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Optimization and determinants of cowpea farmers' output in the Federal capital territory and Kaduna state, Nigeria

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Abstract

Cowpea farming plays a crucial role in the livelihoods of farmers. This study evaluates the optimization and determinants of cowpea farmers' output in the Federal Capital Territory and Kaduna State, Nigeria. Primary data are obtained from a sample of 160 cowpea farmers. Descriptive statistics, Cobb-Douglas Regression Model (CDRM), Return to Scale (RTS), and Elasticity of Production (EP) Model are employed for analysis. The results indicate that cowpea farming is a profitable business venture, since the total returns (₦806,809.70) exceed the cost of production (₦254,128.93). Furthermore, determinants such as farm size, family labour, fertilizers, and seeds have significant effects on cowpea farmers' output, thereby highlighting the importance of efficient resource utilization. Elasticity of production is significantly different from zero, with farm size and pesticides having the highest and lowest values, with estimated coefficients of 0.240 and 0.042, respectively. Additionally, the return to scale, which serves as a measure of total resource productivity, is positive—1.173. The findings suggest that cowpea farmers are operating under conditions of increasing returns to scale, corresponding to Stage One of the production function. Accordingly, the study advocates for policy interventions that enhance access to credit and farm inputs, and reinforce the effectiveness of extension service delivery.

Keywords: cowpea farming, determinants of output, Cobb-Douglas Production Function, elasticity of production

INTRODUCTION

Cowpea (*Vigna unguiculata*) is an important staple legume in Nigeria, serving as a major protein source in the daily diet (Abebe & Alemayehu, 2022). Cowpea plays a significant role in the livelihoods of millions of smallholder farmers who depend on it as a source of economic and nutritional well-being (Bolarinwa et al., 2021). Cowpea is mainly grown for food, vegetable, fodder, cover crop, and green manure (Horn et al., 2022). Cowpea is the second most important food grain legume in tropical Africa (Nimoh & Asuming-Brempong, 2012). West Africa is regarded as the major cowpea-producing region, with 80% of total production attributed to Nigeria and Niger, which have held the first and second positions, respectively, for 14 consecutive years (Horn et al., 2022). Cowpea is commonly cultivated due to its adaptability to arid conditions and its capacity to enhance soil fertility through nitrogen fixation (Bayei & Banta, 2021). In 2022 and 2023, Nigeria produced approximately 4202328.2 and 4292073.51 tons of cowpea, respectively. In 2022 and 2023 the cultivated area reached approximately 4894274 and 4984907 ha, respectively (FAO, 2025). Despite its economic and nutritional benefits the production of cowpea in Nigeria has remained sub-optimal. Some of the constraints affecting the production of cowpea in Nigeria includes: inefficient resource allocation, limited access to modern inputs and inadequate technical know-how (Kuzhkuzha et al., 2021). Addressing some of the constraints requires an understanding of key production determinants influencing cowpea output, as well as optimization strategies that can enhance production efficiency (Nimoh & Asuming-Brempong, 2012).

Agricultural optimization is crucial in enhancing cowpea production and profitability. Production factors such as seeds, labour, land, fertilizers, herbicides, pesticides can significantly improve the overall output of cowpea production if they are efficiently utilized (Onuwa, 2022). According to Akintobi, et al. (2018) many cowpea farmers still make use of traditional farming techniques with limited accessed to modern input, thereby leading to a sub-optimal yield. Furthermore, fluctuations in market prices, incidences of pest breakout, variation of climate has aggravated the risk cowpea farmers' face, thereby reduced their incomes and also discouraged them from venturing into cowpea production (Kiprotich et al., 2015). While numerous studies have examined the profitability of cowpea production in Nigeria, there remains a significant need for research focused on optimizing output and identifying its key determinants.

A notable gap in the existing literature is the absence of region-specific analyses that examine the economics, production efficiency, and determinants of cowpea production across the two regions. Previous studies have largely focused on general agricultural productivity in northern Nigeria, without identifying the specific factors influencing cowpea production (Horn et al., 2022). Furthermore, limited research has been conducted on production elasticity and returns to scale – key factors in understanding how farmers can efficiently utilize scarce resources to maximize output. This study addresses this gap by identifying the determinants that significantly influence cowpea production, examining elasticity and returns to scale, and proposing optimization strategies to enhance productivity and profitability.

Objectives of the Study

This study focused on optimization and determinants of cowpea farmers' output in the Federal Capital Territory and Kaduna State, Nigeria. The specific objectives are:

(i) to describe the farm-specific and characteristics of cowpea growers,

(ii) to model and determine factors influencing the output of cowpea farming, and

(iii) to estimate the elasticity of production and return to scale of cowpea production

The study hypotheses

The research was guided by the following hypotheses, each stated in null form:

H_{01}: There is absence of inefficiency in the production function for the sampled cowpea farming.

H_{02}: The production factors such as farm size, family labour, hired labour, herbicides, fertilizers, seeds, pesticides, and capital do not have any significant influence on the output of cowpea production in the study area.

H_{03}: The elasticity of production is not significantly different from zero.

H_{04}: The return to scale is not significantly different from zero.

MATERIALS AND METHODS

The current study was conducted in the Federal Capital Territory and Kaduna State, Nigeria, using a multi-stage sampling approach. The approach was utilized for a number of reasons, such as time efficiency, cost reduction, flexibility, and enhanced reliability. In the first stage, the Federal Capital Territory and Kaduna State were randomly selected, as they are major cowpea-producing areas in the North Central and North West regions. In the second stage, two local government areas were randomly selected from each state making a total of four local government areas. In the third stage, four villages were randomly selected from each local government area making a total of sixteen villages. At the fourth-stage, a simple random sampling approach was utilized to select 160 cowpea growers from the villages. The sample frame of cowpea producers was comprised of approximately 267 respondents. The sample number of 160 respondents comprising of 80 smallholder cowpea growers selected each from state, respectively. Primary sources of data were utilized based on a well-planned questionnaire that was submitted to the process of reliability and validity test. This sample number was estimated based on the formula suggested by Yamane (1967):

$$n = \frac{N}{1+N(e^2)} = \frac{267}{1+267(0.05^2)} = 160$$

Where: n = sample number, N = complete list of cowpea growers, e = 5%.

The obtained data were evaluated using both descriptive and inferential statistics as follows:

Cobb-Douglas Regression Model (CDRM)

This study chose the Cobb-Douglas functional form as the most suitable specification. A Cobb-Douglas functional form is simple and offers computational feasibility. The resulting regression coefficients also act as elasticity estimates. It is convenient for interpreting production elasticity, and the function can easily be transformed into linear form (Moges, 2019). The Cobb-Douglas regression model is stated as:

$$Log\ Y_i = \beta_0 + \sum_{i=1}^{8} \beta_i\, Log\ X_i + \cdots \beta_n Log\ X_n + \varepsilon_i$$

$$Log\ Y_i = \beta_0 + \beta_1\, Log\ X_1 + \beta_1\, Log\ X_1 + \beta_1\, Log\ X_1 + \beta_1\, Log\ X_1 + \beta_1\, Log\ X_1 + \beta_1\, Log\ X_1 + \beta_1\, Log\ X_1 + \beta_1\, Log\ X_1 + \varepsilon_i$$

Where: Y_i = output of cowpea (kg), X_1= farm size (ha), X_2 = family labour (mandays),
X_3 = hired Labour (mandays),
X_4 = herbicides (L), X_5 = fertilizer usage (kg),
X_6 = seeds (kg), X_7 = pesticides (L),
X_8 = capital (Naira), β_0 = constant,
$\beta_1 - \beta_8$ = regression coefficients,
ε_i = noise term

Return to Scale (RTS) and Elasticity of Production (EP) Model

Elasticity of production (EP) is a measure of a farm success in yielding maximum output from a given set of factors. The (E_P) and (RTS) was estimated following the model of Alabi et al. (2022):

$$E_{P_{x_i}} = \frac{\partial Y}{\partial X_i} \cdot \frac{\overline{X}}{\overline{Y}},\ i = 1, 2 \ldots k$$

$$\sum_{i=1}^{K} E_{P_{x_i}} = RTS$$

Where: $\overline{X}$ = mean of inputs (units),
$\overline{Y}$ = mean of output (units),
$E_{P_{x_i}}$ = elasticity of production of Input x_i ,
$\sum_{i=1}^{K} E_{P_{x_i}}$ = return to scale i.e. sum of elasticity of production.

t-test of difference between means

This is stated thus:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Where: $\overline{X}_1$= mean of values in group 1,
$\overline{X}_2$= mean of values in group 2,
s_1^2, s_2^2= standard deviation in group 1 and group 2,
$n_1 n_2$= number of observation in group 1 and group 2

Hypothesis Test

The null-hypothesis (H_{01}) (absence of inefficiency effects) was tested using the generalized likelihood ratio statistics as follows:

$\chi^2 = -2\,[L(H_0) - L(H_1)]$

Where: $L(H_0)$ = log likelihood under the stochastic production function model without explanatory variables on inefficiency effects,

$L(H_1)$ = log likelihood function under the stochastic production function with explanatory variables of inefficiency effects,

χ^2 = Chi square value.

RESULTS AND DISCUSSION

Continuous variables of farm-specific and characteristics of cowpea growers

The average age of the respondent is 42 years, suggesting that most farmers were in their most productive years (Table 1). The average years of schooling is seven, indicating a relatively low level of education, such as only primary or lower secondary education. The average farming experience is 12 years, indicating a significant level of knowledge in cowpea cultivation. The average household size is eight persons per household, indicating that most of the farmers rely primarily on family labour. The average farm size is approximately 1.78 hectares. This implies that most of the farmers cultivated on small-scale farms, which is consistent with the common subsistence farming system in Nigeria. The estimated average cowpea yield is 550 kg/ha, indicating that the level of productivity is affected by socio-economic and farm management factors.

Table 1. Continuous variables of farm-specific and characteristics of cowpea growers

Variables	Description of variables	Mean	SD
Age	age of the respondents (years)	42	09.01
Education	number of years spent in school education	7	2.05
Experience	number of years spent in sorghum farming	12	5.91
Household Size	number of people per household	8	4.07
Farm Size	average cultivated farm land in hectares	1.78	0.81
Output	kilograms/hectare	550	1.71

Source: Field Survey (2024), SD-Standard Deviation

Table 2. Descriptive statistics involving categorical variables of growers features

Variables	Frequency	Percentage
Gender		`
Male	140	87.5
Female	20	12.5
Marital Status		
Single	18	11.25
Married	142	88.75
Cooperatives		
Yes	98	61.25
No	62	38.75
Extension Contact		
Yes	87	54.37
NO	73	45.63
Total	**160**	**100.00**

Source: Field Survey (2024)

Categorical variables of farm-specific and demographic features of cowpea farmers

The majority of respondents, comprising 87.5%, are male and 12.5% are female, indicating a notable gender disparity in cowpea farming in Nigeria (Table 2). This could be a result of socio-cultural norms that hinder the active participation of women in commercial cowpea farming. The majority of respondents, comprising about 88.75%, are married, while 11.25% are single, suggesting that some farming decisions may be influenced by family responsibilities. In terms of cooperative membership, 61.25% of respondents participate in a cooperative and enjoy numerous benefits such as access to credit, extension services, and improved market opportunities, while 38.75% are not members. More than half of the farmers, comprising 54.37%, report having contact with extension workers, while 45.63% have no access to extension services. This suggests that nearly half of the farmers may lack useful agricultural information and practices that could significantly improve their productivity.

Optimization and determinants of cowpea growers' output

The maximum likelihood estimates of the stochastic frontier model (Cobb Douglas production function) are presented in Table 3. Farm size has a coefficient of 0.240, indicating a positive and significant relationship ($p < 0.05$), implying that for every one-unit increase in farm size, there is a resultant increase in cowpea output by 0.240. This finding aligns with the results of Ojo et al. (2018), who found that the farm size can affect efficiency and productivity. Family labour has a coefficient of 0.147, indicating a positive and significant relationship ($p < 0.05$), implying that for every one-unit increase in family labour, there is a resultant increase in cowpea output by 0.147. This highlights its crucial role in cowpea farming, as most small-scale farmers often depend on family labour to reduce production costs and maintain continuous output. Hired labour has a coefficient of 0.213, although the relationship is not statistically significant. This implies that extra hired labour would contribute to production but may not necessary be the most critical factor for output optimization. This finding is in the consonance with Radlo & Tomeczek (2022).

Fertilizers and seeds have coefficients of 0.127 and 0.215, respectively, indicating that both have a positive and significant relationship ($p < 0.05$). This underscores the relative significance of quality seeds and fertilizers in improving yield. This finding is similar to the results of Wimalasekera (2015), which highlight the importance of using quality seeds to improve yield, as there is a significant correlation between certified seed adoption and increased farm productivity. Pesticides and capital have an insignificant relationship, suggesting that these factors do not hold a significant role in cowpea production in the study area.

Table 3. The Maximum Likelihood Estimates of the Stochastic Frontier Model (Cobb-Douglas Production Function)

Variables	Parameters	Coefficient	Standard Error	t-Value
Constant	β_0	1.480**	0.5670	2.61
Farm Size	β_1	0.240 **	0.0830	2.89
Family Labour	β_2	0.147**	0.0540	2.72
Hired Labour	β_3	0.213^{NS}	0.1990	1.07
Herbicides	β_4	0.172^{NS}	0.1578	1.09
Fertilizers	β_5	0.127^{**}	0.0559	2.27
Seeds	β_6	0.215**	0.0830	2.59
Pesticides	β_7	0.024^{NS}	0.0214	1.12
Capital	β_8	0.042^{NS}	0.0385	1.09
δ^2	4.2052***			
γ(Gamma)	0.8109			
LLF (Log-Likelihood Function)	-829.65			
Mean Efficiency Score	0.67			

Source: Field Survey (2024)

Legend: *Significant at p<0.10, **Significant at p<0.05, ***Significant at p<0.01, NS – not significant

However, the observed effectiveness may be measured only by variations in pest prevalence, while capital resources could be constrained by limited access to finance.

Approximately, the gamma (γ) value is 0.81, indicating that the total variation in cowpea output of 81% is due to inefficiency effects rather than random production shocks. Log-likelihood function (LLF) value is -829.65, supporting the overall fit of the model. The mean efficiency score is 0.67, indicating that farmers operate at 67% of efficiency. This suggests that there is scope for improvement in resource allocation and technical efficiency.

Elasticity of production(ε_p) and return to scale (RTS)

The highest elasticity has farm size with 0.240, emphasizing its relevance in determining productivity (Table 4). Seeds have an elasticity of 0.215, hired labour – 0.213), family labour – 0.147, herbicides – 0.172, fertilizers – 0.127, pesticides – 0.024, and capital – 0.042. The return to scale (RTS) analysis serves as a measure of total resource productivity. The production function can be used to estimate the magnitude of the return to scale. Constant return to scale only holds if the sum of all partial elasticity is equal to one. If the sum is less than one, the function has decreasing return to scale, if more than one, then an increase return to scale exists. The RTS value which is the sum of the elasticities of all variables is 1.173, indicating increasing returns to scale. This means that a proportional increase in all inputs results in a proportional increase in output. Specifically, a one percent increase in all inputs leads to a 1.173 percent increase in cowpea output. This indicates that the cowpea farmers are operating in stage one of the production surface, where output can still be increased by using more inputs. This result implies that there is a substantial benefit for cowpea farmers in increasing input use while maintaining efficiency. This finding is similar to the work of Michelson et al. (2023), which revealed that higher productivity can be achieved when farmers use improved inputs, expand farm size, and optimize labour use.

Table 4. Elasticity of production(ε_p) and return to scale (RTS)

Elasticity(ε_p)	**Estimates**
Farm Size	0.240
Family Labour	0.147
Hired Labour	0.213
Herbicides	0.172
Fertilizers	0.127
Seeds	0.215
Pesticides	0.024
Capital	0.042
RTS= ($\sum\varepsilon_p$)	1.173

Source: Field Survey (2024)

t-Test of differences between cost and returns of cowpea farming

The average cost of production is 254,128.93 and the average returns is 806,809.70 (Table 5). Cost and returns have a standard deviation (SD) of 124,419.52 and 110,834.59, respectively. The calculated t-value is 33.08 which is significantly higher than the critical t-value of 1.96 at 5% level of significance. Since the calculated t-value exceeds the critical t-value, the null hypothesis stating that there is no significant difference between cost and returns is rejected. This implies that the returns of production on production outweighs the production cost, indicating that cowpea business is profitable.

Table 5. T-test of difference between costs and returns

Variable	Estimates (Number)
Costs	254,128.93
Returns	806,809.70
Standard Deviation	125,419.52
Standard Deviation	110,834.59
t-Calculated	33.08
t-Table	1.96

Source: Field Survey (2024)

Table 6. Test of the null-hypothesis of absence of inefficiency in the production function among the cowpea farming

Null-Hypothesis	$L(H_0)$	$L(H_1)$	χ^2 Calculated Value or LR	χ^2 Critical Value	Decision
Absence of Inefficiency in the production function model	-13.23	36.347	99.754	12.59	Reject Null Hypothesis

Source: Computed from Field Survey (2025)

The robust difference in the t-value strongly reinforces statistical evidence that the farmers make substantial profit. The notable profitability could be a result of efficient production methods, favorable market prices and possibly the adoption of cost-effective climate smart technologies.

Test of hypotheses

The tests of hypothesis is conducted so that the size is $\alpha = 0.05$. Thus, if the Chi-square statistics is greater than 95th percentage point for the appropriate Chi-square distribution, then the null-hypothesis involved is rejected (Table 6). The likelihood ratio test (LR) value of 99.754 exceeds the critical χ^2 value of 12.59 at the 5% level of significance.

CONCLUSIONS

The findings of the study provide insights into the optimization and determinants of cowpea farmers' output in the Federal Capital Territory and Kaduna State, Nigeria. The following conclusions were drawn based on the research null hypotheses:

There is absence of inefficiency in the production function model of the cowpea farming. This null-hypothesis is rejected. The computed LR (99.74) is greater the tabulated χ^2value, hence indicating the presence of inefficiency in the production function. Confirming this result further is the result of gamma (γ) of 0.81 of the preferred model. The gamma (γ) is very close to one and significantly different from zero, there by establishing the fact that high level of inefficiencies exists among the sampled farmers. The gamma (γ) value of 0.81n shows that 81% variations of cowpea output from frontier (potential) output was due to inefficiency while the remaining 19% of cowpea output deviation from the frontier level was due to random noises like unexpected rainfall, frost, and other natural disasters beyond the control of cowpea farmers.

The production factors such as farm size, family labour, hired labour, herbicides, fertilizers, seeds, pesticides, and capital do not have any significant influence on the output of cowpea growers in the study area. This null-hypothesis is rejected. Farm size, family labour, fertilizer and seeds, were the major determinants and significantly influence the production of cowpea, with some of the determinants playing a more dominant role in the output. This highlights the relevance of efficiently allocating and management resources to fully optimize output. Farm size has the highest positive and significant coefficient of 0.240, while fertilizers usage have the least positive and significant coefficient of 0.127.

The elasticity of production is not significantly different from zero. This null-hypothesis is rejected. The results indicated that elasticity of production expressed a significantly positive relationship and are greater than zero. This suggests that the cowpea farmers can improve their productivity when access to essential inputs are improved. The results of the parameters that enter the production function directly are presented as partial production elasticities, serving to examine the degree of responsiveness of relative changes in cowpea output to relative changes in input. These elasticities also serve as estimates of resource productivity. Farm size, hired labour, and herbicides had the highest elasticities of production with values of 0.24, 0.213, and 0.172 respectively.

The return to scale is not significantly different from zero. This null-hypothesis is rejected. Findings from the study show that farmers engaged in cowpea production experience increasing returns to scale (RTS), with an estimated RTS value of 1.173. Since this value is greater than one, output can be increased by expanding farm operations and optimizing input use. Specifically, when cowpea farmers increase all eight inputs simultaneously by one unit in the Cobb-Douglas production function, cowpea output rises by 1.173 units. This indicates that the farmers are operating in Stage One of the production surface, where output can still be increased through additional input use.

Based on the findings of this research, are made several policy recommendations: (i) Increase access to improved cowpea varieties: Provide financial supports for farmers to purchase high yielding, disease resistance cowpea seeds. Ensure public-private seed distribution systems, establish and support local seed multiplication programs to ensure a consistence supply of improved seeds. (ii) Farmers Training: Conduct training program to educate cowpea farmers on the benefit and proper use of improved cowpea varieties. (iii) Improved Storage Facilities: Government and private institutions should invest in post-harvest storage facilities to reduce losses due to pests and spoilage. (iv) Road Infrastructure: Improve rural networks to facilitate the transportation of cowpea produce to nearby markets. (v) Integrated Pest Management (IPM): Train farmers on IPM techniques to minimize reliance on chemical pesticides and reduce environmental impact. (vi) Market Information Systems: Establish market information systems to provide farmers with real-time information on prices and demand. (vii) Strengthened Farmers Cooperatives: Encourage the formation and strengthening of farmers cooperatives to improve the bargaining power and access to markets. (viii) Access to Credit: Provide cowpea farmers with access to affordable credit to purchase inputs and invest in improved technologies. (ix) Strengthen Extension Services: Increase the number of extension agents and provide them with adequate training and resources to effectively reach the farmers. (x) Input Subsidies: Provide subsidies on essential inputs like fertilizers and pesticides to reduce the production costs. (xi) Research Development: Invest in research to develop cowpea varieties that are drought-tolerant and adaptive to changing climate conditions.

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