



**TECHNICAL AND ECONOMIC OPTIMUM FERTILIZER APPLICATION RATES FOR
SELECTED CEREALS AMONG SMALLHOLDER FARMERS IN
BENUE STATE, NIGERIA**

Iheanacho, A. C. Okeke, A. M. Aker, I. E.

Department of Agribusiness, Joseph Sarwuan Tarka University, Makurdi, Nigeria.

Corresponding Author's Email: anayomichaelokeke@gmail.com, **GSM:** 07031316191

ABSTRACT

The study determined the technical and economic optimum fertilizer application rates for selected cereals among smallholder farmers in Benue State, Nigeria. Multistage sampling procedure was used to select 120 respondents. Data were collected using structured questionnaire and analysed using production function and multiple regression analysis. The production function analysis reveals that the current fertilizer application rate by the farmers for maize, millet, rice, and sorghum production were 42.89, 63.63, 53.47, and 43.75kg/ha respectively. The technical optimum fertilizer rate for maize, millet, rice, and sorghum production were 94.40, 440.53, 415.44, and 224.24kg/ha respectively while the economic optimum fertilizer rate for maize, millet, rice, and sorghum production were 94.35, 438.77, 413.91, and 222.38kg/ha respectively. The multiple regression results on the determinants of fertilizer use show that household size, age, and farm size of these farmers significantly influence their use of inorganic fertilizer in cereal production. The multiple regression results further show that these farmers' access to credit and membership to cooperative significantly influence their use of inorganic fertilizer in cereal production. The study concludes that gap exist between the current fertilizer application regime of these farmers and the optimum rates, and that their use of fertilizer is influenced by their socio-economic characteristics. It was recommended that the Benue State Ministry of Agriculture should organize training workshops where experts in fertilizer application will be invited to train the farmers on optimum application rates; and Benue State Government should establish and fund community Farmer Field Schools to deliver season-long practical training on fertilizer usage.

Keywords: Optimum, Fertilizer, Application, Rates, Cereals

INTRODUCTION

In spite of efforts by successive administration in Nigeria at encouraging increases in the production of maize, rice, sorghum, and millet, yields per unit area are still low. According to a 2024 report on cereal production in Nigeria, the 2023 aggregate cereal production estimated at 28.1 million tonnes was about five percent below the five-year average (2018 to 2022) estimate of 29.9 million tonnes, and about eight percent below the 2022 estimate of 30.5 million tonnes (Food and Agriculture Organization, FAO, 2024). This decline in cereal yield in the country has persisted. Among identified causes for this low yield per unit area of land, are declining soil fertility and inability of farmers to use the required quantities of mineral fertilizers. According to Anyanwu (2026), a 2026 report by Fertilizer Suppliers Association of Nigeria (FEPSAN) revealed that farmers in Nigeria apply about 24 kilograms of fertilizer per hectare compared to the African target of 50 kilograms per hectare and as such, production gains have come mainly from increases in area planted and not from increases in yield. This report agrees with Njoroge *et al.* (2023) who revealed that fertilizer nutrient use in sub-Saharan Africa (SSA) is the lowest globally at less than 20kg/ha compared to the global average of 135kg/ha. Kihara *et al.* (2020) and Vanlauwe *et al.* (2023) revealed that inability to meet these nutrient requirements over the years is consistently resulting in nutrient mining of the soil and hence, declining agricultural productivity and environmental sustainability. Abdulraheem *et al.* (2022) further revealed that in Nigeria, 87kg NPK/ha is mined yearly, the value being higher than those recorded for Zimbabwe, Cote d'Ivoire, Benin, and Ethiopia. Giving the introduction of new and high yielding varieties, such soil nutrient mining will be on increase when mineral fertilizer additions are absent or not in adequate amounts (Vanlauwe *et al.*, 2023).



In designing any effort targeted to boost the yield per unit area of maize, rice, sorghum, and millet in the country and hence their production, it is imperative to understand the current fertilizer application regime of producers of these crops. Such knowledge will guide the development of models for the technical and economic optimum application of fertilizers among these stakeholders. There are plethora of studies in Nigeria on fertilizer use such as Akpan *et al.* (2021) who investigated the effects of NPK (15:15:15) fertilizer on growth and yield of guinea white yam genotypes in Uyo South-South Nigeria; Iwuchukwu *et al.* (2022) who analyzed the factors influencing inorganic fertilizer use among rice farmers in Ebonyi State, Nigeria; and Bassam (2025) who examined fertilizer recommendation for sesame in Sudan Savannahs of Nigeria. None of these studies however, looked at developing models for the technical and economic optimum application of fertilizers among smallholder farmers for selected cereals in Benue State of Nigeria. Thus, this study aimed at bridging this research gap.

The broad aim of this study was to determine the technical and economic optimum application of fertilizers among smallholder farmers for selected cereals in Benue State, Nigeria. The specific objectives were to:

- i. determine the current fertilizer application regime rate of the cereal farmers;
- ii. determine the technical and economic optimum rate for fertilizer application among selected cereals; and
- iii. develop the models for the determinants of levels of fertilizer application of cereal farmers in the study area.

METHODOLOGY

The Study Area

The study was conducted in Benue State, Nigeria. The State is located in the North-Central zone of the country. Benue State lies between latitudes 6⁰25'N and 8⁰8'N and longitudes 7⁰47'E and 10⁰E. The State shares boundaries with five other States namely: Nasarawa to the North, Taraba to the East, Cross River to the South, Enugu to the South West and Kogi to the West (Benue Agricultural and Rural Development Authority, BNARDA, 2005). The State also shares a common boundary with Republic of Cameroon on the South East and occupies a land mass of 30,955 square kilometers, with a projected population of 6,573,600 people at 2.3% annual increase (Nathan *et al.*, 2025). The State has three agricultural zones namely the North-Eastern Zone, North-Western Zone, and the South-South Zone, and three senatorial zones with 23 Local Government Areas and 102 wards. The ethnic groups that make up this State are Tiv, Idoma, Etulo, Ufia, and Akwaya (ESFAJ and partner, 2012).

The major crops produced in the State include rice, maize, millet, guinea corn, groundnut, citrus, oil palm, melon, African pear, hot pepper, yam, cassava, sweet potato, and beans (ESFAJ and Partner, 2012, Okeke *et al.*, 2022). Most of these crops are produced with artificial fertilizers such as Urea, NPK, and SSP.

Sampling Technique and Sample Size

The population for this study consisted of producers of maize, rice, sorghum, and millet in the 23 Local Government Areas of the State. Due to the large size of the population, a sample size of 120 cereal farmers engaged in rice, maize, sorghum, and millet production were selected for the study using multistage and stratified random sampling techniques. Firstly, each of the State's agricultural zones was stratified based on extension blocks from which two blocks were selected at random, giving a total of six blocks. Secondly, each chosen block was further stratified based on extension circles and concentration of rice, maize, sorghum, and millet production activities from which a circle was randomly selected. Thus, a total of six circles were selected for the study. Thirdly, each circle was stratified based on villages, and two villages were randomly selected from each circle, making a total of 12 villages. In the fourth stage, 10 farmers engaged in maize, millet, rice, and sorghum production were randomly selected from each village, giving a sample size of 120 cereal farmers for the study. A list of cereal farmers in each village compiled with the assistance of the Village Heads and Extension Agents was used.



Method of Data Collection

Data were collected using a set of pretested, structured questionnaire and a checklist, complemented with interview schedule. The questionnaire was divided into four sections namely A, B, C, and D. Section A dealt with the socio-economic characteristics of the respondents; section B dealt with fertilizer application rate of the respondents; section C covered the costs and return in cereal production; while section D covered the challenges in fertilizer use among the respondents. The questionnaire was administered to the respondents through eight enumerators that were trained by the research team.

Method of Data Analysis

Objectives (i) and (ii) were realized using production function. Objective (iii) was realized using regression model.

Model Specification

The production function for technical and economic optimum was implicitly specified as follows:

$$Y_i = f(X_i, U_i) \quad \dots(1)$$

Where,

Y_i = output of maize, rice, millet, sorghum (Kg)

$i = 1, 2, 3,$ and 4

X_i = quantity of fertilizer applied (kg/ha)

U_i = error term

The technical optimum level of fertilizer application was determined at the point where:

$$\frac{dy}{dx} = 0, \text{ i.e. } MPP_x = 0 \quad \dots(2)$$

The economic optimum level of fertilizer application was determined at the point where:

$$\frac{dy}{dx} = \frac{P_x}{P_y} \text{ i.e. } MPP_x = \frac{P_x}{P_y} \quad \dots(3)$$

Two functional forms – quadratic and polynomial were tried, and the more fitted chosen on the basis of coefficient of determination (R^2), *a priori* expectation, and significance of the coefficient. *A priori*, it was expected that the coefficient of X would be positive.

The multiple regression model for the determinants of levels of fertilizer application was specified as follows:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + b_8X_8 + b_9X_9 + b_{10}X_{10} + b_{11}X_{11} + b_{12}X_{12} + e \dots(4)$$

Where:

Y = the amount of fertilizer applied (kg)

a = Constant of the equation

b_1 - b_{12} = Coefficients of the predictor variables

X_1 = age of the respondent (years)

X_2 = level of education (Numbers of years in formal education)

X_3 = household size (Number of persons)

X_4 = farm size (hectare)

X_5 = farming experience (years)

X_6 = access to credit (1 = Have access; 0 = Have no access)

X_7 = membership of cooperative (1 = member; 0 = Non-member)

X_8 = extension agent contact (Number of visits)

X_9 = farm output (kg)

X_{10} = farm income (₦)

X_{11} = gender (1 = male; 0 = female)

X_{12} = marital status (1 = married; 0 = single)

ϵ_i = Error term

The *a priori* expectation was that the coefficients of level of education, farm size, farming experience, access to credit, membership of cooperative, extension agent contact, farm output, farm income, and gender would be positive, while those age, household size, and marital status would be negative.

RESULTS AND DISCUSSION

Current Fertilizer Application Rate for the Respondents in the Study Area

The current application rates for inorganic fertilizer among cereal farmers in the study area are presented in Table 1. The results in Table 1 show that the current fertilizer rate for maize, millet, rice, and sorghum production in the study area were 42.89, 63.63, 53.47, and 43.75 kg/ha respectively. The yield from maize, millet, rice, and sorghum in using these application rates were 1918.97, 3696.88, 1368.97, and 1853.00kg per ha respectively.

These rates are lower than the recommended rates reported by Ajeigbe *et al.* (2020), Kamai *et al.* (2020), Yameogo *et al.* (2022), and Ojeniyi *et al.* (2024) for cereal production (for maize, NPK 15:15:15 at 300kg/ha and urea at 100kg/ha; for millet, NPK20:10:10 at 150kg/ha; for rice, NPK15:15:15 at 200kg/ha and urea at 150kg/ha; and for sorghum, NPK15:15:15 at 200kg/ha and urea at 100kg/ha) in the country and by implication, the outputs from cereal crops in the study area are below the optimal level.

Table 1: Current Fertilizer Application Rates and Yields of Respondents Per Hectare

Cereal crops	Current application rates and yields (kg/ha)	
	Mean rate (kg/ha)	Output (kg/ha)
Maize	42.89	1918.97
Millet	53.47	3696.88
Rice	63.63	1368.97
Sorghum	43.75	1853.00

Field survey data, 2025

Optimum Fertilizer Application Rate for the Respondents in the Study Area

The technical and economic optimum application rates for inorganic fertilizer among the respondents are presented in Table 2. The results in Table 2 show that the technical optimum fertilizer rate for maize, millet, rice, and sorghum production were 94.40, 440.53, 415.44, and 224.24kg/ha respectively. The yield from maize, millet, rice, and sorghum in using these technical optimum rates were 4159.62, 5803.10, 9279.17, and 2434.21kg per ha respectively. Table 2 also reveals the economic optimum fertilizer rate for maize, millet, rice, and sorghum production were 94.35, 438.77, 413.91, and 222.38kg/ha respectively. The yield from maize, millet, rice, and sorghum in using the economic optimum rates were 4159.61, 5802.64, 9278.51, and 2433.77kg per ha respectively. The current fertilizer application rate of the farmers in Table 1 are below the determined technical and economic optimum rates for cereals in the study area. The finding of this study aligns with that of Ojeniyi *et al.* (2024) that revealed cereal production is characterized by low fertilizer application rates in Nigeria's mid-belt region.

This wide gap between the current application regime, and the technical and economic optimum rates could be attributed majorly to the inability of these farmers to afford fertilizers due to high costs. This corroborates the report of Chiaka *et al.* (2022) that most smallholder farmers in Nigeria cannot afford fertilizers.

Table 2: Technical and Economic Optimum Fertilizer Application Rates and Yields of Respondents Per Hectare

Cereal crops	Optimum application rates and yields (kg/ha)			
	TOR (kg/ha)	Output (kg/ha)	EOR (kg/ha)	Output (kg/ha)
Maize	94.40	4159.62	94.35	4159.61
Millet	440.53	5803.10	438.77	5802.64
Rice	415.44	9279.17	413.91	9278.51
Sorghum	224.24	2434.21	222.38	2433.77

Field survey data, 2025 TOR = Technical optimum rate; EOR = Economic optimum rate



Determinants of Fertilizer Usage among Respondents

The socio-economic factors influencing fertilizer use among cereal farmers in the study area are presented in Table 3. The multiple regression model was used in the analysis. The semi-log and double-log functions were selected as the lead equations to estimate the determinants of fertilizer use among maize and rice farmers respectively, while the linear function was selected as the lead equation to estimate the determinants of fertilizer use among millet and sorghum farmers. The selection was based on the *a priori* expectation, magnitude of R square, and the large number of statistical significances of the estimated regression coefficients. The F-value was significant in the models. Thus, the null hypothesis that socio-economic factors do not significantly influence fertilizer use among cereal farmers is rejected.

The coefficient of marital status was significant at 10% for rice producers and negatively related to fertilizer use. The negative sign is in consonance with the *a priori* expectation implying that if the farmer is married, the farmer's use of fertilizer decreases. This negative relationship is expected for married farmers with large household size as more household responsibilities may make them avoid buying large quantities of fertilizer. This finding is at variance with Iwuchukwu *et al.* (2022) who observed a positive relationship between marital status and inorganic fertilizer use among rice farmers in Ebonyi State, Nigeria.



Table 3: Determinants of Fertilizer Use among Cereal Farmers

Variable	Maize			Millet			Rice			Sorghum		
	Coeff.	SE	t	Coeff.	SE	t	Coeff.	SE	t	Coeff.	SE	t
Sex	64.93	75.18	0.86 ^{NS}	-57.99	69.19	-0.84 ^{NS}	-0.53	0.52	-1.02 ^{NS}	-0.68	36.39	-0.02 ^{NS}
Marital status	-77.01	52.81	1.46 ^{NS}	-107.05	76.39	-1.40 ^{NS}	-1.08	0.55	-1.95*	39.23	33.63	1.17 ^{NS}
Household size	342.60	164.40	2.08*	31.40	12.87	2.44**	0.29	0.39	0.74 ^{NS}	-3.23	8.58	-0.38 ^{NS}
Level of education	-3.16	65.04	-0.05 ^{NS}	-7.33	6.10	-1.20 ^{NS}	-0.09	0.42	-0.22 ^{NS}	7.25	4.15	1.75 ^{NS}
Age	-823.37	329.94	-2.50**	-3.73	4.25	-0.88 ^{NS}	2.30	1.64	1.40 ^{NS}	-2.44	2.49	-0.98 ^{NS}
Farming experience	43.17	63.95	0.68 ^{NS}	-3.28	8.71	-0.38 ^{NS}	-0.77	0.69	-1.12 ^{NS}	6.87	7.54	0.91 ^{NS}
Membership of cooperative	-9.43	145.57	-0.06 ^{NS}	-	-	-	1.56	0.55	2.83**	109.30	51.44	2.12*
Farm size	179.66	50.04	3.59***	40.67	19.72	2.06*	-2.95	0.69	-4.26***	20.17	7.57	2.67**
Access to credit extension contact	-63.95	120.03	-0.53 ^{NS}	47.06	109.52	0.43 ^{NS}	-1.63	0.50	-3.28**	-67.89	65.21	-1.04 ^{NS}
Annual farm income	-5.31	91.70	-0.06 ^{NS}	-51.32	57.31	-0.90 ^{NS}	2.39	0.60	4.00***	-66.58	35.62	-1.87 ^{NS}
Farm output	-59.62	50.99	-1.17 ^{NS}	-	-	-	0.13	0.07	1.86 ^{NS}	-8.25 x 10 ⁻⁶	0.000017	-0.50 ^{NS}
Constant	10.75	38.65	0.28 ^{NS}	-	-	-	0.84	0.38	2.20*	0.0056	0.014	0.40 ^{NS}
R square	2771.89	1210.07	2.29**	147.39	111.02	1.33 ^{NS}	-7.96	6.73	-1.18 ^{NS}	12.56	66.22	0.19 ^{NS}
Adjusted R square	0.7959			0.5217			0.8553			0.9026		
F-value	0.5918			0.2685			0.6382			0.7078		
	3.90**			2.06*			3.94**			4.63**		

Source: Field survey data, 2025 ***=sig@1%; **=sig@5%; *=sig@10%; NS=not significant



The coefficient of household size was significant at 5% and 10% for millet and maize producers respectively, and positively related with their use of fertilizer. The positive sign of the coefficients disagrees with the *a priori* expectation implying that as household size of farmer increases, the farmer's use of fertilizer increases. Farmers with large household size have the advantage of having more family labour force vital for field application and intensity of fertilizer use at no cost, compared to hired labour, thus, encouraging the farmers to use more fertilizer compared to farmers with small household size. The outcome of this study aligns with that of Dassa *et al.* (2022) that observed positive and significant relationship between family size and inorganic fertilizer use intensity.

The coefficient of age was significant at 5% for maize producers and negatively related to fertilizer use. The negative sign is in consonance with the *a priori* expectation implying that as the farmer's age increases, the farmer's use of fertilizer decreases. Aged farmers are more risk averse and conservative compared to younger farmers. These attributes negatively impact inorganic fertilizer use among these aged farmers. This result corroborates Dassa *et al.* (2022) that reported a significant negative relationship between age of farmers and their use of inorganic fertilizer.

The coefficient of farm size was significant at 1%, 5%, and 10% for maize, sorghum, and millet farmers respectively, and positively related to fertilizer use. The positive sign aligns with the *a priori* expectation, indicating that as farm size of the farmer increases, the farmer's use of fertilizer increases. High farm income gained by farmers with large farm size will spur them to use more inorganic fertilizer in order to enhance the productivity of their crops and hence their output. This finding is consistent with Iwuchukwu *et al.* (2022) that reported a positive and significant relationship between farm size and fertilizer use among rice farmers in Ebonyi State, Nigeria.

On the contrary, farm size had negative coefficient and significant at 1% for rice producers. The negative sign of the coefficient is at variation with the *a priori* expectation implying that as the farm size of the farmer increases, their level of use of fertilizer decreases. The negative relationship between farm size and fertilizer use could be attributed to financial and credit constraints on larger farms. While larger farms control more land, they may not have proportionally more access to capital and thus, they economize on input use per hectare, including fertilizer. According to Akpan *et al.* (2012), the decrease in fertilizer use intensity as farm size increases could be explained especially in the area of farm inputs and price uncertainty as farm size increases. This finding is in consonance with Mussa *et al.* (2024) that observed a negative relationship between farm size and intensity of fertilizer use among rice farmers in Tanzania and Zhu *et al.* (2022) that observed negative relationship between farm size and fertilizer use intensity in China.

The coefficient of membership of cooperative was significant at 5% and 10% for rice and sorghum producers respectively, and positively related to the use of fertilizer. The positive sign of the coefficient agrees with the *a priori* expectation and indicates that if a farmer is a member of cooperative, the farmer's use of fertilizer increases. Cooperative societies provide several benefits to their members one of which is, access to inputs such as fertilizer. Thus, farmers who are members of cooperatives are more likely to use more fertilizer compared to farmers who are non-member. This finding agrees with Ketema and Kebede (2017) who revealed that membership to cooperative positively affected the use intensity of DAP (Di-Ammonium Phosphate) and Urea among smallholder farmers in Ethiopia.

The coefficient of access to credit was significant at 5% for rice producers, and negatively related to fertilizer use. The negative coefficient is at variance with the *a priori* expectation and this implies that if a farmer accessed credit, the farmer's use of fertilizer decreases. The negative relationship between credit access and fertilizer use could be attributed to credit used for non-agricultural purposes. Even when credit is available, smallholder farmers may divert it to urgent non-farm needs like healthcare, school fees or household consumption-especially in contexts of high poverty and vulnerability. This aligns with Tesfay (2021) who reported a negative relationship between loan taken and intensity of inorganic fertilizer adoption.

The coefficient of extension contact was significant at 1% for rice producers, and positively related to fertilizer use. The positive coefficient aligns with the *a priori* expectation which implies that if a farmer accessed extension support, the farmer's use of fertilizer increases. Farmers exposed to extension contact are better exposed to the importance of fertilizer, the right source, right place, right



time, and right quantity to apply. Thus, motivating them to use more fertilizer. This finding corroborates Iwuchukwu *et al.* (2022) that observed a positive and significant relationship between extension visit and quantity of inorganic fertilizer applied on rice farm in Ebonyi State, Nigeria.

The regression result further revealed that farm output was significant for rice producers and positively related to the use of fertilizer ($\beta = 0.84$, $P < 0.1$). The positive sign of the coefficient is consistent with the *a priori* expectation, implying that as the farm output of the farmer increases, the farmer's use of fertilizer increases. This positive relationship could be attributed to the reinvestment in inputs due to increased output. Farmers who experience higher yields from fertilizer use are more likely to reinvest in inputs in subsequent seasons, reinforcing a positive output-fertilizer relationship. This finding corroborates Iticha *et al.* (2021) who reported a positive relationship between farm income and use of fertilizer in maize production.

CONCLUSION AND RECOMMENDATIONS

The current fertilizer application regime of the cereal farmers shows they are far away from the technical and economic optimum rates. Their inability to attain these optimum rates could be attributed to their socioeconomic characteristics which also affected their use of inorganic fertilizers. Specifically, the household size, age, and farm size of these farmers significantly influenced their use of inorganic fertilizer in cereal production. Also, their access to credit and membership to cooperative significantly influenced their use of inorganic fertilizer in cereal production.

On the basis of these findings, it was recommended that the Benue State Ministry of Agriculture should organize training workshops where experts in fertilizer application will be invited to train the farmers on optimum application rates. Such training when conducted in the three agricultural zones of the state will help improve efficiency in the application of inorganic fertilizer and ultimately cereal production in the State. Besides, the Benue State Government should establish and fund community Farmer Field Schools through partnership with research institutions to deliver season-long practical training on fertilizer usage.

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