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Comparative assessment of technical efficiencies of irrigated crop production farms: A case study of the large-scale Kampe-Omi irrigation scheme, Nigeria

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The technical inefficiencies of crop production system in terms of large-scale irrigation schemes are major problems attributed to the underperformance of crop farms. Therefore, the aim of this study was to estimate and compare farm-level technical efficiencies of four major crop productions system including, pepper, okra, garden egg, and tomato under the large-scale Kampe-Omi irrigation scheme, Nigeria. The data development analysis (DEA) approach was used to study the hypothesized determinants affecting the efficiencies of crop farms using an ordinary least squares regression model. The results showed that the selected pepper, okra, garden egg, and tomato crop farms were fully efficient at 20, 10, 16.92, and 40% under constant return to scale (CRS), and at 13.33, 30, 10.77, and 25.71% under variable return to scale (VRS), respectively. DEA revealed a considerable variation in technical inefficiency among the selected crop farms under the irrigation scheme. The significant determinants of technical efficiencies of the four crop farms include farmers' age, family size, experience, alternative income, education, credit accessibility, and contact with extension agents. The outcomes of this study are useful for improving production efficiencies while serving as a convenient guide for both farmers and irrigation scheme managers of selected crops.

Keywords: crop production, DEA, large-scale irrigation scheme, technical efficiency, Nigeria

Introduction

The significance of the agricultural sector in sub-Saharan African countries including Nigeria is well understood (Ararso et al., 2009). In Nigeria, there has been massive investment in the agricultural sector in the past three decades, intensively focused on the development of different forms of agricultural development projects and programmes including, construction of crop-specific large-scale irrigation facilities (Adelodun and Choi, 2018). This sector has been serving as a livelihood for a majority of rural dwellers (Alawode and Oluwatayo, 2019). In fact, among the different economic sectors in the country, agriculture contributes about 30% of the country's GDP (Sertoglu et al., 2017).

During the past few years, there has been an increasing imbalance between the food production rate of 2.5% and the food demand rate of above 3.5% (Oluwatayo and Adedeji, 2019). The initial expectation was that the agricultural investments would help address the challenges posed by climate variability, through increased cropping intensities and productivity, with implications for increased farmers' income; however, instead, what currently prevails is a country that still largely depends on massive importation of the food needs of its ever-increasing population (FAO, 2017; Oluwatayo and Adedeji, 2019). Although successive governments have tried to leverage irrigation development, in particular, as a means of boosting agricultural production, production to potential capacity remains quite low (Ararso et al., 2009). The farms operating within the irrigation basin are still unable to meet the envisaged output levels,

perhaps due to the inability to produce on a wider scale or possibly because they are being constrained by the problem of inefficiency in their production system. The crop production system is still largely characterized by small-scale holdings, low output, poor resource management, poor access to inputs, low application of technologies and the inadequacy of key professionals. These factors are of serious concern to many stakeholders and policymakers (Adeoye et al., 2014; Ahmed et al., 2018; Mukhtar et al., 2018; Rehman et al., 2019).

The measurement of the productive efficiency of a farm relative to other farms has long been of interest to researchers in the field of agriculture. Theoretically, there has been a spirited exchange about the relative importance of the various components of firm (farm) efficiency (Lingard et al., 1983); and from an applied perspective, measuring efficiency is important because this is the first step in a process that might lead to substantial resource savings.

According to Khandaker (1998), efficiency is the utmost factor in productivity growth. In an economy where resources are scarce and opportunities for new technologies are lacking, inefficiency studies will be able to show that it is possible to raise productivity by improving efficiency without the resource base or developing new technology (Tijani, 2006). It also helps determine the underutilization or overutilization of factor inputs (Akanbi et al., 2011). A number of studies have been done based on the data envelopment analysis (DEA) developed by Charnes et al. (1978), and further elaborated upon by Banker et al. (1984), to examine technical

efficiencies, and of course, those factors responsible for the inefficiencies in the crop production systems (Iliyasu et al., 2016; Oluwatayo and Adedeji, 2019). The DEA has appeared as a useful tool for estimating technical efficiency of production in management science and economics, considering both inputs and output variables simultaneously. Applicability of the DEA in agriculture, especially in crop production, is well documented (Haji, 2007; Speelman et al., 2008; Ajapnwa et al., 2017; Djoumessi et al., 2018; Mukhtar et al., 2018). However, relatively few comparative analysis studies on the measurement of the technical efficiencies of irrigated crop production systems exist, particularly in sub-Saharan Africa, of which Nigeria features prominently. The earlier studies on the large-scale Kampe-Omi irrigation scheme only focused on the examination of its potential for sustainable irrigation operation (Oriola and Alabi, 2014), prospects of achieving the goals of public-private partnership initiatives (Oriola 2012), and determination of the water requirements of selected crops (Adeniran et al., 2010).

Therefore, this study investigated the theory of agricultural production efficiency as affected by large-scale Kampe-Omi irrigation scheme. We estimated and compared the farm-level technical efficiencies of four major crop production systems in the large-scale Kampe-Omi irrigation scheme by employing DEA. The findings of this study sought to proffer answers to the following research questions: (i) How profitable are the crops farms in the study area? (ii) Are the crop production farms technically efficient? (iii) How do the crop production farms differ in terms of technical efficiency? (iv) How have irrigation scheme interventions impacted on the farms' performance in the study area? (v) What constraints limit crop production in the study area?

Materials and methods

Description of the study area

The Kampe-Omi irrigation scheme, one of the large-scale irrigation schemes in Nigeria, located at Ejiba in the North central part of the country between latitude 8°15' N and longitude 5°40' E, is used for this study. The climate of this region is BSh on the Köppen-Geiger system, characterized by low and uneven spatio-temporal rainfall distribution with a long dry season period. The Kampe-Omi (dam) project was constructed and commissioned in 1999 as a multi-purpose project for drinking water, hydro-power generation, and irrigation of farms for the community of about 100,000 people, as part of the federal government interventions on food security and rural development. For the past two decades, since its commissioning, however, the project has only been explored for irrigation of farmlands with a reservoir capacity of 250 Mm³.

The irrigation project covers an area of 1276 km² with 4100 ha of irrigable land. However, at the time of this study only about 100 ha had been developed with irrigation activities. The irrigation system consists of the main canal which is 39 km in length and the feeder canals, with supported drainage lines of about 300 km, through which water is conveyed from the main reservoir by

gravity. The farmers, however, use check basins as field irrigation methods at their own convenience. The major crops grown are maize, rice, sorghum, cowpea, groundnut, Okra, pepper, tomato, onion, amaranths, and garden egg. Considering the data availability and the importance of tomato and vegetables in human nutrition as well as their high dependence on dry season farming, especially in Nigeria, pepper, okra, garden egg, and tomato were selected for this study.

Data collection and sampling technique

The rapid appraisal process of data collection was employed concerning the information on the irrigation scheme, both in the office and on the field for the 2014/2015 cropping season (Mohammed, 2016). This process allowed systematic rapid assessment of the irrigation scheme and the provision of pragmatic insight on the irrigation performance including farm size, water diversion, water use (crop evapotranspiration), yields, farmers' participation, and socioeconomic characteristics of the participating farmers (Burt and Styles, 2004; Borgia et al., 2012). Firstly, secondary data including allocated plot sizes, irrigation water supply, available facilities, and service charges for land preparation and water use, were obtained from the Lower Niger River Basin Development Authority (LNRBDA), a government agency saddled with the responsibility of the operations and maintenance of the irrigation scheme. Since there was no record on the water use by the farmers and there was sufficient diverted water from the dam through the main canal, the irrigation water use data for pepper, okra, garden egg, and tomato were obtained using CROPWAT 8.0 software developed by the FAO (Allen et al., 1998) as described by Adeniran et al. (2010).

Furthermore, a field survey was conducted using both a structured questionnaire and an interview schedule to obtain the input and the yield of selected crop productions for this study. A simple random sampling technique was used to select a total sample of 250 active participating farmers in the irrigation scheme. However, only 245 farmers were able to correctly answer and complete the questionnaire. The respondents (farmers) were evenly distributed: 60 cultivated pepper, 50 cultivated okra, 65 cultivated garden egg, and 70 cultivated tomato. Notwithstanding the number of respondents, the sample size indicates the representativeness of the participating farmers of the total 600 population during the period of this study with a 95% confidence level at a 5% margin of error (Israel, 2003). For easy comparisons of different crop productions, total revenues (in monetary terms in Nigeria Naira, ₦) were used for the outputs based on the yields and the price information from the local market. The corresponding inputs considered were farm size (ha), service charge (₦), seed cost (₦), fertilizer cost (₦), pesticide cost (₦), labour (man-days), and water use (m³).

The quantities and costs of inputs, yields, revenues of outputs, and socioeconomic attributes of the participating farmers were collected between the July and September 2015 cropping season. The questionnaire was administered to literate farmers while the scheduled interviews

were targeted at farmers with a low level of literacy. In this study, the literacy level was measured by the ability of the farmers to read and write in English. This procedure was to avoid subjectivity from the literate farmers and to prevent bias against the low-level literate farmers. The literate farmers were allowed to take the questionnaires home for a maximum of three days while the interview was scheduled for the low-level literate farmers to enable them to prepare properly since the farmers in this kind of setting hardly keep records of farm activities and generally rely on mental recollections.

Efficiency measurement

The performance analysis of the agricultural production unit is becoming increasingly popular, especially with the use of methods based on the non-parametric analysis. Methodologically, the non-parametric technique of data envelopment analysis based on fractional programming model (weighted sum of output and the weighted sum of inputs) was used to estimate and compare the technical efficiencies of pepper, okra, garden egg, and tomato production in Kampe-Omi irrigation scheme. The selection of DEA was based on its ability to evaluate the degree of the relative efficiency of productivity of production units (also known as decision-making units (DMU)) with similar production inputs (Oluwatayo and Adediji, 2019). Given that the farmers have more control over the inputs used, this study considered a multi-stage input-oriented DEA model under the assumptions of variable return to scale (VRS) and constant return to scale (CRS). The revenue obtained from each of the crop productions was used as an output variable while the input variables include farm size, service charge, labour, water use, and expenses on seed, fertilizer, and pesticide for each of the four crop productions. The existence of slacks among the input variables was considered under the VRS technical efficiency following Tone (2001). The input variables mix that would yield the output with the best frontier was estimated. The DEA for this study was performed using DEAP 2.1, an open-source software by Coelli (1996). The detailed framework on the DEA methodology used can be found at Coelli et al. (2005) and Mukhtar et al. (2018).

Regression analysis

The hypothesized variables of farmers' characteristics affecting the technical efficiency of crop productions including age, family size, farming experience, alternative income, education literacy level, credit access, and contact with extension agent were examined. Some studies have investigated the determinants of technical efficiency using the Tobit regression model (Haji, 2007; Speelman et al., 2008; Djoumessi et al., 2018). However, there are strong arguments against the use of Tobit regression in estimating the determinants of technical efficiency (Banker and Natarajan, 2008). It was argued that the estimated determinants of technical efficiency of production in the Tobit regression model are not generated by the censoring process and moreover technical efficiency scores are fractional in nature which could lead to the inconsistency in its estimation (Iliyasu and Mohamed, 2016;

Mukhtar et al., 2018). Ordinary least square (OLS) regression modelling has been suggested and employed as an appropriate technique with improved results better than using the Tobit regression model (Iliyasu and Mohamed, 2016; Mukhtar et al., 2018). In fact, a study by Johnson and Kuosmanen (2012) was of the opinion that under general assumptions, the results of DEA technical efficiency scores provide a more statistically consistent estimator of the coefficients. This study, therefore, used the OLS regression model (Equation 1) to estimate the determinants of technical efficiency obtained from the VRS DEA model for each of the four crop productions.

$$TE_{VRS} = \beta_0 + \beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6 + \delta \quad (1)$$

where TE_{VRS} = technical efficiency under VRS assumption; β_0 = Farmers' age (years); β_1 = family size of the farmer; β_2 = farming experience (years); β_3 = Farmers' alternative income (1 = Yes; 0 = Otherwise); β_4 = education literacy level of the farmer (1 = literate; 0 = otherwise); β_5 = Farmers' access to credit facility (1 = Yes; 0 = Otherwise); β_6 = contact with extension agent (1 = Yes; 0 = Otherwise).

Results and discussion

Descriptive statistic of variables used

The descriptive statistics of the variables used in the DEA model in estimating the technical efficiencies of crop productions are presented in Table 1. The analysis of hypothesized socioeconomic explanatory variables affecting the technical efficiency of each of the considered crop productions is reflected in Table 2. The wide gap in average revenues per hectare of ₦129,095.55, ₦216,341.42, ₦287,719.08, and ₦594,354.87 obtained from pepper, okra, garden egg, and tomato productions indicate considerable variation in the profitability of the crop productions. The variation in the quantity of input used, among the crop productions, was considerably large with an average of 0.6 ha of land used in tomato production while an average of 0.18 ha was used for pepper cultivation (Table 1). The variation in the quantity of input used partly influenced the difference in the respective revenues obtained among the crop productions. While fertilizer and seed constituted the major cost components for tomato, and pepper and okra productions, respectively, low expenses for service charges and pesticide were recorded for all four crop productions.

Generally, the average age of the farmers ranged between 45–54 years, with the majority of older farmers involved in pepper production while the younger farmers were involved in okra and tomato productions. Notwithstanding the difference in the reported age, the farmers were found to be within the economically active age population (Kale and Doguwa, 2015). The average family size of 8, 5, 5, and 4 farmers engaged in pepper, okra, garden egg, and tomato productions, respectively.

Farmers who cultivated pepper had the highest average number of 27 years' experience while garden egg, tomato, and okra farmers had 22, 17, and 13 average number of years of experience, respectively. This can be explained by the interest of the young

Table 1: Descriptive statistics of variables used in DEA analysis.

		Crop productions			
Variable	Unit	Pepper (60) Mean (SD)	Okra (50) Mean (SD)	Garden egg (65) Mean (SD)	Tomato (70) Mean (SD)
<i>Output</i>					
Revenue	Naira, ₦	129,095.55 (62,966.90)	216,341.42 (92,457.19)	287,719.08 (109,624.06)	594,354.87 (204,158.92)
<i>Input</i>					
Farm size	Ha	0.18 (0.17)	0.27 (0.17)	0.27 (0.19)	0.69 (0.34)
Service charge	₦	9391.78 (5167.09)	11,270.80 (8248.83)	1878.75 (1343.78)	1152.23 (4527.03)
Fertilizer	₦	29,658.63 (17,065.14)	43,427.23 (24,460.49)	46,873.35 (29,579.25)	174,889.91 (95,136.46)
Pesticide	₦	1252.86 (783.34)	1908.85 (1525.18)	1878.16 (962.60)	4800.40 (3215.94)
Labour	Man- days	30 (27)	57 (35)	67.27 (47.91)	100 (52)
Water use	m ³	922.53 (842.67)	724.23 (456.85)	1299.74 (938.72)	3739.73 (1816.50)

SD, standard deviation.

farmers in farming, especially in tomato cultivations to explore the soaring prices due to tomato leaf miner (*Tuta absoluta*) infestations (Sanda et al., 2018). The majority of the farmers, ranging between 10–24%, and 13–26%, respectively, across the four crop productions, had low alternative incomes and inadequate access to credit facilities. It was observed that only a low percentage of all the sampled farmers had required literacy level with values ranging between 12–31%. The majority of the farmers, about 84–99%, had had contact with extension agents, considering their many years of farming experience. The summary statistics also indicate the low levels of participation in farming activities in the irrigation scheme, small cultivated farm size per farmer, and inadequate finance for agribusiness.

Estimation of technical efficiencies of crop productions

The descriptive statistical analysis of overall efficiency distribution in terms of both VRS and CRS is presented in Table 3. Figures 1 and 2 show the frequency distribution of the technical efficiencies for the four considered crop productions under VRS and CRS, respectively. The results show that the overall average technical efficiencies for

pepper, okra, garden egg, and tomato productions under the VRS were 0.98, 0.80, 0.77, and 0.83, and for the CRS were 0.97, 0.74, 0.73 and 0.71, respectively.

The observed differences of efficiencies among the crop productions, for both VRS and CRS, indicate the existence of inefficiencies in the cultivations of the four crops among the sampled farmers in the study area. The technical efficiency under VRS shows that pepper, okra, garden egg, and tomato productions were fully efficient (100) at 13.33%, 30%, 10.77%, and 25.71%, respectively (Figure 1). However, under the CRS technical efficiency assumption, pepper, okra, garden egg, and tomato productions were fully efficient at 20%, 10%, 16.92%, and 40%, respectively (Figure 2). The considerable difference between the VRS and CRS estimates further confirmed that some of the farmers cultivating each of the considered crops were not operating at an efficient scale. The result is consistent with Bravo-Ureta et al.'s (2007) meta-analysis study where an average of 0.74 technical efficiencies was reported in less developed countries. Similarly, a substantial inefficiency was also identified among smallholder irrigators in South Africa (Speelman et al., 2008). There is an opportunity to upscale the production potentials of

Table 2: Socioeconomic variables used in the OLS.

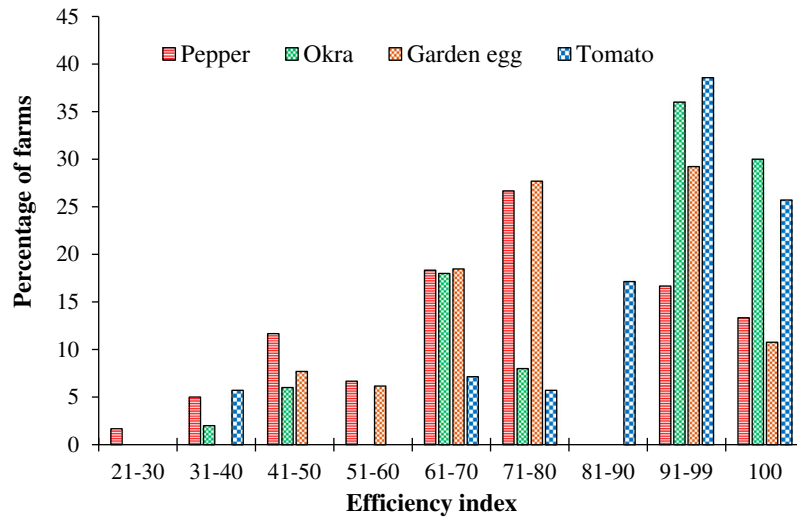
Variable	Unit	Socioeconomic characteristics of farmers			
		Pepper Mean (SD)	Okra Mean (SD)	Garden egg Mean (SD)	Tomato Mean (SD)
<i>Continuous variables</i>					
Age	Years	54 (12)	46 (11)	50 (7)	45 (8)
Family size	Persons	8 (2)	5 (2)	5 (1)	4 (3)
Farming experience	Years	27(6)	13 (8)	22 (3)	17 (5)
<i>Dummy variables</i>					
Alternative income source (1 = Yes; 0 = Otherwise)	(%)	16.67	24.00	13.85	10.42
Farmers' Education literacy (1 = literate; 0 = otherwise)	(%)	11.67	22.00	15.00	31.43
Access to credit facility (1 = Yes; 0 = otherwise)	(%)	13.37	18.35	13.85	26.16
Contact with extension agent (1 = Yes; 0 = otherwise)	(%)	90.28	84.39	92.21	98.57

SD, standard deviation.

Table 3: Descriptive statistics of overall efficiency of crop productions under VRS, CRS, and SE.

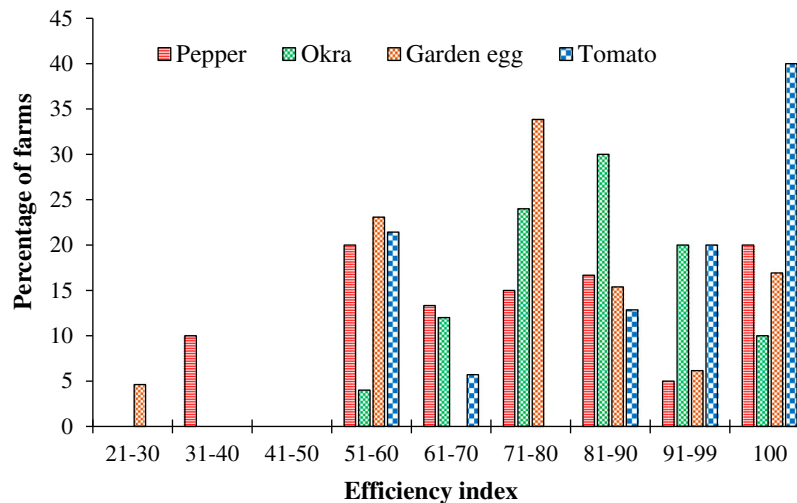
	Mean	Median	Minimum	Maximum	Standard deviation
<i>Pepper</i>					
TE _{VRS}	0.98	0.99	0.96	1.00	0.01
TE _{CRS}	0.93	0.97	0.93	1.00	0.02
SE	0.98	0.99	0.94	1.00	0.02
<i>Okra</i>					
TE _{VRS}	0.80	0.80	0.47	1.00	0.15
TE _{CRS}	0.74	0.77	0.39	1.00	0.15
SE	0.92	0.95	0.80	1.00	0.08
<i>Garden egg</i>					
TE _{VRS}	0.77	0.74	0.71	1.00	0.08
TE _{CRS}	0.73	0.72	0.70	0.78	0.02
SE	0.95	0.98	0.73	0.99	0.08
<i>Tomato</i>					
TE _{VRS}	0.83	0.86	0.37	1.00	0.19
TE _{CRS}	0.71	0.72	0.37	1.00	0.16
SE	0.87	0.91	0.62	1.00	0.12

TE_{VRS} is the technical efficiency from CRS DEA; TE_{CRS} technical efficiency from CRS DEA; SE is the scale efficiency = TE_{CRS} / TE_{VRS}.

**Figure 1:** Technical efficiency distribution under variable return to scale.

pepper, okra, garden egg, and tomato by 2%, 20%, 23%, and 17% under VRS assumption, and by 7%, 26%, 27%, and 29% under CRS assumption, correspondingly, by simply improving the technical efficiency using the

same respective production inputs. The improvement in technical efficiency can subsequently reduce the production costs, increase the yields and, at the same time, improve the farmers' return on investments.

**Figure 2:** Technical efficiency distribution under constant return to scale.

The average values of scale efficiency for the productions of pepper, okra, garden egg, and tomato were 0.98, 0.92, 0.95, and 0.87, respectively (Table 3). The result show that the average measures of scale efficiency for the pepper, okra, and garden egg production were close to 1. Conversely, for tomato production, the average measure scale efficiency was 0.87 with only 10% of the farms operating at increasing return to scale. This result is similar to Haji (2007), where the author obtained scale efficiency of close to 1 for each of the DMU considered in a smallholders' vegetable-dominated mixed farming system. Ajapnwa et al. (2017) also found that farmers tend to be less technically efficient with an increase in the size of farmland. Moreover, in a related study on smallholder vegetable farms in Cameroon, Djoumessi et al. (2018) obtained a mean scale efficiency of 0.89. The results imply that due to the small farm sizes used for the cultivation of pepper, okra, and garden egg as compared to tomato production, the scale inefficiency only existed in tomato production. The factor responsible for the identified inefficiencies can be due to improper input resources utilization.

Analysis of input slack variables under VRS technical efficiency

The selection of appropriate input levels for crop productions is an arduous task. Often, farmers rely on their past experiences or recommendations from other farmers or extension agents to decide on the correct quantity of input to be used on their farms. These approaches sometimes lead to inefficient use of input levels, which may significantly affect the yield and production costs. With the varied input levels in the productions and the different nature of the crops in this study, addressing the imperfect comparison under the VRS assumption is essential. Moreover, Hassan et al. (2014) opined that technical efficiency under the VRS assumption could address both the variability and imperfection relating to efficiency measurement, as it envelops the frontier more closely. The results of input slacks, measured in percentage, for pepper, okra, garden egg, and tomato are presented in Figure 3. The average total estimated percentages of input slacks of farm size, service charge, seed cost, fertilizer cost,

pesticide cost, labour, and water use for all the four crop productions considered in this study were 18.18, 17.27, 36.23, 42.70, 15.19, 35.12, and 23.87, respectively. Farm size slack was found to be significant, with estimated values of 8.24% and 8.35% for okra and tomato productions, respectively, as compared to the observed farm size slack in garden egg and pepper with average percentage estimates of 1.20 and 1.05, respectively. Garden egg and okra production showed a relatively high percentage of slack in labour use with estimated values of 21.36 and 10.31, respectively, as compared to 0.34 and 3.11 for pepper and tomato production, respectively. The majority of the farmers in the study area operate on a small-scale farm size of less than 2 ha and largely depend on family labour for most of the farming activities. For seed slack, the percentage estimates of 4.86, 21.11, and 9.42 were obtained for okra, garden egg, and tomato productions, respectively. Also, the percentages of fertilizer slack for okra, garden egg, and tomato were 10.82, 11.16, and 19.85, respectively, with a lower slack of 0.86% in pepper production. However, only garden egg showed significant slack in pesticide usage with an estimated value of 8.99%. Garden egg and tomato production only exhibited slack in water use. Service charge slack was significant in tomato, okra, and pepper productions with percentage estimates of 8.13, 6.70, and 2.44, respectively.

Regression analysis of the determinants of production technical efficiency

The differences in productive technical efficiency among the farmers for each of the crop productions were investigated. The various farm-specific characteristics including the age of the farmers, family size, farmer years of experience, alternative incomes, farmers' level of education, access to credit facilities, and contact with extension agents were regressed on technical efficiency measures using ordinary least squares regression model (OLS). Prior to applying the OLS model, the hypothesized farm-specific data influencing the technical efficiency of crop productions were tested for OLS model distribution applicability (Table 4). The dummy variables were, however, exempted following Iliyasu and Mohamed (2016). The testing assumptions for the OLS model

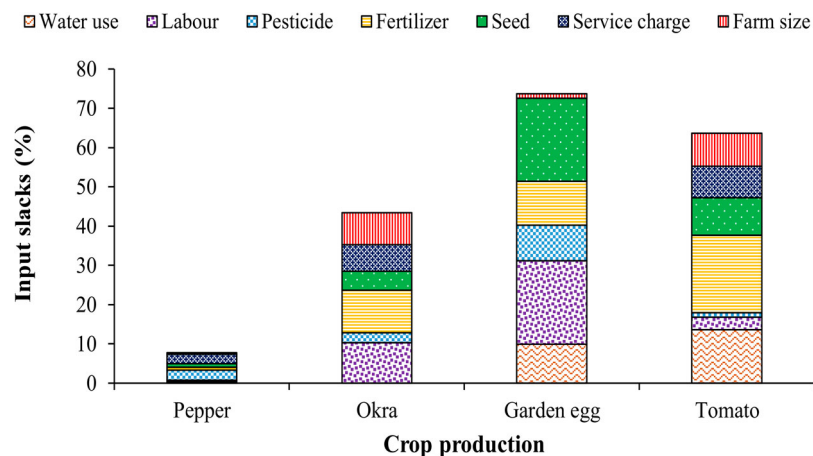


Figure 3: Input slacks among the crop productions.

Table 4: Test assumptions for OLS model.

Statistical test	Test type	Crop production				Decision
		Pepper	Okra	Garden egg	Tomato	
Normality	Kolmogorov-Smirnov	0.66	0.47	0.43	0.41	Accept H_0
	(<i>p</i> -value)					
	Shapiro-Wilk	0.41	0.41	0.28	0.34	
	(<i>p</i> -value)					
Heteroscedasticity	Breusch-Pagan	0.40	0.67	0.10	0.22	Accept H_0
	(<i>p</i> -value)					
	White test	0.52	0.82	0.18	0.10	
	(<i>p</i> -value)					
Multicollinearity	Variance inflation factor (VIF)	3.99	4.91	1.92	2.36	Accept H_0
	Tolerance value (1/VIF)	0.30	0.22	0.56	0.48	

included normality of error, multicollinearity, and heteroscedasticity. The Kolmogorov-Smirnov and Shapiro-Wilk tests for normality of residuals were conducted and the results show insignificant *p*-values of 0.66 and 0.41 for pepper, 0.47 and 0.41 for okra, 0.43 and 0.28 for garden egg, and 0.41 and 0.34 for tomato production systems, respectively. The insignificant *p*-values ($p > 0.05$) observed signify the acceptance of the null hypothesis of normal patterns of residuals, and that the errors of residuals are normally distributed.

Heteroscedasticity assumption was tested using Breusch-Pagan and White tests, and the results show insignificant *p*-values of 0.40 and 0.52 for pepper, 0.67 and 0.82 for okra, 0.10 and 0.18 for garden egg, and 0.22 and 0.10 for tomato production systems, respectively. The insignificant *p*-values of $p > 0.05$ for both Breusch-Pagan and White tests indicate the absence of heteroscedasticity, specifically having a constant variance of random error terms.

The multicollinearity test shows variance inflation factor (VIF) and tolerance value (1/VIF) values of 3.99 and 0.30 for pepper, 4.91 and 0.22 for okra, 1.92 and 0.56 for garden egg, and 2.36 and 0.48 for tomato production systems, respectively. The results show that the null hypothesis of the absence of multicollinearity was accepted. This is in agreement with Mukhtar et al. (2018), where they inferred that serious multicollinearity occurs when the VIF is greater than a value of 10 or the tolerance value, which is an inverse of VIF, is less than a value of 0.1. Hence, the data are appropriate and fitted well to the OLS regression model analysis.

The OLS regression technique was used to investigate the differentials in the farm-specific VRS technical efficiency among the sampled farmers on the four different crop productions. This was carried out using the technical efficiency levels obtained from the DEA model based on their inherently hypothesized socioeconomic characteristics. The results of the OLS regression analysis are presented in Table 5. The regression analysis showed that family size had significant positive impacts on pepper and garden egg productions. The farmers' household size had a coefficient of 0.01 and significant at 5% for pepper production while for garden egg production, the coefficient of the household size of the farmers is 0.009 and significant at 10%. The result indicates that the larger the household size, the technically efficient the farmers would be during the cause of farming activities. Moreover, crop productions in the study area largely

depend on household labour for various farm operations. Haji (2007) also reported a significant impact of household size on technical efficiency for smallholder vegetable mixed farming systems in Ethiopia. Djoumessi et al. (2018) reported similar results for smallholder vegetable farms in Cameroon.

Pepper and okra productions showed the significant impact of farming experience on the technical efficiency with coefficient values of 0.462 and 0.079, which are significant at 5% and 10%, respectively. The significant positive impact of farming experience indicates that farmers with long years of experience tend to be more technically efficient. Farmers' contact with extension agents has a positive effect on all four crop productions. However, only garden egg production indicates statistical insignificance. This result implies that farmers with long years of farming experience could have had contact with extension agents (Amsalu and de Graaff, 2007). As such, this enabled the farmers to master the art of farming the specific crop. Many farmers in this study area have been in the farming business for a very long time but migrated to the Kampe-Omi irrigation project due to inadequate irrigation water on their previous farms in the core northern part of the country. This result is supported by the findings of Djoumessi et al. (2018), Mukhtar et al. (2018), and Iliyasu et al. (2016) that both farming experience and extension service improve the technical efficiency of farmers.

The farmers' level of education had a significant positive influence on the technical efficiency of okra and tomato productions. The coefficient estimates of OLS regression for both okra and tomato productions are significant at 10%. This indicates that many of the farmers who cultivated okra and tomato, and who have relatively higher levels of education than other farmers, are more technically efficient. The literacy level of the farmers is an important variable as it enabled the farmers to interpret some of the vital information on the new ideas on how to improve their farming operations. This result is supported by similar findings reported by Ajapnwa et al. (2017) and Oluwatayo and Adedeji (2019). Access to credit facilities contributed to the technical efficiency of the farmers as it allows them to adequately procure the necessary inputs, including seeds, fertilizer, pesticides, and labour. This is supported by the positive coefficient of credit access variable in garden egg and tomato productions, which

Table 5: OLS estimates of determinants of technical efficiency.

Variable	Pepper (N = 60)			Okra (N = 50)			Garden egg (N = 65)			Tomato (N = 70)		
	Coefficient (SE)	t-value	p-value	Coefficient (SE)	t-value	p-value	Coefficient (SE)	t-value	p-value	Coefficient (SE)	t-value	p-value
Constant	0.992*** (0.025)	4.449	0.000	0.970 (0.878)	1.104	0.312	0.542*** (0.035)	5.638	0.001	0.818 (0.695)	1.177	0.304
Age	0.399* (0.001)	0.707	0.073	-0.004 (0.023)	-0.187	0.858	0.123 (0.009)	12.676	0.241	-0.003 (0.021)	-0.143	0.893
Family size	0.010** (0.004)	2.548	0.040	0.033 (0.069)	0.477	0.650	0.009* (0.003)	2.705	0.073	0.200 (0.535)	0.162	0.655
Experience	0.462*** (0.004)	1.233	0.031	0.079* (0.022)	0.365	0.073	0.011 (0.002)	6.439	0.128	-0.001 (0.033)	-0.032	0.167
Alternative income	-0.021 (0.018)	-1.169	0.327	0.116 (0.212)	0.548	0.603	0.025 (0.013)	2.019	0.137	0.124** (0.050)	0.479	0.050
Education	0.019 (0.010)	1.917	0.151	0.027* (0.272)	0.098	0.094	0.003 (0.028)	0.061	0.421	0.046* (0.318)	0.144	0.093
Credit access	0.026 (0.015)	1.780	0.173	0.179 (0.512)	0.349	0.739	0.126* (0.013)	0.013	0.064	0.260* (0.309)	0.084	0.058
Extension agent contact	0.012 (0.009)	0.642	0.567	0.158* (0.056)	0.619	0.081	0.001 (0.021)	0.065	0.129	0.025*** (0.008)	0.742	0.008

Note: *, **, and *** indicate statistical significance levels at 1%, 5%, and 10%, respectively. SE, standard error.

is statistically significant at 10%. This result is consistent with the findings reported by Djoumessi et al. (2018) and Mukhtar et al. (2018).

The farmers' age had a positive coefficient and was statistically significant at 10% for their technical efficiency in pepper production. The possible explanation is that farmers tend to become more experienced as they age, perhaps through trial and error or through learning from other colleagues. This result is in conformity with the works of Mukhtar et al. (2018) and Oluwatayo and Adedeji (2019). However, some earlier studies had contrary findings (Iliyasu et al., 2016; Ajapnwa et al., 2017; Djoumessi et al., 2018). For example, Ajapnwa et al. (2017) opined that technical efficiency diminishes as farmers get older. Iliyasu and Mohamed (2016) argued that the conservative nature of older farmers restrains their receptivity to new idea and improved methods. Alternative income had a coefficient of 0.124 and was significant at 5% for tomato production. This suggests that farmers with alternative incomes can sustain the financial obligations of agricultural operations before harvesting time.

Conclusions

This study investigated the technical efficiency of farmers in the production of four different crops in the large-scale Kampe-Omi irrigation project, Nigeria. The results of non-parametric data envelopment analysis indicate that among the four crop productions considered, pepper is the most efficient crop production with overall average technical efficiencies of 0.98 and 0.97 under VRS and CRS, respectively. Conversely, okra and tomato crops had the lowest technical efficiencies with overall average values of 0.77 and 0.71 under VRS and CRS assumptions, respectively. Generally, VRS technical efficiency results show that farmers in the study area are operating below the production frontier for all the crops considered, and there is also an existence of substantial slacks in the level of inputs used.

While the levels of labour and seed slacks are very high in garden egg production, fertilizer slack is found to be substantial in okra, garden egg, and tomato productions. Only tomato and garden egg productions indicate a considerable amount of water use slack. The various observed input slacks have a negative influence on the technical efficiency of the respective crop productions. This indicates an opportunity to upscale production potentials under the existing conditions in the study area, especially regarding awareness of appropriate levels of input usages.

The OLS results showed that the hypothesized variables including farmer's age, experience, alternative income, education level, access to the credit facility, and contact with extension agents have specific significant impacts on the technical efficiencies of each of the crop productions.

Policy recommendation

The majority of Nigeria's population still lives in rural areas and over the years, rain-fed agriculture is what they are largely attuned to. As desirable as irrigation

farming is, it is still fraught with a whole lot of challenges, as evidenced by the findings of this study. Therefore, any envisaged policy intervention project or programme designed towards improving upon the crop production systems should duly take cognizance of those factors that had been determined as contributing to the differentials in inefficiencies of the crop farms for any irrigation scheme.

In order to achieve this, policymakers and irrigation scheme managers should refocus their attention on the institutional and socioeconomic framework that can help improve upon the current levels of production efficiency of specific farm crop production systems. Importantly, capacity building at the farm level, which is crucial for improving crop, soil and water management, enhancing the demand for and use of better and more efficient production inputs, and increasing the financial absorptive capacity of farmers, should be undertaken. The farmers should also be acquainted with improved agronomic practices by extension agents in order to improve upon their effectiveness and their farms' efficiencies.

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