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Analysis of input demand, substitutability and complementarity among yam farmers in Ekiti state, Nigeria: A cost function approach

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Abstract: Yam (Dioscorea spp.) is a significant staple crop in Nigeria, particularly in Ekiti State, where it plays a crucial role in food security and the economy. However, in recent times, as prices of inputs increase, the price of yam has increased making it a luxury food rather than a staple food for many people and the management of available resources in such a way as to improve productivity is therefore inevitable. The study employs a translog cost function approach to analyse input demand, substitutability, and complementarity among key inputs—labour, land, capital, and seedyam—used by yam farmers in Ekiti State, Nigeria. Data was collected from 180 respondents and using a multistage sampling technique. The data collected was analysed using descriptive statistics and translog cost function. Results showed that while labour and seedyam are critical inputs, their cost impact varies, with labour showing lower elasticity compared to seed yam. Capital and land, though less significant in terms of cost share, also play vital roles in yam production. The scale effect indicated that yam production using seed yam is capital saving. The study also reveals significant substitutability and complementarity among inputs, with important policy implications for improving input efficiency, reducing production costs, and enhancing yam productivity. The findings suggest that targeted interventions, such as providing quality and affordable seedyam and improving access to capital, could enhance resource allocation and support sustainable yam production in Ekiti State.
Keywords: Yam production, input demand, substitutability, complementarity, resource allocation, elasticity.

INTRODUCTION

Yam (Dioscorea spp.) is a crucial staple food in Nigeria, playing a vital role in both food security and the national economy. Nigeria is the world's largest producer of yam, contributing over 60% of the global output (Verter and Bečvářová, 2015). Within Nigeria, Ekiti State, located in the southwestern region, is one of the leading producers of yam. Yam is one of the major staple food in Nigeria and has potential for livestock feed and industrial starch production (Ayanwuyi et al, 2011). It is one of the principal tuber crops in the economy, regarding land under cultivation and in the volume and value of production (Toluwase and Sekunmade, (2017). Amusa *et al.* (2018) observed that white yam alone contributes about 200 dietary calories daily for more than 95 million people in Nigeria while also serving as an important source of income and livelihood security to many people who are involved in various stages of its production, transportation, marketing and processing. The crop is a significant source of calories for the local population and a vital commodity in cultural practices and ceremonies. Interestingly, yam is categorised as chief among the major staple foods of Nigerians on account of its indispensability. Worthy of note is the fact that many important cultural values are also attached to yam, especially during weddings and other social ceremonies. Despite its importance, yam production in Ekiti State, like in many other parts of Nigeria, faces several challenges, including low productivity, high labour costs, land fragmentation, and suboptimal input use (Umeh *et al.,* 2017).

Enhancing agricultural productivity often involves a dual approach: boosting farm resource levels and optimizing the use of existing resources. However, the uncertainty in productivity, especially noted in yam production compared to other crops, is not due to a lack of resources only but also their inefficient utilization. The relationship between the inputs used in yam production is of great interest to agricultural economists and policymakers, particularly in understanding how these inputs can be effectively managed for optimum resource allocation and improving farmers' livelihood (Adeyeye *et al.*, 2024). The concepts of input substitutability and complementarity are central to this understanding. Input substitutability refers to the ability to replace one input with another in the production process without affecting the output level, while complementarity indicates that the use of one input enhances the productivity of another (Otunaiya *et al.*, 2013). If an increase in the price of one input leads to an increase in the demand for another input, the two inputs are considered complements but if it leads to a decrease in the demand for the other input, then the two inputs are substitutes.

While previous studies have explored input use in Nigerian agriculture, they have predominantly focused on production functions (Adeyeye *et al.,* 2024; Anugwo and Egwue, 2024). These studies, though valuable, often fail to capture the complex interactions between inputs that a cost-function approach can reveal. This study aims to fill this gap by employing a translog cost function to analyze the price elasticities of input demand, and input substitutability and complementarity among key inputs—labour, land, capital, and fertilizer—used by yam farmers in Ekiti State. Understanding these relationships is crucial for designing policies that enhance the efficiency of input use, reduce production costs, and ultimately increase yam productivity.

This study is particularly relevant in the context of Nigeria's broader agricultural policy objectives, which emphasize increasing food production to ensure food security and reduce poverty. By identifying the nature of input relationships, this study provides evidence-based insights that can guide policymakers in developing targeted interventions to support yam farmers.

The concept of production function is used to represent the technical relationships between maximum output and a set of inputs given the state of technology. A specific functional form for the production function must be assumed. The parameters of this function provide information on important characteristics of the technology i.e. elasticity of scale and elasticity of substitution (Russell, 2020). Elasticity of scale measures the proportional change in output due to a proportional change in all inputs. The concept of elasticity of substitution measures the ease of substitutability between two different inputs with constant output. Empirical estimation in production analysis is based on two main approaches i.e primal and dual approaches. The primal approach consists of specifying a functional form for the production function and then solving the cost minimisation problem. Essentially the firm is faced with the constrained minimisation problem, i.e. produce output with the minimal costs. In order to minimize costs, the firm should produce at that point on the isoquant at which the rate of technical substitution of inputs is equal to the ratio of the inputs' prices (Varian, 2010). From a mathematical point of view, the constrained optimisation problem can be solved through the Lagrange multiplier method. At the same time, profit maximisation requires that the firms hire each input up to the point where its marginal contribution to revenue is equal to its market price. The first-order conditions of the cost minimisation problem, given the prices, lead to an implicit demand for inputs, which is contingent on the level of output being produced. Moreover, the production function approach is based on the physical quantities of inputs, which can be considered endogenous variables to the firm. Instead, in a more realistic setting, decisions on factor use are made according to factor prices, which are exogenous. Over time, there has been a movement from the 'primal approach', based on the production function, to the 'dual approach'. The dual approach offers a simple way of deriving input demand and output supply systems directly from the dual objective function. One of the advantages of the duality approach is the ability to accommodate a multiple output as well as a multiple input. As it was first shown rigorously by Shephard (1953), there exists a duality between production and cost functions, which implies that if producers minimise input costs, then the cost function contains sufficient information to completely describe the technology (Kreps, 2012). Essentially a cost function can be simply defined as:

$C = f(Y, w)$ ……………………………….(1)

Where cost (C) is a function of output (Y), which is predetermined, and of input prices (w).

The advantages of specifying the cost function are that the factor levels are now endogenous and the input demand functions for the factors of production can be easily derived as the partial derivatives of the total-cost function with respect to the factor prices (Shephard's lemma). Because the output produced enters the total-cost function, input demand is contingent on that variable and this is why we refer as 'contingent' demand functions.

METHODOLOGY

Ekiti State situates in the Southwestern geopolitical zone of Nigeria. It is located within latitude $7^0 30^1$N and $8^0 15^1$N and Longitude $4^0 47^1$E to $5^0 40^1$E of the Greenwich Meridian. It shares boundaries with Kwara State in the North, Kogi State in the East, Ondo State in the South and Osun State in the West. It covers a total land area of about 6,353 square kilometres with a population of 2, 398, 957 people as at 2006 and projected to 3,785,003 as at 2021 (Ekiti State Bureau of Statistics, 2022). The State is mainly an upland zone located in the rainforest agro-ecological zones with two distinct seasons namely: wet and dry seasons. The Wet season characterised by rainfall, is between April and October while the dry season is between November and March. The mean annual rainfall ranges between 1,000mm and 1,500mm while the mean temperature is 30^0C. Farming is the major occupation of the people. They cultivate tree crops such as cocoa and food crops such as yam, cocoyam, cassava and maize. A multistage sampling technique was used to select respondents 180 respondents for the study. The state is divided into three zones based on the Agricultural Development Program (ADP) zoning and 2 local government areas (LGAs) were purposively selected from each of the three zones (these include: Oye Ekiti and Ikole Ekiti from northern zone; Aramoko Ekiti and Irepodun Ekiti from central zone and Emure Ekiti and Ose Ekiti from the southern zone) based on their predominance in yam production. The second stage involved the simple random selection of 3 villages from each of the LGAs and in the third stage, 10 yam farmers were randomly selected.

Data were collected, using structured questionnaire, on farmers' socio economic characteristics (such as gender, age, years of experience, educational status), input and output especially, labour for yam production activities (land preparation, mulching, planting, weeding, staking), costs and prices.

Empirical Model

The translog form of the production cost model was stated as:

$$lnC(Y,w) = ln \propto_0 + \sum_{i=1}^{n} \propto_1 lnw_i + \frac{1}{2} \cdot \sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} lnw_i lnw_j + \propto_Y lnY + \frac{1}{2}\gamma_{YY}(lnY)^2 + \sum_{i=1}^{n} \gamma_{iY} lnw_i lnY \quad ......(2)$$

Where, C = Total Cost of yam production (Naira), Y= Total value of yam output (Kg)

w_1= price of land (Naira), w_2= price of seed yam (Naira), w_3= price of capital (Naira), w_4= price of labour (Naira).

The cost share equation was derived from the above as:

$$S_i = \left(\frac{\partial lnC}{\partial lnw_i}\right) = \propto_i + \sum_{j=1}^{n} \gamma_{ij} lnw_j + \gamma_{iY} lnY \quad ......(3)$$

Where;

$$S_i = \frac{w_i X_i}{C} \quad ......(4)$$

$$\frac{w_i X_i}{C} = \propto_i + \sum_{j=i}^{n} \gamma_{ij} lnw_j + \gamma_{iY} lnY \quad ...... (5)$$

$$X_i = \frac{C\left[\propto_i + \sum_{j=i}^{n} \gamma_{ij} lnw_j + \gamma_{iY} lnY\right]}{w_i} \quad ...... (6)$$

Where, S_i is the cost share of the ith input; X_i is the quantity of the ith input demanded. The parameters estimates were used to estimate the Allen Elasticity of Substitution related to input demand and the price elasticity of demand for each of the input. The elasticity estimates represent the structure of the production system for the yam farms in the study area. The complementarity and substitutability of inputs was checked using the Allen Elasticity of Substitution (AES), this is given as:

$$\sigma_{ij} = \frac{Y_{ij} + S_i S_j}{S_i S_j} \qquad i \neq j ......(7)$$

$$\sigma_{ii} = \frac{Y_{ii} + S_i^2 - S_i}{S_i^2} ...... (8)$$

The own price elasticity of demand and the cross-price elasticity of demand for the inputs were examined and given as follow:

$$\in_{ij} = S_j \sigma_{ij} ...... (9)$$

$$\in_{ii} = S_i \sigma_{ii} ...... (10)$$

The symmetry and homogeneity properties of the cost function was also examined to ensure the equality of the cross partial derivatives as follows:

$$Y_{ij} = Y_{ji}, \qquad i \neq j ...... (11)$$

$$\sum_{i=1}^{n} \propto_i = 1\ , \ \sum_{i=1}^{n} Y_{ij} = \sum_{j=1}^{n} Y_{ji} = \sum_{i=1}^{n} \gamma_{iY} = 0 \quad ...... (12)$$

RESULTS AND DISCUSSION

Description of input use, output and cost share by respondents.

Table 1 shows the mean input use of the sampled yam farmers in the study area. The table revealed that the mean Labour usage is 398 man-days per hectare, with a cost of ₦189,421.00 per hectare, contributing 45.32% to the total production cost. The high-cost share indicates that labour is the most significant factor in yam production costs and labour is scarce and expensive in the study area, probably because of rural-urban migration of the able-bodied men or their engagement in other non-farm activities, especially commercial motor cycle business, which gives better daily income rather than the more labour intensive farming activities. This finding is consistent with existing literature, which often emphasizes the labour-intensive nature of yam cultivation, particularly in traditional farming systems as in the study area. Studies like those by Anyiro et al. (2013) and Adeyeye *et al.* (2024) have also highlighted that labour is a dominant cost factor in yam production due to the manual operations involved, such as planting, staking, and harvesting. Seedyam, which is the planting material for yam, has a cost of ₦140,354.86 per hectare and constitutes 33.58% of the total production cost. This cost is relatively high compared to land capital costs probably due to the large quantity needed and the importance of using disease-free material to ensure good yields. The high cost of seedyam aligns with findings of Okeke (2016), who reported that the high cost of quality seedyam is a challenge for yam farmers. Table 1 also reveals relatively low capital cost and land cost shares. The mean capital cost per hectare amount to ₦86,489.00, representing 20.69% of total production costs. This relatively low capital cost share is in line with findings of Agyei-Holmes *et al.* (2014) which also observed that capital investments in inputs like fertilizers, pesticides, and equipment contribute significantly to yam production costs, but to a lesser extent than labour. In contrast to the cost share of labour and capital, the cost of land per hectare is relatively very low at ₦1,661.80, with a cost share of 0.40%. This very low-cost share is typical in the study area where land is either abundant or leased at low rates such as in the study area. However, in areas where land is scarce or more expensive, this share could be higher. The very low land cost suggests that land is not a major constraint in yam production in the study area. However, this might change with increasing land competition or if policies alter land tenure arrangements. The average output per hectare is 8,624.5 kg, with a standard deviation of 3,420.12, indicating significant variability in yield.

Table 1: Description of output and factor costs shares

Factor	Quantity per hectare	Cost per hectare	Cost Share
Labour (Man-day)	398 (77.16)	189,421.00 (90925.32)	0.45324
Capital (Naira)	86,489.00 (42071.85)	86,488.78 (42071.85)	0.206947
Land cost (Naira)	1661.80 (974.65)	1,661.80 (974.65)	0.003976
Seedyam (kg)	2,772.60 (1272.00)	140,354.86 (66381.52)	0.335836
Total		417926.44	1.00
Output (Kg)	8624.5 (3420.12)		

Figures in parenthesis are standard deviations

Determinants of input demand in yam production

Table 2 shows the determinants of factor share estimates of the translog cost equations. The coefficient of Yam output is positive and significant in the seedyam (0.0171) and negative in capital (-0.0123) equations. This means that the scale effect is seedyam and capital using. This implies that the quantity of seedyam concerning the share of the seedyam cost increases with the output of yam, while the amount of capital with regard to the share of the capital costs decreases with the output. Hence, the scale effect is capital saving but seedyam using but labour and land inputs in Yam production are not significantly affecting output. This agrees with the findings of Otunaiya *et al.*, (2013) who also reported that the scale effect in yam production is planting material using. The coefficients of capital variable is significant in land, labour and capital equations, whereas the coefficient has a negative sign in land and labour inputs, it has a positive sign in the capital equation. The implication is that capital use is land-saving and labour-saving. This means that the greater the quantity of capital used, the lower the shares of land and labour input costs. This may be due to a low capital use rate observed in the study area probably because majority of the farmers are poor and do not have collateral for credits. The coefficients of seedyan variable is also significant in seedyam, labour and capital equations. The coefficient has negative sign in capital and labour input equations, it has positive sign in seedyam equation. This implies that seedyam use is capital-saving and labour-saving. This means that the greater the quantity of seedyam used the lower the shares of capital and labour input costs. This may be due to the fact that many farmers in the study area did not buy their seedyam. They often get them from the savings from their past harvests. The coefficients of labour variable is significant in seedyam, labour and capital equations. The coefficient has negative sign in seedyam and capital input equations, but positive sign in labour equation. This implies that labour use is seedyam-saving and capital-saving. This means that the greater the quantity of labour used the lower the shares of seedyam and capital input costs. This may be because many farmers in the study area depend more on family labour, which is not appropriately priced. Despite this, the cost share of labour input is still the highest in the study area (Table1).

Table 2: Factors share estimates of the translog cost function

Inputs	Constant	Land	Seedyam	Labour	Capital	Output	R^2
Land Cost	-0.0423***	0.0046***	0.0005	0.0026	-0.0009**	0.0001	0.3274
Share	(0.0143)	(0.0005)	(0.0012)	(0.0016)	(0.0004)	(0.0002)	
Seedyam	0.2533	0.0100	0.2054***	-0.1338**	0.0015	0.0171**	0.1876
Cost Share	(0.5199)	(0.0195)	(0.0446)	(0.0577)	(0.0131)	(0.0072)	
Labour	0.1663	-0.0012	-0.1166**	0.2476***	-0.0891***	-0.0049	0.2705
Cost Share	(0.5762)	(0.0216)	(0.0495)	(0.0639)	(0.0146)	(0.0079)	
Capital	0.6227**	-0.0133	-0.0893***	-0.1164***	0.0886***	-0.0123***	0.5635
Cost Share	(0.2826)	(0.0106)	(0.0243)	(0.0314)	(0.0071)	(0.0039)	

Figures in parenthesis are standard errors, ** and *** represents 5% and 1% significance levels

The price elasticity of input demand

Table 3 shows the price elasticities of input demand. All own price elasticities of factor demand have expected negative sign implying that the demand for these inputs decrease with increase in their respective prices. This result is consistent with the law of demand, which states that ceteris paribus, the quantity demanded of a commodity is inversely proportional to the price of the commodity. The negative own price elasticity of land demand aligns with findings of Du *et al.* (2019), which indicated that higher land prices reduce land demand. The own price elasticities of all the inputs (except for seedyam which is elastic) are also less than one indicating that they are inelastic. The high elastic nature of demand for seedyam (3.77) in the study area could probably be as a result of abundance of seedyam from savings of past harvests from where farmers can source for seedyam when there is an increase in price of seedyam. The relatively high inelastic nature of demand for labour (-0.539) suggests scarcity of labour in the study area; since the own price elasticity of labour shows that labour is a normal good. The cross price elasticity of demand refers to the degree of responsiveness of quantity demanded of an input to the change in price of another factor. Positive cross price elasticity of demand means that the factors are substitutes while negative cross price elasticity of demand implies that the inputs are complements. The results of cross-price elasticity of demand for the factors are also presented in Table 3. The results reveal that labour-capital pair and labour-land pair are substitutes. These results are theoretically correct and practically plausible. The result implies that as the price of labour increases, less labour is employed in production and more of capital and land inputs are demanded. The labour-seedyam pair and capital-seedyam pair, on the other hand, are complements. The complementarities of labour-seedyam pair and capital-seedyam pair implies that an increase in the price of labour (or capital) will reduce demand for labour (or capital) and result in a consequential decrease in demand for seedyam. The positive cross price elasticities of demand for labour-capital pair and labour-land pair are consistent with Prajapati (2021) who found some degree of substitutability between land and labour in conventional farms.

Table 3: Estimates of Price Elasticities of Input Demand

Price Elasticity	Land	Seedyam	Capital	Labour
Land	-0.8409	0.061	0.314	0.399
Seedyam	0.787	-2.498	-0.384	-0.274
Capital	0.180	-0.017	-0.651	0.438
Labour	0.173	-0.009	0.331	-0.539
Yam output	0.195	0.015	0.339	0.45

Elasticities of substitution and complementarity of the input demand

Table 4 shows the estimated values of the allen elasticities of substitution and complementarity of input demanded by the sampled yam farmers. This concept is used to indicate the relative demand change in one factor when its price changes relative to another factor price. The major diagonal found in Table 4 is composed of each of the four factor's own elasticity of substitution. The values outside the main diagonal are symmetric; positive signs indicate substitution and negative signs indicate complementarity. As expected by the theory, all the values in the main diagonal are negative. This result has little economic meaning but does indicate that each production factor is self-complementary and confirms the concavity of the cost function. For example, the elasticity of substitution for land with itself is negative and quite large. This indicates that the substitution between different uses of land is extremely limited or negative (-4.312), suggesting that increasing the intensity of land use does not compensate for a reduction in the quality or availability of land. This finding is consistent with literature that shows land is a critical and relatively inelastic factor in agriculture.

According to the Allen elasticity of substitution concept, seedyam and capital factor pair and seedyam and labour factor pair are complementary in yam production. For a 1 % relative increase (decrease) in seedyam price, the relative demand for capital decreases (increases) by 1.129%. Considering capital and seedyam factors, the same rationale applies because Table 4 is symmetric. This result shows a strong complementary relationship, since the relative demand change of one factor is more than proportional to its relative price change. This result is consistent with findings of Otunaiya *et al.* (2013), which reported that the combination of inputs like seedyam and capital is not easily interchangeable. Most of the other elasticities presented in Table 4 show a positive sign, indicating substitution between these yam production factors. There is a substitution relationship between land and labour, land and capital, and labour and capital. Among these pairs of factors, capital and labour pair has the largest elasticity of substitution (0.974), indicating that the relative demand for that pair of factors is inelastic. The value of the Allen elasticity of substitution between land and seedyam is larger than one. In this case, as the relative price of one factor increases (decreases) 1 %, the relative demand for the substitute factor increases (decreases) 4.036%, i.e., there is an increase (reduction) in the relative demand for the substitute factor that is more than proportional.

Table 4: Estimates of Elasticities of Substitution of Input Demand

Input	Land	Labour	Capital	Seedyam
Land	-4.312	0.886	0.925	4.036
Labour		-1.198	0.974	-0.608
Capital			-1.916	-1.129
Seedyam				-164.339

CONCLUSION

Yam production in Ekiti State, Nigeria, is a labour-intensive activity, with labor costs accounting for a significant portion of total production expenses. This reflects the broader challenges faced by yam farmers in Nigeria, where traditional farming techniques and rural-urban migration exacerbate labor scarcity. While the cost of labor is high, other inputs such as seedyam and capital also contribute to production expenses, though to a lesser extent. The findings of this study reveal that the scale effect is capital saving and seedyam using but labour and land inputs are not significantly affecting output. It also revealed that while capital use is land-saving and labour-saving, seedyam use is capital-saving and labour-saving and labour use is seedyam-saving and capital-saving. Furthermore, there are significant input relationships, with labour and capital acting as substitutes, while seedyam is complementary to both labor and capital. Understanding these relationships is crucial for improving resource allocation and reducing production costs. The study further highlights that the price elasticity of demand for inputs such as labor and seedyam significantly affects input use and cost shares, offering insights into potential efficiency improvements in yam farming. The analysis reveals the elasticity of substitution and complementarity between key inputs. Labour and capital exhibit a substitution relationship, meaning an increase in the use of capital inputs (such as tools or machinery) can reduce the reliance on labour. On the other hand, seedyam demonstrates complementarity with labor and capital, implying that an efficient increase in seedyam use requires proportional increases in labor and capital to optimize productivity.

RECOMMENDATIONS

The study recommended that given the substitution relationship between labor and capital, promoting affordable and improved access to capital will reduce labor dependency and overall production costs. Supporting farmers with capital investment, such as subsidies for fertilizers and equipment, will enhance the substitution of labor with capital, improving productivity and reducing production inefficiencies. Since seedyam is complementary to both labor and capital, policies that provide farmers with affordable, high-quality seedyam will ensure that labor and capital investments are maximized for better yields. Lastly, Farmers should be encouraged to expand their scale of farming operation through provision of improved and affordable seedyam since the scale effect is seedyam using. This will help to optimize the use of inputs.

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