried to unite the treatment effect literature with the classical selection-bias literature by considering a model of potential outcomes of the type attributed to Roy [43].

$$Y_1 = X_1\gamma_1 + \upsilon_1 \tag{4}$$

$$Y_0 = X_0\gamma_0 + \upsilon_0 \tag{5}$$

Equations 4 and 5 are the two potential outcomes equations in the two possible states (user and non-user) of the farmers.

$$T^* = Z_T\psi_T + V_T \tag{6}$$

If T(Z) represents the observed outcome, where T(Z) = 1 if the farmer used the technology T(Z) = 0 if the farmer is a non-user. The T^* is a latent variable which generates T(Z) as follows:

$$T(Z) = 1\{T^*(Z) \geq 0\} = 1\{X_\varphi + \upsilon_\rho \geq 0\} \tag{7}$$

The following counterfactual choice variables are also defined. For any z which is a potential realization of Z, we define the variable $T(z) = 1[Z_{\phi} \geq V_T]$, which shows whether or not the individual farmer would adopt the technology. The value of Z been externally set to z, holding constant the unobserved υT. This requires an exclusive restriction and denoted by Zn some element of Z which is not in X, it is possible for us to employ an individual farmer's probability of using the irrigation technology without tampering with the potential outcomes. Finally, we assume (υTυ1υ0) is independent of X and Z. If the observed outcome is:

$$Y = TY_1 + (1 - T)Y_0 \tag{8}$$

The average treatment effect (ATE), defines the gain or impact of adoption of irrigation technology on crop income, crop yield and food security this can be expressed as follows:

$$Y = Y_1 - Y_0 \tag{9}$$

Therefore, the ATE conditional on X = x can be expressed as:

$$ATE\ (x) = E\ (\Omega|X = x) = x_1(\psi_1 - \psi_0) \tag{10}$$

The average treatment effect on the treated (ATT), which is the gain in crop income, crop yield and food security those farmers that actually select the adoption of irrigation technology, can be expressed as follows:

$$ATT = (x,z\ T(z) = 1) = E\ (\Omega|X = x, Z = z, T(z) = 1) = x_1(\psi_1 - \psi_0) + E(v_1 - v_0|v_T \geq -z_1\eta) \tag{11}$$

The ATE and ATT were obtained using the etregress command available in Stata version 14. According to the StataCorp (2013) [44], the etregress estimates an ATE of a linear regression model that also includes an endogenous binary treatment variable. In addition to the ATE, the parameters estimated by etregress can be used to estimate the ATT when the outcome is not conditionally independent of the treatment and can also be used to account for heterogeneity in the impact of the treatment variable. The description and definition of all the variables used in the models is presented in Table 1 below.

Table 1. Summary statistics of some selected variables.

Variable	Variable label	Pooled (n = 2334)		Technology users (n–282)		Technology non-users (n = 1939)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Food security	Per capita food expenditure (naira)	6399.469	28564.07	4871.06	19814.28	6634.462	30348.54
Crop income	Per capita value of maize sold (naira)	20290.240	23427.54	21255.77	24880.98	20414.66	23276.86
Yield	Maize yield in kilogram per hectare	1152.098	1270.814	1143.71	1254.774	1162.535	1275.64
Education years	Education level of household head (years)	7.504	5.769	7.129	5.745	7.507	5.828
Age new	Age of household head (years)	47.451	13.971	47.450	13.305	47.662	14.112
Field size	Total size of farm land owned by household head (hectare)	4.419	3.163	5.368	3.462	4.256	3.130
Access credit	1 if access credit, 0 otherwise	0.152	0.360	0.131	0.338	0.159	0.366
Experience drought	1 if experienced drought, 0 otherwise	0.182	0.386	0.191	0.394	0.186	0.389
Rainfall information	1 if receive information on rainfall and temperature, 0 otherwise	0.547	0.497	0.518	0.500	0.554	0.497
Gender	Gender of household head (1 if household head is male; 0 otherwise)	0.878	0.326	0.943	0.231	0.887	0.315
Marital status	1 if married, 0 otherwise	0.886	0.317	0.943	0.231	0.898	0.302
Farming experience	Experience of household head in farming activities (years)	25.487	16.275	26.950	13.744	25.949	16.327
Member any association	1 if household head belong to any group; 0 otherwise)	0.622	0.484	0.503	0.500	0.656	0.474
Household size	Number of people in the household	7.175	4.606	7.926	4.769	7.251	4.480
North-West	1 if farming household is resident in northwest geo-political zone; 0 otherwise	0.352	0.477	0.609	0.488	0.312	0.463
South-South	1 if farming household is resident in south-south geo-political zone; 0 otherwise	0.047	0.213	0.017	0.132	0.053	0.224
South-East	1 if farming household is resident in south east geo-political zone; 0 otherwise	0.043	0.204	0.028	0.166	0.046	0.209
North-Central	1 if farming household is resident in north central geo-political zone; 0 otherwise	0.269	0.443	0.187	0.391	0.271	0.444
North-East	1 if farming household is resident in northeast geo-political zone; 0 otherwise	0.047	0.212	0.028	0.166	0.052	0.221
South-West	1 if farming household is resident in south west geo-political zone; 0 otherwise	0.238	0.426	0.127	0.334	0.266	0.442

3. Data and sampling framework

This study uses household survey data collected by International Institute of Tropical Agriculture (IITA) in Nigeria for the purpose of evaluating the impact of various interventions on important outcomes of interest. The survey was carried out in the course of November, 2014–February, 2015. One vital aspect of any credible impact assessment is a randomly selected, nationally representative sample. In order to achieve this, this study adopted the multistage stratified random sampling technique in order to obtain a nationally representative data, and also to ensure that at least one crop farming household is picked from each of the strata, even if the probability of being selected is far less than 1. In addition, this sampling technique reduces sampling error and can produce a weighted mean that has less variability than the arithmetic mean of a simple random sample of the crop famers' population in Nigeria. The states in Nigeria were divided into homogenous sub-groups based on the hectare of land devoted to crop production. This gave five groups, out of which 18 states were randomly selected. The selected states contributed about 62.21% to the total land size devoted to crop production in Nigeria. This shows that the selected states are major crop producing areas in Nigeria and can therefore nationally represent the crop farming households in Nigeria, hence allowing a generalization of the results to the whole nation.

On the overall the sampling framework generated a total of 2305 farming households. In arriving at this sample size, account was taken of the constraints imposed by limitation of resources, the need to ensure a manageable and controllable sample structure and the three important levels at which data are required for any future agricultural development planning purposes, viz national, state and LGAs levels. Among many others, the survey includes information on socio-economic/demographic characteristics of the households, household expenditure on food and non-food, output for maize and other notable crops, and income from various sources also irrigation use. The data was collected electronically using the "surveybe" software.

We found that minority (12.70 percent) of the crop farmers used the technology. Though with little disparities, more irrigation user has experienced drought at certain period in their farming experience which is pose to be a potential reason to adopt irrigation technology. Majority of the farmers are male with mean age of 47 years. The technology users have more farming experience than the non-users and they have more farm size to practice the irrigation.

4. Result and discussion

4.1. Determinants of irrigation technology use: A logistic regression model

To identify the factors that affect household use of irrigation technology in the study area, the Logit model was used to generate propensity scores for the matching algorithm. The pseudo R-square indicates that about 10.6% of the variation in the irrigation decision model can be explained through the included explanatory variables. The overall model is statistically significant at a P-value of 0.006. Hence, the chosen observable characteristics adequately explain the probability of use. The signs show the direction of change in the probability of the farmers that adopted the irrigation technology given the change in the explanatory variables. A positive sign shows increase in the probability of adoption if irrigation technology while a negative explains the converse. The significant variables that determine the adoption of the irrigation technology are education years, household size, rainfall information, access to credit, regional dummies.

The model revealed a significant and positive relationship between education years and the probability of adoption of irrigation technology. This is suggest number of years spent in school by farmers will increase the probability of adoption of irrigation technology. This clearly depicts the role of education and literacy as a major determinant of adoption of technology among farmers in Nigeria. Studies [3,45,46] have shown that education plays systematic role in adoption of technology. This is consistent with prior expectation as more educated farmers have better knowledge on the importance of adopting new technologies. Household size was statistically significant, and it is negatively associated with the probability of use irrigation in farming. The possible reason is that household with larger family size can probably have other household expenses that can hinder the adoption of irrigation technology if beyond the household budget. Hence, households with larger household size can probably choose to participate in irrigation farming in the area. More specifically, a unit increase in household size will reduce the probability of adoption of irrigation technology by 31.09 percent. This is in line with the finding of Wetengere [47].

Access to rainfall information was found to increase the probability of irrigation use. The positive coefficient of rainfall information implies that, farmers with more access to rainfall information were more likely to adopt irrigation technology. The probable reason can be associated to the fact that access to rainfall information can help the farmers to put up adaptation strategies against rainfall shortage as the agricultural production system in Nigeria is predominantly rain-fed [48]. Positive and significant relationship was found between farmer's access to credit and adoption of irrigation technology, suggesting that the farmers with credit availability have higher opportunities to engage in irrigation farming. One of the major causes of different rates of adoption is a differential access to credit among farmers [46]. Access to credit is one way to improve farmer's access to new technology and increase farmer's ability to purchase inputs. Access to credit played an important role in improving household livelihoods. Households with access to credit purchased more inputs (fertilizer, improved seed variety, pesticides, herbicides) than those without. Access to credit support also ensures that farmers can secure inputs in time. This leads to improved agricultural output, resulting in increased farm income. Machete et al. [49] suggest that one of the most critical problems threatening the viability of irrigation is the lack of credit.

The regional dummies included in the model are the South-South, South-East, North-East, North-West and North-Central and they significantly determined the use of irrigation technology in Nigeria. All the southern dummies (South-South and South-East) are negative implying that most farmers in these regions were less likely to adopt or use irrigation technology. The southern region of Nigeria is a humid-tropics region where there is more rainfall compare to the northern region [50]. On the other hand, the northern dummies (North-East, North-West and North Central) are positive and significant, suggesting that farmers in these regions are more likely to adopt irrigation technology. This is expected due to variation in rainfall pattern across regions, especially North-East and North-West of Nigeria coupled with social crisis in this region [10]. Northern region mostly suffer from drought which necessitate adoption of irrigation technology in order to enhance productivity and food security. Additionally, in the northern regions, there is easy access to big commercial markets particularly for exotic vegetables, which serves as an incentive for farmers [51].

Table 2. Determinants of the use of irrigation technology.

Variables	Coefficient	Standard error	Marginal effect
Age	−0.2120	0.1136	0.0030
Farming experience	−0.0011	0.0046	0.0450
Primary occupation	0.2249	0.1316	0.3409
Education years	0.0205**	0.0087	0.3423
Farm size	0.0104	0.0157	0.4590
Household size	−0.3216**	0.1404	0.3109
Rainfall information	0.1896*	0.0969	0.2349
Access to credit	0.3216**	0.1404	0.5609
Drought experience	0.0276	0.1227	0.2356
Gender (male)	0.1435	0.2127	0.3567
Marital status (married)	−0.1402	0.2253	0.1234
Membership group	0.1122	0.1082	0.5670
Regional dummies			
South-South	−0.4003*	0.2436	0.4570
South-East	−0.3060**	0.1467	0.1240
North-Central	0.3656***	0.1428	0.9089
North-West	0.3216**	0.1404	0.9803
North-East	0.5282**	0.2337	0.4560
Constant	0.8432***	0.2986	
Prob > Chi2 = 0.006			
PseudoR^2 = 0.0160			
Log likelihood = −1329.62			
****Significant at 1% level, **Significant at 5% level, *Significant at 10%*			

Source: Author's estimation, 2017. ***Significant at 10% level, **Significant at 5% level, *Significant at 1% level.

4.2. Impact of irrigation technology use on crop yield, crop income and food security: PSM

We used the propensity score matching to estimate the impact of irrigation use on outcome of interest. The propensity score was operationalized as the predicted probability of use estimated from a logistic regression of irrigation technology on the predictors. To further test for balancing, that is, quality of match, a common support graph was drawn (Figure 1). This test is effective because it shows visual presentation of overlap of propensity scores between the treated and control cases. A larger proportion of overlap implies a good match of treated and control cases [52]. From Figure 1, it can be seen that there is a considerable overlap of propensity scores between the treated and control cases; this implies that the match is good and balanced. The empirical results of the impact of irrigation technology use on crop yield, crop income and food security are presented in Tables 3 and 4. It showed that the use of irrigation technology exerted a positive and significant impact on crop yield, crop income and food security (proxy with mean per capita food expenditure) in Nigeria. Specifically, the PSM estimate showed that use of irrigation technology significantly increased the crop yield, crop income and food security of the users compare to the non-users' counterpart. This represented the average change in value of the outcomes brought about by the use of irrigation technology. According to the Dowgert [53], irrigated crop yields are 2.3 times higher than those from rain-fed ground. These numbers demonstrate that irrigated agriculture will continue to play an important role as a significant contributor to the worlds food supply. Our estimate is in consistence with this submission as we found that the average treatment effect on the treated (ATT) of the irrigation technology use on crop yield for the users was 1954.66 kg/ha for NNM and 2354.66 kg/ha for KBM, this shows that the causal effect of irrigation technology use on crop yield is between 1954.66 kg/ha and 2354.66 kg/ha. However, picking any crop farmers at random, the average treatment effect (ATE) was found to be 507.09. This implies that if any crop farmers in the population used the irrigation technology the crop yield of the farmers will be increased by 507.09 kg/ha. This result corroborates with the finding of Jin et al. [54] that irrigation technology use has a strong and significant impact on crop productivity with the dominant effects on cropping intensities (see Table 3—NNM and Table 4—KBM).

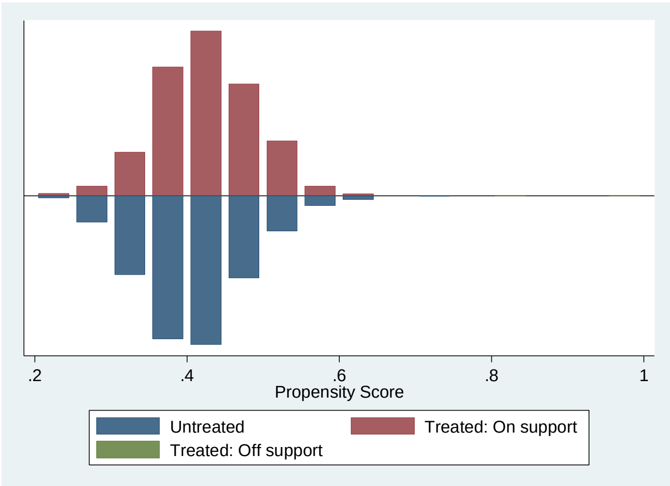

Figure 1. Density distributions of propensity scores using kernel matching.

Table 3. Average impact estimates of PSM: Nearest to neighbor matching (NNM).

Outcome	Sample	Treated	Control	Difference	t-stat
Crop yield	Unmatched	2907.08	638.33	2268.75	6.33***
	ATT	2907.08	952.42	1954.66	5.09***
	ATU	1087.04	754.89	332.15	
	ATE			507.09	
Crop income	Unmatched	196007.43	96228.93	99778.50	2.45**
	ATT	196007.43	103445.02	92562.41	3.60***
	ATU	117808.00	87903.81	29904.19	
	ATE			22007.24	
Food security	Unmatched	180677.04	120998.98	59678.06	6.03***
	ATT	180677.04	129525.09	51151.95	6.09***
	ATU	76328.33	56983.17	19345.16	
	ATE			36977.24	

Source: Author's estimation, 2017. ***Significant at 10% level, **Significant at 5% level, *Significant at 1% level.

Table 4. Average impact estimates of PSM: Kernel based matching.

Outcome	Sample	Treated	Control	Difference	t-stat
Crop yield	Unmatched	2907.08	638.33	2268.75	5.89***
	ATT	2907.08	552.42	2354.66	2.43**
	ATU	1087.04	655.21	425.83	
	ATE			299.19	
Crop income	Unmatched	196007.43	96228.93	99778.50	3.45***
	ATT	196007.43	123490.03	72517.40	1.79*
	ATU	117808.00	84579.81	33228.19	
	ATE			28887.90	
Food security	Unmatched	180677.04	90998.98	59678.06	7.77***
	ATT	180677.04	128885.38	51791.66	6.07***
	ATU	67028.83	50083.45	16945.38	
	ATE			23468.80	

Source: Author's estimation, 2017. ***Significant at 10% level, **Significant at 5% level, *Significant at 1% level.

Similarly, the empirical result of the impact of irrigation technology use on income for the entire households in the study area is presented in Table 3 (NNM) and Table 4 (KBM). Household income is not synonymous with cash income but is a computed value that includes cash income earned from various on-and-off farm employments; which are summarily grouped based on the sources which are agriculture wage employment, agriculture self-employment, non-agriculture self-employment, non-agriculture wage employment, remittances. In this study, different sources of household income were identified but we specifically used the crop income[3]. We found that crop farmers that used the irrigation technology had an average crop income increase of ₦92562.41k for NNM and ₦72517.40k for KBM than their counterparts in the counterfactual category. Increased crop income can be convincingly attributed to the fact that the irrigation technology focused on assisting smallholder farmers in the study area. This is part of the importance of the usage, to increase yield, develop profitable and resource efficient agro-enterprises. It will help to meet existing market opportunities as opposed to them marketing any surplus that they grew for subsistence. In Ethiopia, Mengistie et al. [55] found that the use of irrigation technology significantly improved crop income. Dananto et al. [15–17] also have the same submission on the positive and significant impact of irrigation technology use on crop income.

Furthermore, we estimated the impact of the use of irrigation technology on food security proxied with the mean per capita food expenditure. Several studies [17,56,57] have submitted that developing countries cannot assure food security with rain-fed agriculture alone without a substantive contribution of irrigation. In congruence, we found that the use of the irrigation had a positive and significant relationship with the food security status of the crop farmers. The average treatment effect on the treated (ATT) of irrigation technology use on food security for the users was 51151.95 and 51791.66 for nearest to neighbor matching and kernel based matching respectively. Implicatively, usage of irrigation technology has increased the mean per capita food expenditure of the irrigation users by ₦51151.95k and ₦51791.66k. This is consistent with the findings of previous studies [58–62].

[3] Crop income in this study is the income generated from the sales of the crop produce in naira value.

4.3. Impact of irrigation technology use on crop yield, crop income and food security: Endogenous treatment regression model

Due to the problem of unobservable differences between the users and non-users of irrigation technology, the use of the PSM approach alone cannot provide a conclusion about the impact of irrigation technology use. As all the biases have not been controlled, the results could lead to overestimation or underestimation of the impact and be capable of providing erroneous policy recommendations. To be sure that the estimated impacts on crop yield, crop income and food security was due to the irrigation technology use and not a result of any other unobservable characteristics of the farmers, we employed the linear regression with endogenous treatment effects model. In this regression, we used awareness of irrigation technology (as instrument) that certified the exclusive restriction. This variable can influence usage but does not have any effect on the crop yield, crop income and food security except through irrigation technology use.

We estimated the ATT of being a user of irrigation technology on crop yield, crop income and food security and also included other covariates, such as number of gender, age, farm size, household size, rainfall information, formal education, occupation, drought experience, membership of social group and marital status. In addition, we also accounted for the heterogeneity effect of the treatment by interacting the treatment with three covariates, gender, credit access and contact with extension agents. The result of the analysis, which fitted the model well, is presented in Table 5. With more robust estimation, there is consistence on the impact of irrigation technology use on the outcome of interest (crop yield, crop income and food security). Considering the value of the impact recorded, usage of the technology increased the crop yield, crop income and food security by 4647.94, 68379.62 and 44760.772 respectively. By implication, the usage of the irrigation technology has increase the crop yield by 4647.94 kglha, income generated from crop has also increased by ₦68379.62k while the mean per capita food expenditure was found to increase by ₦44760.77k due to the usage of the irrigation technology. As noted by researchers [3,46,61,62], adoption of improved technology is key to transforming rural economy, reducing poverty and improving livelihood outcomes.

5. Conclusion and policy recommendation

This study focused mainly on providing an answer to the question of how much impact the use of irrigation technology has had on crop yield and by extension how irrigation technology use has contributed to the improved crop income and food security of the users in Nigeria. We started by documenting the factors that drives the usage of the technology among the sampled farmers. We found that years of education, household size, rainfall information, access to credit, regional dummies are the main drivers of usage decision. The study has substantiated that irrigation in the study area has significantly improved the crop yield, crop income and food security. Meanwhile, it is noteworthy to state that improved outcomes of interest (crop yield, crop income and food security) cannot be solely attributed to use of irrigation. Irrigation use is complemented with the other productivity enhancing indicators (such as access and adoption of improved crop varieties, land access and tenure security, better market access for products, better input supply in the form of seeds, fertilizers, and other input technologies. Therefore, irrigation technology use is not a substitute for other productivity enhancing factors rather a complementary factor.

We suggest to policy makers, implementers, and any funding agencies with similar interest to further capitalize and scale up the irrigation technology facilities and create more awareness in order to achieve improving livelihood outcomes of rural households, especially to offset the effect of drought in the arid and in semi-arid regions which is mainly the Northern region of Nigeria. However, despite the positive impact of irrigation technology use, we contend that other sustainable irrigation sources, such as rainwater harvesting should be used due to possible environmental impact in the excessive use of irrigation technology. Moreover, rained agriculture can be improved with other farming techniques such as agroforestry and soil and water conservation practices.

Table 5. Result of the endogenous treatment regression model.

Variables	Crop yield		Crop income		Food security	
	Coefficient	S.E	Coefficient	S.E	Coefficient	S.E
Age	−3.3228	9.3320	−125.3645	59.3572	1.1038	8.3044
Farming experience	0.4695	7.7574	20.18756	49.786	9.8750	7.0131
Primary occupation	120.7675	0.1316	659.7518	1416.958	350.1165*	200.2302
Education	494.0205***	188.9929	10.32202	94.919	−5.736246	13.40864
Farm size	214.8894***	25.8689	2165.709***	167.4617	167.74***	23.4614
Household size	41.18438**	17.69379	−899.881***	115.2294	223.8107***	16.66079
Rainfall information	0.1896*	0.0969	2072.89*	1178.917	545.5303	147.5792
Access to credit	−1.850908	297.1006	−1254.206	1894.704	200.3829	267.435
Drought experience	−335.3837*	204.154	15.244	1313.894	209.8444	186.2093
Gender	−787.936***	360.474	−74.98902	2334.579	−63.33046	333.4062
Marital status	614.7571	389.1616	−272.8022	2544.522	−120.0415	366.0315
Membership group	538.7804***	182.4609	4111.756***	1043.501	562.3102***	166.4803
Use of irrigation	4647.94***	256.5054	68379.62***	3371.974	44760.772***	367.0886
Interacted variables						
Use gender						
1	689.1731***	235.1647	9371.148***	1598.72	896.2523**	363.353
Use credit access						
1	1257.305***	247.2008	5572.105***	1519.601	−840.8188**	381.2318
Use rainfall information						
1	−135.7006	376.7113	6778.066**	2693.451	942.8195	343.1673
Constant	3158.036***	546.2643	8547.731**	3768.564	3158.722	520.1051
Use of irrigation technology with instruments						
Awareness of the technology	0.1512***	0.0450	0.0894	0.04778	0.66016***	0.066016
Constant	0.2482***	0.0361	0.2613	0.0375	0.2586977	0.2586977
Lambda			18138.86	2011.879	3022.455	217.3875
Rho	0.7381015	0.01955	0.6877071	0.0524703		
Sigma	4270.546	95.9732	26375.85	978.5741	3927.184	125.2088
Prob > Chi^2	0.0000		0.0000		0.0000	
Wald chi^2	487.76		486.29		315.06	

Acknowledgments

The author acknowledges the International Institute of Agriculture for the release of the data.

Conflict of interest

The authors declare no conflict of interest.

References

1. World Bank (2015) World Development Indicators 2015. Washington, D.C., USA.
2. Olinto P, Beegle K, Sobrado C, et al. (2013) The state of the poor: Where are the poor, where is extreme poverty harder to end, and what is the current profile of the world's poor? *World Bank–Econ Premise* 125: 1–8.
3. Awotide BA, Abdoulaye T, Alene A, et al. (2015) Impact of access to credit on agricultural productivity: Evidence from smallholder cassava farmers in Nigeria. International Conference of Agricultural Economists. August 9–14, Milan, Italy.
4. International Finance Corporation (IFC) (2014) Impact of efficient irrigation technology on small farmers. IFC Brochure.
5. Edgerton MD (2009) Increasing crop productivity to meet global needs for feed, food, and fuel. *Plant Physiol* 149: 7–13.
6. Yang H, Zehnder AJB (2001) China's regional water scarcity and implications for grain supply and trade. *Environ Plann A* 33: 79–95.
7. Byerlee D, Janvry AD, Sadoulet E (2009) Agriculture for development: Toward a new paradigm. *Annu Rev Resour Econ* 1: 15–31.
8. Fraiture CD (2005) Assessment of potential of food supply and demand using the Watersim model. *IWMI Res Rep* 18: 55.
9. Rosegrant MW, Cline SA, Li W, et al. (2005) Looking ahead: Long-term prospects for Africa's agricultural development and food security. *Vision Discuss Pap* 1: 7–8.
10. Ogunniyi A, Olagunju K, Kabir SK, et al. (2016) Social crisis, terrorism and food poverty dynamics: Evidence from northern Nigeria. *Int J Econ Financ Issues* 6.
11. Inocencio A, Kikuchi M, Tonosaki M, et al (2007) Costs and performance of irrigation projects: A comparison of sub-Saharan Africa and other developing regions. Research report, IWMI, Pretoria.
12. Hillel D (1997) Small-scale irrigation for arid zones Principles and options. FAO.
13. Averbeke WV, Denison J, Mnkeni PNS (2011) Smallholder irrigation schemes in South Africa: A review of knowledge generated by the Water Research Commission. *Water SA* 37: 797.
14. Bhattarai M, Sakthivadivel R, Hussain I (2002) Irrigation impacts on income inequality and poverty alleviation, policy issues and options for improved management of irrigation systems. *IWMI Work Pap* 37: 350–352.
15. Dananto MD, Alemu E (2014) Irrigation water management in small scale irrigation schemes: The case of the Ethiopian rift valley lake basin. *Environ Res Eng Manage* 67: 5–15.
16. Teshome W (2003) Irrigation Practices, state intervention and farmer's life: Worlds in drought-prone Tigray. Ph.D.Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

17. Taffesse N (2002) The role of irrigation development in enhancing household food security: A case study of three small-scale irrigation schemes in southern nations, nationalities and peoples' region. Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
18. Faurès JM, Hoogeveena J, Bruinsmab J (2002) The FAO irrigated area forecast for 2030. FAO, Rome, Italy.
19. Smith LED (2004) Assessment of the contribution of irrigation to poverty reduction and sustainable livelihoods. *Int J Water Resour Dev* 20: 243–257.
20. Garten JE, Rothkopf DJ, Archer D (2000) Dams and development: A new framework for decision-making. WCD, London, UK.
21. Takeshima H, Nagarajan L, Salau S, et al. (2015) Nigerian farmers' preferences on the timing of the purchase of rice, cowpea, and maize seeds. *NSSP Work Pap* 20: 5–12.
22. Sani A, Yakubu AA, Bello HM (2010) Resource-use efficiency in rice production under small scale irrigation in Bunkure Local Government Area of Kano State. *Niger J Basic Appl Sci* 18.
23. IFAD (2012) Youth in agriculture. Special session of the Farmers' Forum Global Meeting, Synthesis of Deliberations, 18 February, Italy.
24. Ohikere JZ, Ejeh AF (2012) Impact of small scale irrigation technologies on crop production by fadama users in Kogi State, Nigeria. *Adv Appl Sci Res* 2: 854–861.
25. Dauda TO, Asibiro OE, Akinbode SO, et al. (2009) An assessment of the roles of irrigation farming in the millennium development goals. *Afr J Agric Res* 4: 445–450.
26. Adewumi MO, Omoresho OA (2002) An analysis of production objectives of small-scale rural farming households in Kwara State, Nigeria. *J Rural Dev* 25: 201–211.
27. Ndanitsa MA, Umar IS (2005) Optimum farm plans for fadama farms in Niger State, Nigeria. *J Agric Ext Soc Niger (AESON)* 2005: 1–6.
28. Rahmato D (2011) Water resources development in Ethiopia: Issues of sustainability and participation. *Cancer Res* 70: 173.
29. Takeshima H, Adeoti A, Okoli, S, et al. (2010). Demand characteristics for small-scale private irrigation technologies: Knowledge gaps in Nigeria. *NSSP Work Pap* 2010: 717–723.
30. Mendola M (2007) Agricultural technology adoption and poverty reduction: A propensity-score matching analysis for rural Bangladesh. *Food Policy* 32: 372–393.
31. Cochran WG, Rubin DB (1973) Controlling bias in observational studies: A review. *Sankhya, Ser A* 35: 417–446.
32. Rubin DB (1979) Using multivariate matched sampling and regression adjustment to control bias in observation studies. *J Am Stat Assoc* 74: 318–328.
33. Rubin DB (1973) Matching to remove bias in observational studies. *Biometrics* 29: 159–183.
34. Bassi LJ (1984) Estimating the effects of training programs with nonrandom selection. *Rev Econ Stat* 66: 36–43.
35. Rosenbaum P, Rubin D (1985) Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. *Am Stat* 39: 33–38.
36. Friedlander D, Greenberg DH, Robins PK (1997) Evaluating government training programs for the economically disadvantaged. *J Econ Lit* 35: 1809–1855.
37. Heckman JJ, Ichimura H, Todd PE. (1997) Matching as an econometric evaluation estimator: Evidence from evaluating a job training programme. *Rev Econ Stud* 64: 605–654.
38. Heckman JJ, Navarro S (2004) Using matching, instrumental variables and control functions to estimate economic choice models. *Rev Econ Stat* 86: 30–57.

39. Guo S, Fraser MW (2010) Propensity score analysis: Statistical methods and applications. 2nd Edition, Sage, Thousand Oaks, CA.
40. Heckman JJ, Tobias J, Vytlacil E (2003) Simple estimators for treatment parameters in a latent-variable framework. *Rev Econ Stat* 85: 748–755.
41. Dehejia RH, Wahba S (1999) Causal effects in non-experimental studies: re-evaluating the evaluation of training programs. *J Am Stat Assoc* 94: 1053–1062.
42. Rosenbaum PR (1995) Observational Studies. New York: Springer-Verlag.
43. Roy AD (1951) Some thoughts on the distribution of earnings. *Oxford Econ Pap, New Ser* 3: 135–146.
44. Stata Software, Endogenous treatment effects, 2013. Available from: https://www.stata.com/stata13/endogenous-treatment-effects/.
45. Ozdemir ZD, Abrevaya J (2007) Adoption of technology-mediated distance education: A longitudinal analysis. *Inf Manage* 44: 467–479.
46. Ogunniyi A, Oluseyi OK, Adeyemi O, et al. (2017) Scaling up agricultural innovation for inclusive livelihood and productivity outcomes in sub-Saharan Africa: The case of Nigeria. *Afr Dev Rev* 29: 121–134.
47. Wetengere K (2009) Socio-economic factors critical for adoption of fish farming technology: The case of selected villages in Eastern Tanzania. *Int J Fish Aqua* 1: 28–37.
48. Olayide OE, Tetteh IK, Popoola L (2016) Differential impacts of rainfall and irrigation on agricultural production in Nigeria: Any lessons for climate-smart agriculture? *Agric water Manage* 178: 30–36.
49. Machete CL, Mollel NM, Ayisi K (2004) Smallholder irrigation and agricultural development in the Olifants River basin of Limpopo Province: Management transfer, productivity, profitability and food security issues. WRC Report, South Africa.
50. Bisseleua DHB, Idrissou L, Olurotimi P, et al. (2018) Multi-stakeholder process strengthens agricultural innovations and sustainable livelihoods of farmers in Southern Nigeria. *J Agric Educ Ext* 24: 1–21.
51. Adeoti AI (2008) Factors influencing irrigation technology adoption and its impact on household poverty in Ghana. *J Agric Rural Dev Trop Subtrop* 109: 51–63.
52. Dehejia RH, Wahba S (2002) Propensity score-matching methods for nonexperimental casual studies. *Rev Econ Stat* 84: 151–161.
53. Dowgert MF (2010) The Impact of Irrigated Agriculture on A Stable Food Supply. Proceedings of the 22nd Annual Central Plains Irrigation Conference, Kearney, February 24–25. Available from CPIA, 760 N.Thompson, Colby, Kansas.
54. Jin S, Yu W, Jansen HGP, et al. (2012) The impact of irrigation on agricultural productivity: Evidence from India. 2012 Conference, August 18–24, 2012, Foz do Iguacu, Brazil 126868, International Association of Agricultural Economists.
55. Mengistie D, Kidane D (2016) Assessment of the impact of small-scale irrigation on household livelihood improvement at Gubalafto District, North Wollo, Ethiopia. *Agric* 6: 27.
56. Kumar MD (2003) Food security and sustainable agriculture in India: The water management challenge. *IWMI Work Pap* 9: 4–5.
57. Hussain I, Regassa N, Madar S (2004) Water for food security for the poor. A collection of thematic papers, Asian Development Bank.

58. Tesfaye A, Bogale A, Namara RE, et al. (2008) The impact of small-scale irrigation on household food security: The case of Filtino and Godino irrigation schemes in Ethiopia. *Irrig Drain Syst* 22: 145–158.
59. Gebregziabher G, Namara, RE, Holden S (2009) Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. *Agric Water Manage* 96: 1837–1843.
60. Bacha D, Namara R, Bogale A, et al. (2011) Impact of small-scale irrigation on household poverty: Empirical evidence from the Ambo district in Ethiopia. *Irrig Drain* 60: 1–10.
61. Kuwornu JKM, Owusu, ES (2012) Irrigation access and per capita consumption expenditure in farm households: Evidence from Ghana. *J Dev Agric Econ* 4: 78–92.
62. Sinyolo S, Mudhara M, Wale E (2014) The impact of smallholder irrigation on household welfare: The case of Tugela Ferry irrigation scheme in KwaZulu-Natal, South Africa. *Water SA* 40: 145–156.