ASSESSING NUTRIENT MANAGEMENT PRACTICES INFLUENCING MAIZE FARMERS YIELDS IN NIGER STATE USING THE 4R CONCEPT

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ABSTRACT

This study analyzed nutrient management practices influencing maize farmers' yields in Niger State using the 4r concept. A multi-stage sampling method was used to select 304 maize farmers, and data were collected using a structured questionnaire. The data were analyzed using descriptive statistics, the Stochastic Frontier Model, the Cobb-Douglas production function, and a five-point Likert scale. The result shows that most farmers (68.4%) sourced fertilizers from local agro-input dealers, with most applying fertilizer three times or less during the maize production cycle, contrary to the recommended four times rate. The band placement method was the most common placement technique, despite the drilling method being recommended for optimal efficiency. The Cob Douglass regression results reveal that 4R farmers achieve significantly higher maize yields compared to non-4R farmers due to more effective utilization of fertilizer sources, rates, timing, and placement. Stochastic frontier estimates further indicate that 4R farmers demonstrate better productivity across key agricultural inputs, including land, labour, seed, fertilizer, age, and education were all significant, highlighting the effectiveness of 4R practices in optimizing these factors for enhanced maize production. Technical efficiency among farmers showed a marked difference between 4R and non-4R farmers, with the former demonstrating higher efficiency levels. The study identified constraints to increasing maize yields are poor agronomic practices, high cost of improved seeds and agrochemicals, lack of access to credit, and pest and disease infestations. The study recommends that government and agricultural extension services promote adherence to best fertilizer application practices and address the high cost of inputs.

Keywords: Nutrient Usage, 4R Concept, Technical Efficiency, Maize Productivity

INTRODUCTION

The global population is projected to increase 2.5-fold by 2050, leading to a substantial rise in cereal demand, particularly for rice, maize, millet, wheat, and sorghum. This demand is expected to triple current levels (Van-Ittersum *et al.*, 2016). Among cereals, maize (Zea mays L.), a key crop in the Poaceae family, is vital to global food systems. It is the most widely cultivated cereal, contributing over half of the total global grain production (International Grain Council-IGC, 2020; Erenstein, 2022). Maize is not only a staple for human consumption but also a crucial component of animal feed and industrial applications. Its advantages make it poised to become the most produced crop globally (International Institute of Tropical Agriculture-IITA, 2020).

Global maize production averages 1,127 million tons annually (Organization for Economic Cooperation and Development-OECD, 2020). Leading producers, including the United States, China, Brazil, Argentina, and Ukraine, account for 74.86% of global maize cultivation, achieving yields of 10.5 tons per acre (United States Department of Agriculture-USDA, 2021). However, Africa's maize yields remain significantly low, with African producers such as South Africa, Nigeria, and Ethiopia producing 1 to 2 tons per hectare, far below global standards (Food and Agriculture Organization-FAO, 2020; Price Waterhouse-Coopers-PWC, 2021). In Niger State, maize is a primary income source for farmers, yet low yields and profitability persist due to inefficient fertilizer use (Adekiya, 2019; Ichami *et al.*, 2018; Bonilla *et al.*, 2020; John *et al.*, 2023).

Efficient nutrient management is essential for optimizing maize yields and ensuring sustainable agriculture. The 4R concept (Right Source, Right Rate, Right Time, Right Place) provides a sustainable framework for nutrient management, promoting precise fertilizer application tailored to specific site conditions (Mueller *et al.*, 2020). Proper 4R implementation can improve food production, farmer income, and soil fertility, particularly for smallholder farmers in Africa (African Plant Nutrition Institute-APNI, 2021; Shamie, 2021). These improved management practices are crucial for narrowing the maize yield gap and enhancing food security (Adiele *et al.*, 2020).

Effective implementation of the 4R principles is critical for addressing these challenges, but barriers remain. Selecting appropriate fertilizer sources is complicated by variations in availability, cost, and suitability for specific conditions (Sogbedji *et al.*, 2019). Determining optimal rates requires balancing crop needs, soil fertility, and environmental factors, with errors leading to adverse outcomes (Tarfasa *et al.*, 2018). Timely application is essential to match crop nutrient demand but is hindered by weather uncertainties and logistical constraints (John *et al.*, 2023). Proper placement ensures efficient nutrient delivery to crop roots but faces technological and resource limitations (Jayne *et al.*, 2019).

Poor nutrient management is a major contributor to maize yield gaps. Sustainable fertilizer use, guided by the 4R concept, offers a pathway to improving yields (Shehu *et al.*, 2018; Tarfasa *et al.*, 2018). However, limited access to information on correct fertilizer use hampers adoption, leading to suboptimal returns for farmers (Harou *et al.*, 2017; Benson and Mogues, 2018; Jayne *et al.*, 2019). Research on the 4R concept’s impact on maize yields is limited, with most studies focusing on isolated aspects such as timing or placement (Shan, 2018; Yusuf *et al.*, 2021).

This study aims to address these gaps by assessing nutrient management practices affecting maize yields in Niger State through the 4R framework. Its objectives are to (i) identify fertilizer sources, rates, timing, and placement in maize production; (ii) determine yield influencers based on the 4R principles; (iii) assess the technical efficiencies of 4R farmers and non 4R farmers maize farmers; and (iv) identify constraints to increasing maize yields in the region.

METHODOLOGY

The study was conducted in Niger State, Nigeria, a region spanning 76,363 km² with 25 Local Government Areas, a population of 5,337,148 (51% males, 49% females), and located between latitudes 8.12°N–11.3°N and longitudes 3.30°E–7.2°E (Niger State Bureau of Statistics-NSBS, 2020). The study targeted maize farmers in Niger State, employing a multi-stage sampling technique to select 304 respondents from six villages across three randomly chosen Local Government Areas from the state's agricultural zones, with the sample size determined using Cochran's formula. Primary data was collected using structured questionnaires administered by extension agents with GPS technology and face-to-face interviews, analyzed through descriptive statistics, the Cobb-Douglas production function, the stochastic frontier model, and a Likert-scale questionnaire.

To determine the factors influencing maize yields using the 4R Nutrient concept, a Cobb-Douglas production function was applied. The model is mathematically expressed as:

$$Y = \alpha + b1X1 + b2X2 + b3X3 + b4X4 + €$$

Where;

Y=Maize yield

α = Intercept, representing the yield level when all independent variables are absent

β1 to β3 = Regression coefficients

X_1= Source of fertilizer (Formal and informal sources)

X_2= Placement of fertilizer (Method of applications per growing season)

X_3= Time of fertilizer application (Stages of applications per growing season)

X_4= Rate of fertilizer application ((number of applications per growing season)

€ is the error term, accounting for unexplained variability in the model.

To analyze the technical efficiency of maize farmers in the study area, a stochastic frontier model was employed based on Coeli (2009). The model captures multiple production factors and is specified as:

$$\text{Log } Y = bo + b_I \text{ Log}X_1 + b_2\text{Log}X_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; b_8 \text{ Log}X_8$$

Y = Output of maize (kg)

X_1 = Land (Hectares)

X_2 = Labour (Number)

X_3 = Seed (kg)

X_4 = Fertilizer (kg)

X_5= Herbicide (Liters)

X_6 = Age of farmer (Years)

X_7 = Household size (Number of people)

X_8 = Education (Highest level of education attained)

X_9 = farming experience (Years)

X_{10} = extension services (Frequency of visits)

e = error term

To compare the technical efficiency levels between 4R maize farmers and non-4R maize farmers, a t-test was conducted between the alternate and null hypothesis below. The technical efficiency scores for both groups were collected, and the means, standard deviations, and sample sizes for each group were computed. Using the formula for an independent t-test, the t-value was calculated, and the degrees of freedom were determined. The calculated t-value was then compared to the critical t-value at a 0.05 significance level, or the p-value was checked to assess whether to reject the null hypothesis. If the p-value was less than 0.05, the null hypothesis was rejected, indicating a significant difference in technical efficiency levels between the two groups:

- **Null Hypothesis (H_0):** There is no significant difference between the mean technical efficiency levels of 4R and non-4R maize farmers.
- **Alternative Hypothesis (H_1):** There is a significant difference between the mean technical efficiency levels of 4R and non-4R maize farmers.
- Using the t-test formula:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s1}{n1} + \frac{s2}{n2}}}$$

where:

- $\bar{x}_1$ and $\bar{x}_2$: Sample means of groups 1 and 2, respectively.
- s_1^2 and s_2^2: Sample variances of the two groups.
- n_1 and n_2 are the sample sizes of the two groups.

RESULT AND DISCUSSION

4.1 Demographic Characteristics of Maize Farmers

Descriptive statistics were employed to summarize key variables and provide an overview of the data findings for 304 respondents' demographic characteristics. The demographic analysis of maize farmers revealed several key characteristics. Gender distribution showed a predominance of males, with 71% of respondents being male and 29% female, indicating that men are more involved in maize farming, potentially due to the labour-intensive nature of the work and possible barriers for women (Ahmed, 2022). Age-wise, 62.2% of farmers were aged 40 years or below, suggesting a youthful and potentially dynamic farming community, while 37.8% were above 40 years, with an average age of 39.2 years and a standard deviation of 10.5 years (Ojetunde and Odum, 2021). Marital status revealed that 73% of farmers were married, with the rest being single, divorced, or widowed, which aligns with Jibrin *et al.* (2021) who also noted a majority of married maize farmers. Further, the average household size was 8 members, with 62.2% having 8 or fewer members and 37.8% having more than 8, which contrasts with Ahmed (2022) who reported a mean household size of 10. Educational qualifications varied, with 28.6% holding secondary education, 23.7% having HND/BSc, and 19.7% with primary education.

Table 1: Demographic Characteristics of Maize Farmers

Variables	Categories	Frequency	Percentage
Gender	Female	88	29
	Male	216	71
Age	Mean (39.2)	Std. (10.5)	
	≤40	189	62.2
	>40	115	37.8
Marital status	Married	222	73
	Single	61	20
	Divorced	12	4
	Widow(er)	9	3
Household size	Mean (7.8)	Std. (3.50)	
	≤8	196	62.2
	>8	108	37.8
Educational Qualification	Postgraduate	11	3.6
	HND/BSc	72	23.7
	NCE/OND	56	18.4
	Secondary	87	28.6
	Primary	60	19.7
	None (informal)	87	28.6
Occupation	Civil Servant	18	5.9
	Farmer	195	64.1
	Maize farming (only)	76	25
	Retiree	3	1
	Student	13	4.3
	Trader	3	1
Yearly income	₦10,000 - 50,000	30	9.9
	₦51,000 - 100,000	69	22.7
	₦1010,000 - 200,000	109	35.9
	₦201,000 - 400,000	53	17.4
	₦401,000 & above	43	14.8

Source: Field survey, 2024.

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4.2 Source, Rate, Time and Placement of Fertilizer Application

The findings of the study provide insights on the right source, rate, time, and placement of fertilizer application for maize production in the study area.

Table 2: Source, Rate, Time and Placement of Fertilizer Application

Categories	Best Standard Practices	Observed Practices	Frequency	Percentage
Right source				
Formal	Government agricultural agencies/cooperatives	Cooperatives/NGO	28	9.21
	Fertilizer companies / agricultural supply stores	Government agricultural agencies	30	9.87
Informal	Home/farms	Home/farms	38	12.50
	Local distributors	Local agro-input dealers	208	68.42
Right rate	**Mean (2.76) Std. (0.87)**			
Number of times fertilizer is applied for maize production	4 times	≤3	246	80.92
		>3	58	19.08
Right time				
1st stage	At planting 2 weeks after germination= NPK 4 bags, Urea 2 bags	Planting stage	70	23.03
2nd stage	During Germination, at flowering= NPK 2 bags	Growing stage	62	20.39
3rd stage	Cob coming out= Urea 1 bag	Planting and growing stage	172	56.58
4th stage	Cob out stage = Urea 1 bag			
Right placement				
Method 1	Drilling method	Band placement	160	52.64
Method 2	Drilling method	Drilling	19	6.26
Method 3	Drilling method	Fertigation	5	1.64
Method 4	Drilling method	Side placement	111	36.52
Method 5	Drilling method	Foliar	9	2.96

Source: Field survey, 2024.

The study provides comprehensive insights into the practices of fertilizer application for maize production. For the right source of fertilizer, 68.4% of farmers predominantly sourced their inputs from local agro-input dealers, while home/farm sources (12.50%), government programs (9.87%), and cooperatives/NGOs (9.21%) were less common. This reliance on local dealers suggests farmers value accessibility and convenience but highlights the need for more diverse procurement options to enhance reliability and affordability, aligning with Kiptum *et al.* (2022). Regarding the right rate, 80.92% of farmers applied fertilizer three times or less, with a mean application rate of approximately twice per season, deviating from the recommended four times. This variation in application rates may lead to significant yield differences, as noted by Abdullahi *et al.* (2023). For timing, 56.58% of farmers applied fertilizer at both planting and growing stages, while standard practices suggest applications at planting, germination, flowering, and cob development stages (Raj *et al.*, 2021). Lastly, band placement was the most common method of fertilizer placement (52.64%), followed by side placement (36.52%), with drilling used by only 6.26% of farmers, despite its recommendation in standard practices (Efretuei and Udounang, 2020).

4.3 4R Nutrient Factors Influencing Maize Yield

The result in Table 6 shows the Cobb Douglass regression analysis on 4R Nutrient factors influencing (Right Source, Right Rate, Right Time, Right Place) maize yield among the two groups: 4R farmers and non-4R farmers.

Table 3: 4R Nutrient Factors Influencing Maize Yield

Variables	Coefficient (Non-4R Farmers)	Standard Error (Non-4R)	Coefficient (4R Farmers)	Standard Error (4R)
Constant	1.709	.4916	2.950***	0.189
Source of fertilizer	.2645	.2959	0.310***	0.095
Rate of fertilizer	.2444*	.1365	0.460***	0.067
Time of fertilizer	.5560**	.2359	0.220**	0.058
Placement of fertilizer	-.0126	.1232	0.280***	0.105
R-Square	**0.430**		**0.826**	
Adjusted R-Square	**0.302**		**0.805**	
F-Statistic	**37.36**		**45.20**	
Prob > F	**0.003**		**0.000**	

Source: Field survey, 2024. Note: ** significant at 5%, * significant at 10%.

The analysis of maize yield factors reveals important differences between 4R and non-4R farmers in Niger State. The intercept values indicate that 4R farmers have a higher baseline productivity, with an intercept of 2.950 compared to 1.709 for non-4R farmers. The model explaining maize yield for 4R farmers fits much better, with an R-squared value of 0.826, showing that 82.6% of yield variation is explained by the 4R factors, including fertilizer source, rate, timing, and placement. In contrast, the model for non-4R farmers has a much lower R-squared value of 0.430, suggesting that the factors included in the model only explain 43% of the yield variation.

Despite these differences, both models show significant F-statistics, underscoring their overall relevance. Among the key factors, the source of fertilizer has a significant positive effect on maize yield for 4R farmers (0.310, $p < 0.01$), while its effect is not statistically significant for non-4R farmers. Similarly, the rate of fertilizer application boosts yields for both groups, but it has a stronger impact for 4R farmers (0.460, $p < 0.01$) than non-4R farmers (0.244, $p < 0.10$), indicating better optimization of fertilizer use. The timing of fertilizer application also has a positive effect on yield for both groups, with a more moderate impact for 4R farmers (0.220, $p < 0.05$). Finally, fertilizer placement is particularly significant for 4R farmers (0.280, $p < 0.01$), contributing meaningfully to yield improvements. These findings highlight the importance of the 4R Nutrient Stewardship approach in enhancing maize productivity through more precise and effective fertilizer management. These results align with research by International Plant Nutrition Institute (2020), and Olatunji *et al.* (2021) who highlighted that the 4R Nutrient Stewardship approach, including proper fertilizer placement, timing, source and rate are a valuable strategy for farmers aiming to improve productivity through more efficient resource use.

4.4 Stochastic Frontier Production Estimate for Maize Yield

Table 4 presents the results of factors affecting maize yield through a Stochastic Frontier Production model, comparing non-4R farmers and 4R farmers. The coefficients represent the expected change in maize production for a one-unit increase in each respective variable, holding all other variables constant. The Stochastic Frontier Production model of maize farmers in Niger State reveals significant differences between 4R and non-4R farmers in terms of resource utilization and productivity. Land has a positive and highly significant effect on maize yield for both groups, with 4R farmers (0.420) showing higher initial yield due to more efficient land management practices than non-4R farmers (0.228). Labour also plays a crucial role, non-4R farmers (0.061) compared with 4R farmers 0.250) benefiting more from additional labour input, which leads to higher maize output. The use of quality seeds has a similar positive effect, with 4R farmers (0.280) again demonstrating a greater impact, likely due to the use of better seed varieties. Fertilizer use is another area where 4R farmers (0.540) show a much stronger positive effect on yields, highlighting the importance of proper fertilizer application under the 4R approach. The findings of the study agree with that of Zongkui *et al.*, (2023) who noted that efficient fertilizer management practices help in enhancing maize productivity. Additionally, 4R farmers (0.360) experience a significant positive impact from herbicide use for effective weed management, unlike non-4R farmers (-0.002), where the effect of herbicides is negligible. This finding aligns with previous studies that have emphasized the importance of effective weed control practices in improving crop yields (Abubakar *et al.*, 2021).

The inefficiency model identifies several factors that contribute to lower technical efficiency, particularly among non-4R farmers. Older farmers tend to be less efficient, as age negatively correlates with the adoption of modern farming techniques (-0.065 for non-4R and -0.012 for 4R).

Larger household sizes also contribute to inefficiency, particularly for non-4R farmers (-0.206 for non-4R and a positive 0.055 for 4R), where resource constraints and labour division may limit productivity. Education has a significant positive impact on efficiency, with educated farmers showing lower inefficiency, especially in the non-4R group (-0.810 for non-4R and a positive 0.085 for 4R). Farming experience also plays a critical role in improving efficiency, particularly for 4R farmers (0.090). These findings suggest that factors like education, experience, and effective household labour management are key drivers of improved farming practices and productivity. This result agrees with the study of Ahmed, (2021) who reported that as age of farmers, education, seed fertilizer affect the yield of the farm.

In terms of overall efficiency, non-4R farmers have a mean efficiency of 40.7%, indicating significant room for improvement, while 4R farmers have a much higher mean efficiency of 80.0%. The lower variance in inefficiency for 4R farmers suggests that the 4R practices contribute to more consistent and reliable performance, reducing both inefficiency and the influence of random factors. The statistical analysis confirms the significance of these findings, with the models for both groups showing high levels of validity and fit. The lower lambda and sigma values for 4R farmers further reinforce the conclusion that the 4R Nutrient Stewardship approach leads to better and more sustainable maize farming outcomes.

Table 4: Stochastic Frontier Production Estimate for maize Yield

Variables	**Coefficient (Non-4R Farmers)**	**Standard Error (Non-4R)**	**Coefficient (4R Farmers)**	**Standard Error (4R)**
Constant	1.520	0.145	1.745	0.189
Land	0.228***	0.070	0.420***	0.095
Labour	-0.061**	0.043	0.250**	0.067
Seed	0.270***	0.050	0.280***	0.058
Fertilizer	0.117*	0.080	0.540***	0.105
Herbicide	-0.002	0.060	0.360***	0.074
Inefficiency Model				
Constant	2.94	0.947	2.98	0.986
Age	-0.065**	0.005	-0.012*	0.006
Household size	-0.206*	0.007	0.055***	0.008
Education	-0.810**	0.012	0.085***	0.017
Farming Experience	-0.008	0.013	0.090***	0.015
Diagnostic statistics	**Non-4R Farmers**		**4R Farmers**	
Lambda (λ)	**1.210**		**1.150**	
Sigma_v (σ_v)	**0.130**		**0.900**	
Sigma_u (σ_u)	**0.366**		**0.280**	
Sigma Squared ($σ^2$)	**0.110**		**0.075**	
Log Likelihood	**-157.9**		**-195.3**	
Wald Chi-Squared ($χ^2$)	**249.7**		**285.3**	
Prob > Chi-Squared	**0.001**		**0.000**	
Mean Efficiency	**40.7%**		**80.0%**	

Source: Field survey, 2024. Note: *** significant at 1%, ** significant at 5%, * significant at 10%.

4.5 Estimated Technical Efficiency Levels for Non-4R And 4R Maize Farmers

The result shows the frequency distribution of the technical efficiency estimates for non 4R and 4R maize farmers. The technical efficiency scores are categorized into different ranges: <0.2, 0.20-0.40, 0.41-0.60, 0.61-0.80, and 0.81-1.00. The efficiency scores indicate the degree to which each farmer is operating efficiently relative to their peers.

Table 5: Distribution of Technical Efficiency levels for 4R and none 4R Maize Farmers

Non-4R Maize Farmers Technical Efficiency	Frequency	Percentage (%)	4R Maize Farmers Technical Efficiency	Frequency	Percentage (%)
<0.20	81	33.2%	0.61-0.80	36	60
0.20-0.40	107	43.9%	0.81-1.00	24	40
0.41-0.60	50	20.5%			
0.61-0.80	6	2.45%			
Total	**244**		**Total**	**60**	
Minimum	**0.05**		**Minimum**	**0.61**	
Maximum	**0.80**		**Maximum**	**0.99**	
Mean	**40.7**		**Mean**	**80.0**	

Source: Authors survey, 2024.

The result presents the distribution of technical efficiency levels among maize farmers practicing the 4R Nutrient Stewardship and those who do not. Among the non-4R farmers, the majority (43.9%) have a technical efficiency between 0.20-0.40, with a mean efficiency of 40.7%. A significant portion (33.2%) has a very low efficiency below 0.20, and only 2.45% achieve a level between 0.61-0.80, with no farmers exceeding this range. This finding agrees with Baiyegunhi *et al,* (2022) who reported that most farmers in Nigeria are not obtaining maximum output from their given quantum of inputs and only about one-quarter of the potential profit is realizable from maize production. In contrast, the 4R farmers exhibit higher efficiency levels, with 60% of them falling in the 0.61-0.80 range and 40% reaching 0.81-1.00, resulting in a mean efficiency of 0.8. This indicates that 4R practices are associated with significantly higher technical efficiency among maize farmers. The results coincide with that of Ahmed (2021) who noted that the mean technical efficiency scores of maize farmers were above 0.66, implying that farmers could increase their corresponding efficiency levels by using current inputs and technology.

4.6 T-test Analysis

The t-test was carried out to determine whether there is statistically significant difference in the mean technical efficiency scores between 4R and non-4R maize farmers. This helps determine whether the adoption of 4R practices has a meaningful impact on technical efficiency. The result indicates that since the calculated t-statistic (−2290.08) is much larger in magnitude than the t-tabulated (±1.973), we reject the null hypothesis and accept the alternative hypothesis. Which shows that there is a statistically significant difference between the mean technical efficiency levels of 4R and non-4R maize farmers.

This result implies that 4R farmers and non-4R farmers do not perform similarly in terms of technical efficiency. This finding suggests that adopting the 4R Nutrient Stewardship (Right Source, Right Rate, Right Time, Right Place) contributes to improved technical efficiency in maize production. The finding coincides with the study of Johnston and Bruulsema, (2014) and Smith (2022) who validated that practices like the 4R Nutrient Stewardship has shown to enhance productivity and resource efficiency which led to optimal plant growth and resource use, reducing waste and increasing crop yields.

Table 6: T-test Result Comparing the Means of 4R And None 4R Maize Farmers

Group	Observations	Mean	Std. Error	Std. Deviation
None 4R	244	0.4000	0.0120	0.0950
4R	60	0.8000	0.0122	0.1875
Combined	304	1.2000	0.0171	0.2825
t-cal = 2290.08				
t-tab = 1.973				
Degrees of freedom = 185				
95% confidence interval (0.05)				

Source: Authors survey, 2024.

Null hypothesis: H_o: There is no significant difference between the mean technical efficiency levels of 4R and non-4R maize farmers. i.e. H_o: $U_1 = U_2$

Alternative Hypothesis: H_A: There is a significant difference between the mean technical efficiency levels of 4R and non-4R maize farmers. i.e. H_o: $U_1 \neq U_2$.

- If T – cal>t-tab: reject (H_o) null hypothesis and accept alternative hypothesis (H_A); If T – cal<t-tab: accept (H_o) null hypothesis.

4.7 Constraints to Increasing Maize Yields

This section identifies the constraints faced by smallholder farmers in increasing maize yields. A Likert scale survey instrument (Strongly Agreed-5 to Strongly Disagreed-1) was employed. The mean and rank response provide valuable insights on the perception of maize farmers on the constraints. All figures in brackets or parentheses are percentages. Findings show the result of maize farmers regarding constraints to increasing maize yields. The most pressing challenge identified was poor agronomic practices, which received the highest score of 4.51, indicating widespread recognition of the need for better farming techniques. Lack of access to credit (4.32) ranked second, showing that financial limitations are a major barrier to acquiring essential resources for improved maize production. The high cost of agrochemicals and seeds (4.25) ranked third, further compounding the financial challenges farmers face. Pests and diseases (4.19) were also significant obstacles, with farmers struggling to manage crop health. Additionally, the high cost of renting tractors and machinery (4.17) emerged as a fifth constraint, hindering efficient land preparation and mechanization.

Poor soil fertility (4.10) ranked sixth, underlining the need for better soil management practices to enhance productivity. Other challenges included the use of sub-standard agrochemicals (4.08), herdsmen attacks (4.02), storage losses and low market prices (4.01), and theft or banditry (3.89). Environmental challenges like drought and floods (both with a score of 3.72) were also significant but ranked lower in comparison to other constraints. This suggests a critical need to reduce constraints aimed at improving maize productivity. These findings align with Adams, (2018), Baker and Nuno (2021) and Obianefo, *et al*, (2020) who identified inadequate funding, infestation of pests/diseases, theft/banditry attacks, climate, lack of credit, storage loses/low market prices, among others as constraint to limiting maize yield among maize farmers.

Table 7: Constraints to Increasing Maize Yields

S/N	Constraints	SA	A	U	D	SD	MEAN	RANK
1	Poor Agronomic Practices	216 (71.1)	61 (20.1)	2 (0.7)	17 (5.6)	8 (2.6)	4.51	1st
2	High cost of agrochemical's/seeds	171 (56.3)	90 (29.6)	6 (2.0)	24 (7.9)	13 (4.3)	4.25	3rd
3	Sub-standard agro-chemical	135 (44.4)	107 (35.2)	32 (10.5)	14 (4.6)	16 (5.3)	4.08	7th
4	High cost of renting tractors/machines	157 (51.6)	95 (31.3)	15 (4.9)	21 (6.9)	16 (5.3)	4.17	5th
5	Lack of access to Credit	203 (66.8)	52 (17.1)	11 (3.6)	21 (6.9)	17 (5.6)	4.32	2nd
6	Drought (low rainfall)	84 (27.6)	115 (37.8)	56 (18.4)	36 (11.8)	13 (4.3)	3.72	11th
7	Flood	96 (31.6)	98 (32.2)	51 (16.8)	47 (15.5)	12 (3.9)	3.72	11th
8	Infestation of Pests & Diseases	183 (60.2)	65 (21.4)	9 (3.0)	26 (8.6)	21 (6.9)	4.19	4th
9	Poor Soil Fertility	144 (47.4)	97 (31.9)	24 (7.9)	29 (9.5)	10 (3.3)	4.10	6th
10	Theft/banditry attacks	137 (45.1)	79 (26.0)	26 (8.6)	44 (14.5)	18 (5.9)	3.89	10th
11	Herdsmen farm attacks	143 (47.0)	84 (27.6)	30 (9.9)	37 (2.2)	10 (3.3)	4.02	8th
12	Storage Loss / Low market price	131 (43.1)	108 (35.5)	17 (5.6)	34 (11.2)	14 (4.6)	4.01	9th

Source: Field survey, 2023/2024.

CONCLUSION AND RECOMMENDATIONS

This study highlights the role of the 4R Nutrient Stewardship (Right Source, Right Rate, Right Time, Right Place) in enhancing nutrient use efficiency and increasing maize yields in Niger State. While many farmers have a basic understanding of nutrient application, gaps in knowledge and implementation, particularly in selecting the right source of nutrients and applying them at the correct rate, persist. Farmers often rely on traditional methods and lack access to quality fertilizers, which limits the effectiveness of nutrient applications. Additionally, proper timing and placement of fertilizers, key factors for efficiency, are often overlooked. The study shows that 4R farmers achieve higher productivity through optimized fertilizer use, better resource management, and improved seed quality. In contrast, non-4R farmers struggle with lower productivity due to inefficient practices. Challenges such as poor agronomic practices, limited access to credit, and pest infestations further hinder yield improvements. However, with targeted education, better access to quality inputs, and training on the 4R framework, significant improvements are possible. The study concludes that the adoption of the 4R Nutrient Stewardship framework significantly enhances maize farming practices in Niger State, improving nutrient use efficiency and productivity. For broader adoption, targeted interventions are needed to address knowledge gaps, provide better access to quality inputs, and support farmers with training and financial resources. By focusing on these areas, the potential for increased maize yields and sustainable farming practices can be realized, ultimately contributing to improved food security and economic development in the region.

Based on the findings of the study, the following recommendations are proposed:

i. The government should encourage adherence to recommended fertilizer application practices, including proper sourcing, timing, rate, and placement, with agricultural extension services playing a key role in training and information dissemination.
ii. Farmers should focus on enhancing technical efficiency by optimizing fertilizer and agrochemical use, supported by training programs and advisory services to improve overall farm management.
iii. Addressing high input costs is essential for boosting productivity, with potential solutions including subsidy programs or cooperative purchasing to make improved seeds and agrochemicals more affordable.
iv. Developing targeted capacity-building initiatives on fertilizer application, agronomic practices, pest management, and climate-smart agriculture can further support farmers in adapting to changing conditions and improving productivity and resilience.

REFERENCES

Abdoulaye, T., Wossen, T., & Awotide, B. (2018). Impacts of improved maize varieties in Nigeria: Ex-post assessment of productivity and welfare outcomes. *Food Security*, *10*(2), 369–379. https://doi.org/10.1007/s12571-018-0772-9

Adekiya, A., Agbede, T., Aboyeji, C., Dunsin, O., & Ugbe, J. (2019). Green manures and NPK fertilizer effects on soil properties, growth, yield, mineral, and vitamin C composition of okra (*Abelmoschus esculentus* (L.) Moench). *Journal of the Saudi Society of Agricultural Sciences*, *18*(2), 218–223. https://doi.org/10.1016/j.jssas.2017.05.005

Adiele, J., Schut, A., van den Beuken, R., Ezui, K., Pypers, P., Ano, A., Egesi, C., & Giller, K. (2020). Towards closing cassava yield gap in West Africa: Agronomic efficiency and storage root yield responses to NPK fertilizers. *Field Crops Research, 253*, 107820. https://doi.org/10.1016/j.fcr.2020.107820

Ahmed, A. (2022). How COVID-19 pandemic obstructed maize production activities in Niger State of Nigeria. *Journal of Agripreneurship and Sustainable Development (JASD), 5*(2), 2.

Ahmed, M. A. (2021). Comparative study on technical efficiency of maize-producing farms in Nigeria. *Journal of Agripreneurship and Sustainable Development*, *4*(2), 1–13. https://doi.org/10.59331/jasd.v4i2.203

Abubakar, S., Sule, B. A., & Emefesi, B. O. (2021). Profitability analysis and socio-economic determinants of maize output in Rijau Local Government Area of Niger State, Nigeria. *Journal of Agripreneurship and Sustainable Development*, *1*(3), 3–4. https://doi.org/10.59331/jasd.v4i1.199

Baiyegunhi, L. J. S., Akinbosoye, F., & Bello, L. O. (2022). Welfare impact of improved maize varieties adoption and crop diversification practices among smallholder maize farmers in Ogun State, Nigeria. *Heliyon, 8*(5), e09338.

Baker, M. M., & Nuno, D. B. (2021). Socio-economic determinants of maize production of smallholder farmers in Eastern Oromia, Ethiopia. *Grassroots Journal of Natural Resources, 4*(1), 29–39. https://doi.org/10.33002/nr2581.6853.040103

Benson, T., & Mogues, T. (2018). Constraints in the fertilizer supply chain: Evidence for fertilizer policy development from three African countries. *Food Security*, *10*(6), 1479–1500. https://doi.org/10.1007/s12571-018-0863-7

Bonilla, C., Chamberlin, J., Guo, Z., & Hijmans, R. J. (2020). Spatial variation in fertilizer prices in Sub-Saharan Africa. *Journal of Agriculture, 15*(1), e0227764. https://doi.org/10.1371/journal.pone.0227764

Erenstein, O., Jaleta, M., Sonder, K., & Prasanna, B. M. (2022). Global maize production, consumption, and trade: Trends and R&D implication. *Food Security*, *14*, 1295–1319.

Food and Agriculture Organization Statistical Databases (FAO). (2020). Top maize production. *Food and Agriculture Organization, Statistics Section.* Retrieved from http://faostat3.fao.org/browse/Q/*/E

Harou, A. P., Liu, Y., Barrett, C. B., & You, L. (2017). Variable returns to fertiliser use and the geography of poverty: Experimental and simulation evidence from Malawi. *Journal of African Economies*, *26*(5), 655. https://doi.org/10.1093/jae/ejx017

Ibrahim, F. D., Oformata, A. O., Jirgi, A. J., & Adewumi, A. (2019). Optimum production plan for maize-based crop farmers in Niger State, Nigeria. *Journal of Tropical Agriculture, Food, Environment and Extension, 18*(3), 35–41.

Ichami, S. M., Shepherd, K. D., Sila, A. M., Stoorvogel, J. J., & Hoffland, E. (2018). Fertilizer response and nitrogen use efficiency in African smallholder maize farms. *Nutrient Cycling in Agroecosystems, 113*(1), 1–19. https://doi.org/10.1007/s10705-018-9958-y

International Grain Council (IGC). (2021). *International Grain Council Market Report.* Retrieved from https://www.ig.int/downloads/gmrsummary/gmrsumme.pdf

International Institute of Tropical Agriculture (IITA). (2020). Increasing maize production in West Africa. Retrieved from http://www.iita.org/newsitem/increasing-maize-production-west-africa/

International Plant Nutrition Institute (IPNI). (2021). *4R Plant Nutrition: A Manual for Improving the Management of Plant Nutrition.* Retrieved December 22, 2021, from https://www.ipni.net/article/IPNI-3255

Jayne, T., Snapp, S., Place, F., & Sitko, N. (2019). Sustainable agricultural intensification in an era of rural transformation in Africa. *Global Food Security, 20,* 105–113. https://doi.org/10.1016/j.gfs.2019.01.008

Jibrin, S., Ajayi, O. J., Salihu, I. T., Bello, L. Y., & Loko, A. I. (2021). Factors affecting awareness of maize farmers on health risks of agrochemical usage in Niger State, Nigeria. *Journal of Agripreneurship and Sustainable Development (JASD), 4*(2).

John, K., Bidzakin, A. G., Dadson, A., Osei, Y., Iddrisu, Y., & Ester, W. (2023). Utilization of organic fertilizer: Implication for crop performance and commercialization. *Advance in Agriculture,* 1–6. https://doi.org/10.1111/agec.12299

Johnston, A. M., & Bruulsema, T. W. (2014). Nutrient stewardship: Addressing nutrient management practices. *Nutrient Management Symposium, 20.*

Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N., & Foley, J. A. (2020). Closing yield gaps through nutrient and water management. *Nature Journal, 490*(7419), 254–257. https://doi.org/10.1038/nature11420

Niger State Bureau of Statistics (NSBS). (2020). *National and State Population and Housing Tables.* Retrieved from www.nigerstats.ni.gov.ng

Obianefo, C. A., Nwigwe, C. A., Meludu, T. N., & Anyasie, I. C. (2020). Technical efficiency of rice farmers in Anambra State value chain development programme. *Journal of Development and Agricultural Economics*, *12*, 67–74.

OECD. (2020). *OECD-FAO Agricultural Outlook 2018–2027.* OECD Publishing: Paris, France; Food and Agriculture Organization of the United Nations: Rome, Italy.

Ojetunde, B. S., & Odum, E. E. B. (2021). Profitability of various cropping patterns among arable crop farmers in Niger State, Nigeria. *Pesquisa Agroprenuer Gaúcha Journal*, *27*(1), 185–198. https://doi.org/10.36812/pag.2021271185-198

Oyinbo, O., Mbavai, J. J., Shitu, M. B., Kamara, A. Y., Abdoulaye, T., & Ugbabe, O. O. (2019). Sustaining the beneficial effects of maize production in Nigeria: Does adoption of short-season maize varieties matter? *Experimental Agriculture*, *55*(6), 885–897. https://doi.org/10.1017/s0014479718000467

Price Waterhouse Coopers (PWC). (2021). *Positioning Nigeria as Africa's leader in maize production for AfCFTA.*

Raj, K. A., Yuriko, K., Takashi, S., Tashi, T., Sanjib, K. P., & Hiroyuki, K. (2021). Smart fertilizer management: The progress of imaging technologies and possible implementation of plant biomarkers in agriculture. *Soil Science and Plant Nutrition*, *67*(3), 248–258. https://doi.org/10.1080/00380768.2021.1897479

Shamie, Z. (2021). The 4R nutrient stewardship in the context of smallholder agriculture in Africa. In B. Vanlauwe et al. (Eds.), *Agro-ecological intensification of farming systems in the East and Central African highlands* (pp. 77–84).

Shehu, U. A., Ibrahim, A., Hassan, T., & Bello, M. (2017). Analysis of resource use efficiency in small-scale maize production in Tafawa-Balewa Local Government of Bauchi State, Nigeria. *Agrosearch, 10*(2), 29–35. https://doi.org/10.9790/2380-1002012935

Smith, R. (2022). Enhancing agricultural productivity through nutrient management practices: A review of the 4R nutrient stewardship approach. *Journal of Agricultural Science*, *11*(3), 45–59.

Tarfasa, S., Balana, B. B., Tefera, T., Woldeamanuel, T., Moges, A., Dinato, M., & Black, H. (2018). Modeling smallholder farmers' preferences for soil management measures: A case study from South Ethiopia. *Ecological Economics*, *145*, 410–419. https://doi.org/10.1016/j.ecolecon.2018.09.003

United States Department of Agriculture (USDA). (2021). Corn yield by country in MT/HA. Retrieved from https://www.indexmundi.com/agriculture/?commodity=corn&graph=yeild

Yusuf, S. A., Ayinde, O. E., & Ojehomon, V. (2021). Factors influencing market participation decisions of smallholder maize farmers in Nigeria. *Journal of Agribusiness in Developing and Emerging Economies, 11*(3), 273–290.

Zongkui, C., Xinrui, L., Tao, L., Hao, F., Xiaojuan, Y., Qingyue, C., Qin, L., Yue, Z., Weitao, L., Yongjian, S., Zhiyuan, Y., Jun, M., & Xiafei, L. (2023). Strategies for fertilizer management to achieve higher yields and environmental and fertilizer benefits of rice production in China. *Science of the Total Environment, 904,* 048–9697. https://doi.org/10.1016/j.scitotenv.2023.166325