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Modelling and Sensitivity Analysis of Energy Inputs for Rice Production in Nigeria

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Authors' contributions

This research was carried out in collaboration between both authors. Author BSK designed the study, carry out the data collection and performed the statistical analysis. Author AIB managed the analyses of the study. Both authors were deeply involved in the writing, reworking of the manuscript and approved the final manuscript.

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ABSTRACT

The influence of energy inputs and form of energy on the output level for rice production in Nigeria was investigated. The sensitivity of energy inputs was estimated using the marginal physical productivity (MPP) method and partial regression coefficients on rice yield. Energy related data for two (2) growing seasons were collected in nine (9) rice farms. The farms consist of three (3) small, medium and large farms, respectively. Data were obtained through field surveys, direct measurements, interviews with farmers and structured questionnaires. Standard equations were used to evaluate the energy requirement for each defined unit operations. Econometric model evaluation showed that nitrogen and phosphorus fertilizer and biological (seed) energy were the most important energy input that influences energy output. The elasticity of nitrogen, phosphorus fertiliser and biological energy on the output were 0.86, 0.44 and 0.13, respectively. While, mechanical, thermal and manual energy were 0.08, 0.050 and 0.026, respectively. The coefficient of indirect energy and direct energy were 0.90 and 0.05, respectively. Sensitivity analysis results

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indicate that additional use of 1 MJ of phosphorus fertiliser, manual, biological (seeds) and machinery energy would increase rice yield of 6.36, 1.08, 1.05 and 0.82kg, respectively. Energy inputs and patterns of energy consumption in rice production was modelled. The models adequately predicted the energy inputs and output for rice production.

Keywords: Energy; rice; modelling; Cobb–Douglas; sensitivity of energy.

1. INTRODUCTION

Rice is one of the world's most important staple consumed by over 50 percent of the world's population, most especially in Nigeria [1]. Rice which belongs to the grass species of genus Oryza, of the tribe Oryzeae is a starchy food with macronutrient composition of carbohydrate (73%), protein (7%) and fat (less than 1%). Its protein composition is relatively high in sulfur-containing amino acids, cysteine and methionine, but low in lysine [2].

Rice (*Oryza sativa* L.) is widely consumed as polished grains, where its bran and germ are removed during milling. There is a significant reduction in its micronutrients after milling process since the nutrients are located in the bran and germ fractions. The bran contains almost 65 % of the nutrients that include fibres, minerals, vitamins and phenolics [3]. Since the last two decades in Nigeria, the average annual rice consumption rate is put at 11% with only 3% explained by population growth. About 24.8 kg of rice is consumed by an average Nigerian per year accounting for 9% of the total calories intake. On the assumption that there will be 10% increase in rice demand annually and with demand for local rice growing at half the rate of the imported rice, domestic rice consumption was projected to rise to 8.3 million tons by 2014 [4].

Presently, Nigeria is the largest producer of rice in West Africa but the second largest importer in the world, accounting for 25% of continent's imports [5]. In 2017, the nation's annual production capacity was about 5.3 million tonnes, and over 2.7 million tonnes ($600 million worth) of rice was imported into the country [6]. Despite this production capacity, Nigeria rice sub-sector could not meet the domestic requirement. The inability of the sector to meet the demand is attributed to low productivity, inefficient use of resources and low mechanisation level [7]. Several researchers have asserted that crop yields are directly linked to energy availability or consumption. High yield and acreage obtained in developed nations were due to commercial energy inputs and improved varieties usage [8]; [9]. For optimum utilisation of energy resources in an agricultural system, a solution is to determine the best production function [10]. In recent years, econometric models were developed for different agricultural crops from which the Cobb-Douglas production function was attested to be efficient [11,12]. Hatirli et al. [13] in Turkey and Mobtaker et al. [14] in Hamedan province of Iran established the relationship between energy inputs and crop yield for greenhouse tomato and barley production, respectively using Cobb-Douglas production function.

Rafiee et al. [15] also established the link between energy resources used in apple productions and its yield. They analysed the sensitivity of energy inputs on yield using marginal physical productivity (MPP) technique. Sensitivity analysis of energy inputs in crop production is valuable because it reveals the impacts the energy inputs have on the output. Furthermore, it identifies those parameters which have the most influence on the response of the model.

They reported that human labour, total fertiliser, machinery, diesel fuel, electricity and water for irrigation energies were the important inputs that significantly contributed to output.

Currently, there is no study on sensitivity analysis of energy inputs for rice production in Nigeria. This study was designed to model and analyse the sensitivity of the energy inputs for rice production in Nigeria.

2. MATERIALS AND METHODS

2.1 Data Collection

This study was carried out in nine (9) established rice farms in the south western part of Nigeria. Three (3) rice growers for each category of farms were purposively selected. The characteristics of the farms are as follows:

i. Small Farm: Farms less than 2 hectares

ii. Medium Farm: Farms between 2 – 10 hectares
iii. Large Farm: farm greater than 10 hectares.

2.2 Energy Balance Analysis Method

The input energy (MJ/ ha) used from various energy resources such as human labour (x_1), fuel (x_2), machinery (x_3), biological (x_4), N.P.K fertiliser (x_5, x_6, x_7), herbicide (x_8) and the output, rice yield (kg/ha) were obtained through field surveys, direct measurements, interviews with farmers and structured questionnaires. The collected data belonged to the production two (2) growing seasons (2012 and 2013 periods).

The data were transformed to energy term by appropriate energy equivalent factors (Table 1). The energy input and output of rice production were calculated according to Bamgboye and Kosemani [16].

$$The\ energy\ input\ = Quantity\ of\ inputs\ used\ per\ hectare \times energyequivalent\ factors \quad (1)$$

$$The\ energy\ output = Yield\ per\ hectare \times energyequivalent\ factors \quad (2)$$

2.3 Model Development and Validation

2.3.1 Model development

The estimation of energy balance, the relationship between energy inputs and output was investigated using a prior mathematical function relation. In specifying a fit relation, Cobb-Douglass production function was selected as the best function in terms of statistical significance and expected signs of parameters [13,14,17]. The Cobb-Douglass function has been used by several authors to investigate the relationship between input energies and production yield [12,13,17]. The Cobb-Douglass production function is expressed as follows:

$$y = f(x)\exp(u) \quad (3)\ [18]$$

Equation (3) can be linearized and expressed in the following form as:

Model:

$$\ln Y_i = a \sum_{j=1}^{n} a_j \ln\left(X_{ij}\right) + e_i \qquad i = 1,2\,, \ldots\ldots\ldots.n \quad (4)$$

Where:

Y_i = Yield of the *i*th farmer
X_{ij} = Vector of inputs used in the production process
a = Constant term
j = Coefficients of inputs which are estimated from the model
ei = Error term.

With assumption that when the energy input is zero, the crop production is zero Equation 4 changed to Equation 5 as

$$\ln Y_i = \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \qquad i = 1,2\,, \ldots\ldots\ldots.n \quad (5)\ [18]$$

With the assumption that yield is a function of inputs energy, Equation 5 was expanded to Equation 6:

$$\ln Y_i = \ \alpha_1 \ln(X_1) + \ \alpha_2 \ln(X_2) + \ \alpha_3 \ln(X_3) + \alpha_4 \ln(X_4) \ \ \alpha_5 \ln(X_5) \ + \alpha_6 \ln(X_6) \quad (6)\ [18]$$

Table 1. Energy equivalent of inputs and outputs in agricultural production

Energy Input and output	Unit	Energy equivalent (MJ)	References
A. Input			
Human labour (x_1)	h	1.96	[19]
Diesel fuel (x_2)	L	56.3	[19]
Machinery (x_3)	kg	62.71	[19]
Biological(rice seed) (x_4)	kg	14.57	[20]
Nitrogen (x_5)	kg	78.1	[21]
Phosphorus (x_6)	kg	17.4	[21]
Potassium (x_7)	kg	13.7	[21]
Chemicals (herbicide) (x_8)	kg	120	[19]
B. Output			
Rice (y)	kg	14.57	[20]

Cobb–Douglas function was used to evaluate the impact of direct and indirect energies in a mathematical form as shown in equation 7:

Model 2:

$$\ln Y_i = \quad \beta_o + \beta_1 \ln DE + \ln \beta_2 \ln \ IDE + e_i \qquad (7)\ [14]$$

Where: *Yi* is the *i*th farmer's yield, *βi* and *γi* are coefficients of exogenous variables. DE and IDE are direct and indirect energies, respectively. Equation 4 and 5 was estimated using Ordinary Least Square (OLS) technique.

2.3.2 Sensitivity analysis

The Marginal Physical Product (MPP) technique, based on the response coefficients of the inputs, was utilised to analyse the sensitivity of energy inputs on maize yield. The MPP of the various inputs was calculated using the α_j of the various energy inputs. MPP was found by dividing the change in the total physical product by the change in the variable input as follows:

$$MPP_{xj} = \frac{GM(P)}{GM\ (E_j)}\alpha_j = \frac{GM(Y)}{GM\ (X_j)} \times \alpha_j \qquad (8)\ [17]$$

Where, MPP_{xj} is marginal physical productivity of *j*th input, α_j is regression coefficient of *j*th input, *GM(P)* is geometric mean of production, $GM\ (E_j)$ is geometric mean of *j*th input on farm ($E_{ji} = X_{ij}A_i$), *GM(Y)* is geometric mean of productivity and *GM(Xj)* geometric mean of *j*th input on per hectare basis.

2.3.3 Model Validation

In validating these models, autocorrelation was performed using Durbin-Watson (DW) test [22].

$$d = \frac{\sum_{t=2}^{T}(e_t - e_{t-1})^2}{\sum_{t=1}^{T} e_t^2} \qquad (9)$$

Where:

T = number of observations.

$e_t = \text{residual associated with the observations}$

3. RESULTS AND DISCUSSION

3.1 Econometric Model Estimate of Rice Cultivation

The result of the interaction among the energy inputs as it affects the energy output is as shown in Table 2 and represented by equation 10. From the equation, the coefficient of determination was 0.99, indicating that all the different energy inputs contributed immensely to the energy output. The variability in the energy inputs could be explained by this model up to 99%. As shown in Table 2, Durbin-Watson value was 2.25, the value closer to two (2) indicated that the developed model was capable of predicting energy output at different energy inputs beyond the two seasons considered in this work. It means that the equation is valid beyond two seasons.

Manual, mechanical, thermal, nitrogen fertiliser, phosphorous fertiliser and seed energy inputs were statistically significantly ($p < 0.01$). On the other hand, the impacts of chemical energy input from potassium fertiliser and herbicide on energy output were estimated to be statistically insignificant. All the variables contributed significantly to outputs except potassium fertiliser which showed a negative relationship with output. The same trend was observed in the study by Mobtaker et al. [14] on barley production. As shown in equation 10, Nitrogen and phosphorus fertilizer was observed to be the most important energy input that influences energy output. It had the highest elasticity of 0.86 and 0.44 on energy output. The third and fourth important energy inputs were biological and mechanical energy with a coefficient of 0.13 and 0.08, respectively. With respect to the obtained results, an increase of 1% in the consumed energy from chemical (nitrogen and phosphorus fertilizer), biological and mechanical energy, would lead to 0.86, 0.44 0.13 and 0.08% increase in energy output, respectively. The coefficient of thermal and manual were 0.050 and 0.026, respectively, indicating that increase of 1% in this input would lead to 0.050 and 0.026%, increase in energy output respectively. Herbicide and potassium fertiliser (chemical energy) on the other hand was the energy input that least influenced the output of rice. There coefficient were 0.0043 and -0.064, respectively, as shown by equation 10.

Phosphorus fertiliser and manual energy had the major Marginal Physical Productivity value (MPP) of 6.36 and 1.08, respectively. It was followed by seed and mechanical with MPP value of 1.05 and 0.8, respectively, as shown in Table 2. This implies that an additional use of 1 MJ ha^{-1} from each of the seed, manual energy and mechanical would lead to an additional increase in yield of rice by 1.08, 1.05 and 0.8 kg ha^{-1}, respectively. In other words, there is a high potential for increasing output by additional use of these inputs for rice production in the surveyed region. On the other hand, the MPP value of potassium fertiliser was found to be negative, indicating that use of this input is high for rice production, resulting in energy dissipation as well as imposing negative effects to the environment and human health. The energy input can be reduced by reducing the quantity of potassium fertiliser input and supplement with organic fertiliser. Mobtaker et al., [14] analysed the sensitivity of energy inputs on barley productivity. They reported that the significant MPP was from human labour energy (7.37), followed by machinery energy (1.66). Also, Zeynab et al. [18] examined the sensitivity of energy inputs on canola production. They reported that seed had the highest MPP value (13.45) and followed by human labour (2.69).

The value of return to scale (RTS) for model I (equation 10) was 0.96, as shown in Table 2. The value lower than one implies decreasing returns to scale (DRS). This implied that 1% increase in the total energy inputs would lead to 0.96% increase in the rice yield. Therefore, an increase in the total energy input would not increase the output in the surveyed region.

$$Model\ I : \ln Y_i = 0.03\ lnx_1 + 0.05\ lnx_2 + 0.08\ lnx_3 + 0.14\ lnx_4 + 0.86\ lnx_5 + 0.44\ lnx_6 - 0.64\ lnx_7 + 0.003\ lnx_8 \quad R^2 = 0.99 \tag{10}$$

The effect of direct and indirect energies (DE and IDE) on output was also established as shown in equation 11. From equation 9, the coefficient of determination was 0.99, indicating that all the different energy inputs contributed immensely to the energy output. The variability in the energy inputs could be explained by this model up to 99%. Direct and indirect energies were statistically significant ($p< 0.01$). The coefficient of DE and IDE were 0.05 and 0.90, respectively, as shown in equation 11, implying that 1% increase in direct and indirect energy inputs would lead to 0.05 and 0.90 increase in yield, respectively. This indicated that the indirect energy has a higher influence on energy output than direct energy. This is similar to that obtained by Hatirli et al. [22] in greenhouse tomato production.

The Durbin- Watson (DW) value for the model was 2.32 as shown in Table 3. The value closer to two (2) indicated that the developed models were capable of predicting energy output at the different input for the two seasons and beyond. The marginal physical productivity value of indirect energy and direct energy were 0.50 and 0.22, respectively, as shown in Table 3. This implies that an additional use of 1 MJ ha^{-1} from each of the indirect energy and direct would lead to an additional increase in the yield of rice by 0.50 and 0.22kg ha^{-1}, respectively.

Table 2. Econometric estimation results of energy inputs for rice cultivation

Endogenous variable: Exogenous variables	Rice yield	
	Coefficients (α_1)	MPP
1. Manual Energy (X_1)	0.03	1.08
2. Thermal Energy (X_2)	0.05	0.33
3. Mechanical Energy (X_3)	0.08	0.82
4. Biological Energy (X_4)	0.14	1.05
5. Chemical Energy N (X_5)	0.86	0.62
6. Chemical Energy P_2O_5 (X_6)	0.44	6.36
7. Chemical Energy K_2O (X_7)	-0.64	-11.20
8. Chemical Energy Herbicide (X_8)	0.003	0.10
Return to Scale (RTS)	0.96	
Durbin Watson Test (DW)	2.25	
R-square	0.99	

Table 3. Econometric estimation results for direct and indirect energy for rice cultivation

Endogenous variable: Exogenous variables	Rice yield	
	Coefficients (β_1)	MPP
1. Direct Energy (DE)	0.05	0.23
2. Indirect Energy (IDE)	0.90	0.50
Return to Scale (RTS)	0.95	
Durbin Watson Test (DW)	2.32	
R-square	0.99	

The value of return to scale for model II (equation 9) obtained was 0.95 as shown in Table 3. The value lower than one implies decreasing returns to scale (DRS). This implied that 1% increase in the total energy inputs would lead to 0.94% increase in the rice yield. Therefore, increasing the total energy input would not increase the output in the surveyed region.

$$Model\ II : \ln Y_i = 0.04726\ lnDE + 0.89942\ lnIDE \quad R^2 = 0.99 \tag{11}$$

4. CONCLUSION

The relationship between the inputs energies and output in rice production have been developed. The models adequately predicted the input and output energies. Nitrogen and phosphorus fertilizers and biological (seed) energy were the most important energy input that influences energy output. Additional use of 1 MJ for each of biological (seeds), machinery energy would increase rice yield by 6.36, 1.08 and 1.05kg, respectively. The coefficient of indirect energy and direct energy were 0.90 and 0.05, respectively, indicating that indirect energy has a higher influence on energy output than direct energy. Reduction in chemical fertilizer consumption is important for energy saving and decreasing the environmental risk problem. This could be achieved by substituting with farmyard manure. Improved varieties of seed should also be used.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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