Bridging Knowledge Gaps in Phosphorus Fertilization: Insights into Rice Farmers' Practices and Environmental Sustainability

Chukwudi, Uchechukwu P.[1*]; Achike, Anthonia I.[2]; Eze, Emmanuel I.[3]

[*1,3]Department of Crop Science, University of Nigeria, Nsukka Enugu State NIGERIA
[2]Department of Agricultural Economics, University of Nigeria, Nsukka Enugu State NIGERIA
*Corresponding Author

Received:- 13 October 2024/ Revised:- 05 November 2024/ Accepted:- 15 November 2024/ Published: 30-11-2024

Abstract— *Phosphorus plays a crucial role in agricultural productivity, yet its mismanagement, particularly excessive application, poses significant environmental risks, including water quality degradation and eutrophication. This study aimed to assess rice farmers' knowledge, perceptions, and practices regarding phosphorus fertilization. A structured questionnaire was administered to 210 rice farmers across 18 villages within three states (Anambra, Ebonyi, and Enugu) following a multistage sampling procedure. The survey data were analyzed using IBM-SPSS statistical software. Farmers demonstrate a good understanding of phosphorus's essential role in plant growth, maturity, and resilience, as well as the major symptoms of phosphorus deficiency, such as stunting and reduced tillering. The farmers' fertilizer purchasing behaviour was mostly influenced by price, nutrient content, safety, subsidies, and social influence. The import status of fertilizer is less important in the purchasing decision. Though the results revealed a high level of awareness among farmers regarding the environmental impacts of excessive phosphorus application, gaps were identified, particularly regarding the effects of phosphorus runoff on water bodies, where 22.9% of the farmers were unaware of its detrimental impact on water quality. The study concludes that while rice farmers in Southeastern Nigeria have a significant understanding of the environmental effects of phosphorus use, targeted education and outreach programs are necessary to bridge knowledge gaps and promote sustainable fertilization practices. The study recommends the development of training programs and the promotion of climate-resilient phosphorus management strategies to mitigate environmental risks and enhance sustainable agricultural production in the region/*

Keywords— Innovation Diffusion, Rice Farming, Small-Scale Farmers, Soil Nutrient Management, Sustainable Agriculture.

I. INTRODUCTION

Phosphorus (P) is one of the most essential nutrients for plant growth and development, second only to nitrogen in its importance for crop productivity. In global agriculture, phosphorus plays a vital role, with its low availability significantly influencing crop yields. Specifically, in rice farming, phosphorus enhances root development, accelerates plant maturity, and boosts grain yield, making it indispensable for sustainable agricultural systems [1,2]. Although phosphorus is abundant in soil, only a small portion is readily accessible for plant uptake, necessitating the addition of phosphorus fertilizers to sustain optimal growth. The derived Guinea Savannah in Nigeria, characterized by severely weathered tropical soils, faces an elevated risk of phosphorus deficiency [3].

This research was sponsored by TETFund (TETF/DR&D/CE/UNI/NSUKKA/BR/2024/VOL.I)

In Nigeria, where rice is a staple food crucial to national food security, small-scale farmers, responsible for approximately 80% of rice production [4], face significant challenges in maintaining adequate soil nutrient levels, particularly phosphorus. Low phosphorus availability, coupled with underuse of fertilizers, has been identified as a leading cause of poor agricultural output in the country [5]. Across sub-Saharan Africa, rice farmers encounter phosphorus deficiency due to low fertilizer use, which not only hampers crop yields but also affects long-term soil health and agricultural sustainability [6]. Furthermore, inefficient phosphorus management exacerbates environmental risks, as excessive runoff contributes to eutrophication in water bodies, leading to ecological degradation [7]. As Nigeria struggles to meet domestic rice demand despite being one of Africa's largest producers, the judicious use of phosphorus, a non-replaceable and finite resource, is critical for improving yields and minimizing environmental impacts [2,8].

This study aims to address these challenges by assessing rice farmers' knowledge, perception, and use of phosphorus fertilization in the derived Guinea Savannah agro-ecological zone. Specifically, the study seeks to: (i) identify and characterize the socioeconomic features of rice farmers, (ii) assess their fertilizer-use patterns and purchasing behavior, and (iii) evaluate their knowledge of phosphorus application in rice farming. Understanding these factors is vital for promoting more effective and sustainable nutrient management practices. Although soils may contain phosphorus pools significantly higher than what is required for plant growth, only a small soluble fraction is available for uptake, further complicating nutrient management [9]. This research will contribute to broader efforts aimed at enhancing agricultural productivity, ensuring food security, and protecting the environmental integrity of farming systems through balanced fertilizer application [8].

II. METHODOLOGY

2.1 Description of Study Areas:

The research was undertaken in 18 villages across six local government areas (LGAs) in three states out of the five southeastern states in Nigeria. These areas are typified by the derived Savannah agro-ecological zone, known for its agricultural activities, especially rice farming. The study focuses on Anambra, Ebonyi, and Enugu states, which together contribute significantly to rice production in the region [10]. The respondents were evenly distributed across the three key states, with each contributing 33.3% to the total sample. This balance ensures a representative view across these regions. At the local level, the sample was similarly spread across six LGAs: Abakaliki LGA and Ikwo LGA in Ebonyi State, Awka South LGA and Ayamelum LGA in Anambra State, and Aninri LGA and Uzo-Uwani LGA in Enugu State.

2.2 Sampling Procedure:

A two-stage sampling method was employed for this study. The first step involved selecting the major rice-producing areas within the derived Savannah zone, guided by existing literature [10,11]. Anambra, Ebonyi, and Enugu states were purposively selected due to their high involvement in rice farming. The second stage involved random selection of 210 rice farmers across these three states, with an average of 35 farmers chosen from each LGA. Farmers were included if they had cultivated rice in the previous growing season.

2.3 Questionnaire Design and Data Collection:

Semi-structured questionnaires were designed and pre-tested to gather relevant data from the farmers. The instrument was validated by experts in agricultural extension and agricultural economics at the University of Nigeria, Nsukka. Suggestions were made to refine the wording and sequence of questions to ensure clarity and reliability. A pilot test was conducted, and the

reliability of the instrument was confirmed, yielding a Cronbach's alpha value of 0.88, which is above the acceptable threshold of 0.7 [12].

The questionnaire covered various aspects such as socio-economic characteristics, land ownership, farming experience, fertilizer-use patterns, and knowledge of phosphorus application. Data were collected from March 2024 to May 2024 through in-person interviews conducted in the local Igbo language, using trained enumerators familiar with the region's dialect and customs. In line with ethical procedures laid down by the University of Nigeria, oral informed consent was obtained from all participating farmers prior to data collection. Farmers were briefed about the study objectives, assured of the voluntary nature of their participation, and informed that they could withdraw at any time if they felt uncomfortable. To ensure confidentiality, all personal identifiers were removed before the data analysis stage.

2.4 Data Analysis:

Data collected through the questionnaires were entered into a spreadsheet and analyzed using IBM SPSS version 26. Descriptive statistics, including frequencies and percentages were employed to summarize the data, particularly for farmers' knowledge of phosphorus application and fertilization patterns. The result is presented as graphs and tables.

III. RESULT AND DISCUSSION

3.1 Demographic information:

The data reveals significant demographic patterns. The majority of respondents are male (67.1%), which aligns with the traditional gender roles in farming in many regions (Table 1). The predominant age group is between 41 and 50 years, suggesting that rice farming in these areas is largely managed by middle-aged individuals. Younger participants are notably fewer, with minimal representation from those aged 21 to 30 years. This might point to a generational shift where younger people are not as actively engaged in rice farming, possibly due to migration to urban centers or the pursuit of other career paths. The participants' marital status also provides insight into their social structure, with 73.3% of respondents being married. A smaller proportion are single (14.8%), while divorced (6.2%) and widowed (5.7%) individuals make up the remainder. This demographic distribution could influence household decision-making processes in farming. Notably, 72.9% of the respondents are household heads, indicating that most of these farmers are key decision-makers in their families, which may affect their farming practices and land use strategies.

Education plays a critical role in the effectiveness of agricultural practices, and the data shows that while 75.2% of respondents can read and write; a significant portion (24.8%) cannot. This lack of literacy could be a barrier to the adoption of modern farming techniques that require the understanding of written instructions or technological tools [13]. Most respondents have attained the West African Senior School Certificate (45.7%) or the First School Leaving Certificate (31.4%), with only a few having undergraduate (13.3%) or postgraduate degrees (3.3%). This educational landscape suggests that while there is a foundation of basic education, the overall low level of formal qualifications may limit access to advanced agricultural knowledge and innovations. The occupational background of the respondents is largely agricultural, with 74.8% identifying as farmers. A smaller segment engages in private business or government employment, which might supplement their agricultural income. Interestingly, 7.1% of the sample are students, reflecting some engagement of younger individuals in farming alongside their education. The farming experience of the respondents is significant, with 50% having between 6 to 10 years of experience, and 32.4% having more than 10 years. This wealth of experience suggests a deep understanding of local farming conditions, although it also highlights a potential resistance to adopting new technologies due to established practices.

TABLE 1
DEMOGRAPHIC INFORMATION OF RICE FARMERS

		Frequency	Percent	Cumulative
Sex	Female	69	32.9	32.9
	Male	141	67.1	100
Age Group	21 – 30 years	2	1	1
	31 – 40 years	7	3.3	4.3
	41 – 50 years	199	94.8	99
	51 – 60 years	2	1	100
Marital status	Divorced	13	6.2	6.2
	Married	154	73.3	79.5
	Single	31	14.8	94.3
	Widowed	12	5.7	100
Household head	No	57	27.1	27.1
	Yes	153	72.9	100
Nationality	Nigeria	210	100	100
Ethnicity	Hausa	2	1	1
	Igbo	207	98.6	99.5
	Yoruba	1	0.5	100
Can you read and write?	No	52	24.8	24.8
	Yes	158	75.2	100
Highest educational qualification	First School Leaving	66	31.4	31.4
	Other qualifications	13	6.2	37.6
	Postgraduate degree	7	3.3	41
	Undergraduate degree	28	13.3	54.3
	WAEC or equivalent	96	45.7	100
Are you the owner of the land?	No	91	43.3	43.3
	Yes	119	56.7	100
What is the size of your rice farm?	1 to 3 hectares	58	27.6	27.6
	4 to 6 hectares	101	48.1	75.7
	7 to 9 hectares	35	16.7	92.4
	Less than 1 hectare	5	2.4	94.8
	More than 10 hectares	11	5.2	100
Occupation	Farmer	157	74.8	74.8
	Government employee	17	8.1	82.9
	Others	1	0.5	83.3
	Private business	20	9.5	92.9
	Student	15	7.1	100
Rice cultivation period	Both early and late	76	36.2	36.2
	Early	129	61.4	97.6
	Late	5	2.4	100
Average rice yield per hectare	Above 4 tons	101	48.1	48.1
	Between 2 and 4 tons	93	44.3	92.4
	Less than 2 tons	16	7.6	100
No of years of experience in rice farming	2 to 5 years	34	16.2	16.2
	6 to 10 years	105	50	66.2
	Less than 2 years	3	1.4	67.6
	More than 10 years	68	32.4	100

Land ownership is another crucial factor in the farming dynamics of this population. The majority of the participants (56.7%) own the land they farm, which provides them with the autonomy to make long-term investments in their land. Those who do not own their land (43.3%) may face limitations in making such investments. Farm sizes are relatively moderate, with most farmers managing between 4 to 6 hectares of land, indicating a substantial scale of rice farming. Smaller farms, below 3 hectares, are less common, and only a small percentage (5.2%) manage more than 10 hectares. This distribution of farm sizes points to a semi-commercial scale of farming, where productivity is a central focus. The rice cultivation practices of the respondents show a preference for early cultivation (61.4%), with a smaller portion (36.2%) practicing both early and late cultivation cycles. According to Okeke and Oluka [11], rice farmers in southeast Nigeria plant rice between May and August. The focus on early cultivation may be influenced by environmental factors such as rainfall patterns or market demands. The yield data shows a positive trend, with 48.1% of farmers producing more than 4 tons per hectare, indicating high productivity levels. Only a small portion (7.6%) reports yields below 2 tons per hectare, which may be due to suboptimal farming practices or environmental challenges.

3.2 Farmers' fertilizer-use patterns:

The data on farmers' fertilizer-use patterns presents a detailed view of the types of fertilizers and application methods prevalent among the respondents. The findings indicate that the majority of farmers rely heavily on inorganic fertilizers, with 68.6% of them using this type on their cultivated lands (Table 2). Organic fertilizers, although still in use, are applied by only 31.4% of the respondents. This significant inclination towards inorganic fertilizers suggests that farmers in the region may prioritize quick and more consistent nutrient delivery over the longer-term benefits of organic amendments. Simpson, *et al.* [14] indicate that when P inputs are minimal, the soil experiences a net loss of P, leading to unsustainable production over time. This nutrient depletion establishes a lower limit for sustainable soil fertility management. Even in low-yield farming systems, it is essential to provide P inputs that at least match the amount of P removed in harvested products [14]. A striking 99% of the respondents confirmed the use of chemical fertilizers, demonstrating the widespread adoption of these inputs in rice farming. Compound fertilizers (84.8%) was the dominant fertilizer type used by the respondents. The minimal use of straight fertilizers, reported by just 1%, does not reflects a clear preference for nutrient blends that offer balanced nutrition to the crops but an indication of the non-availability of the straight fertilizers in the region. Interestingly, only 13.3% of the farmers report using both organic and inorganic fertilizers, hinting at limited adoption of integrated nutrient management practices, which could otherwise offer sustainable benefits to both crop yield and soil health.

The timing of phosphorus application is critical for crop development, and the data reflects varied practices among farmers. About half (50%) of the farmers apply phosphorus at the planting stage, which is a common practice for ensuring early nutrient availability. A significant number of farmers (39%) also apply phosphorus during the tiller phase, when rice plants begin to develop their vegetative structure. The relatively lower percentage of farmers (6.2%) who apply phosphorus at the grain-filling stage suggests that fewer farmers recognize the importance of this nutrient at later stages of crop development. Meanwhile, only a small fraction (4.8%) apply phosphorus before planting, which may limit the early uptake of nutrients by seedlings. Nasution, *et al.* [15] reported a significant influence of time of P application on the growth, development and yield of rice. In terms of application methods, broadcasting is by far the most common, used by 88.6% of farmers. This practice, although convenient and time-efficient, may lead to uneven nutrient distribution and potential losses due to runoff. Direct placement, which is a more efficient method of ensuring phosphorus reaches the plant roots, is practiced by only 3.3% of farmers. Foliar spraying, a more targeted approach, is employed by 8.1% of the respondents. The overall dominance of broadcasting reflects a possible need for extension services to educate farmers on more efficient and sustainable fertilizer application methods to optimize nutrient use and reduce environmental impact. Direct placement of fertilizer significantly increased grain yields and net economic return on rice compared to broadcasting method of applying fertilizer [16]. This finding was corroborated by Li, *et al.* [17] that direct placement of fertilizers substantially improved the yield and energy output in rice production systems compared to broadcasting of fertilizer.

TABLE 2
RICE FARMERS' FERTILIZER USE PATTERNS

		Frequency	Percent	Cumulative Percent
What is the dominant fertilizers used in your cultivated land	Inorganic	144	68.6	68.6
	Organic	66	31.4	100
Do you use chemical fertilizers	No	2	1	1
	Yes	208	99	100
If you use chemical fertilizers, do you use	Both	28	13.3	13.3
	Compound fertilizer (NPK)	178	84.8	98.1
	Do not use chemical fertilizer	2	1	99
	Straight fertilizer	2	1	100
At what rice growth phase do you apply phosphorus fertilizer?	At grain filling	13	6.2	6.2
	At planting	105	50	56.2
	At tiller phase	82	39	95.2
	Before planting	10	4.8	100
How do you apply phosphorus in your rice farm?	Broadcasting	186	88.6	88.6
	Direct placement	7	3.3	91.9
	Foliar spray	17	8.1	100

3.3 Farmers' Purchasing Behaviour:

The responses on farmers' purchasing behaviour offers valuable insights into the key factors influencing their fertilizer choices (Fig. 1). Price emerges as one of the most critical determinants, with 68.1% of farmers rating it as "very important." An additional 31% of respondents consider price "important," reinforcing its pivotal role in decision-making. This echoes the findings of Acheampong, *et al.* [18], who highlighted the financial constraints faced by farmers in Ghana, noting that many farmers are willing to adopt improved practices such as fertilizer application if the cost is manageable. The emphasis on subsidization, with 38.6% of respondents rating it as "very important," and 39% considers it as "important" further supports the role of price in purchasing behaviour. Acheampong, Nsiah Frimpong, Adu-Appiah, Asante and Asante [18] stressed the need for extension services and investments to improve access to inputs, suggesting that subsidies could enhance farmers' ability to adopt fertilizers, similar to the willingness observed in the present study. Given the financial constraints that many farmers face, subsidization likely provides an essential incentive for purchasing fertilizers, making it an influential element in their decision-making process.

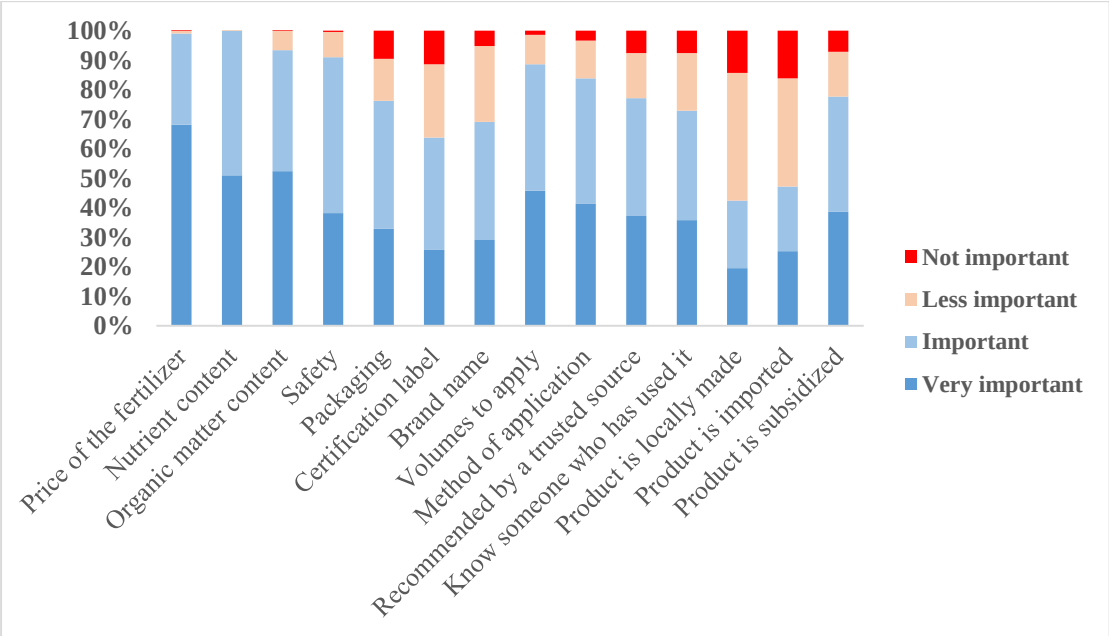

FIGURE 1: Rice farmers' purchasing behaviour

Nutrient content, also rated as an important factor by many farmers, reflects an awareness of the role fertilizers play in optimizing crop yield and productivity. Acheampong, Nsiah Frimpong, Adu-Appiah, Asante and Asante [18] found that rice farmers were eager to seek information and apply it effectively, particularly in agronomic practices such as fertilizer use. This suggests that education and information access are key to helping farmers make informed decisions about the fertilizers they use, aligning with the high importance placed on nutrient content by respondents in the current study.

The significance placed on organic matter content and safety of fertilizers in this study aligns with the findings of Li and Wu [19], who explored the impact of social norms on the use of organic fertilizers among Chinese rice farmers. Li and Wu (2021) found that social influences, alongside individual education levels, significantly affected the adoption of organic fertilizers. In the current study, 52.9% of farmers considered safety as "important," which can be linked to an awareness of the environmental impact of fertilizer use. The growing concern for environmental safety and organic content may signal a shift toward more sustainable practices, as seen in Li and Wu [19]'s research, where social norms and education moderated fertilizer behaviour.

Social influence also emerged as a factor in this study, with 37.1% of farmers considering peer recommendations as "very important" when purchasing fertilizers. This is consistent with Li and Wu [19] findings that social norms strongly influence fertilizer application decisions. The social dynamic observed in both studies points to the importance of community influence in shaping agricultural behaviors, particularly in regions where access to formal extension services may be limited. Adnan, *et al.* [20] stressed the significance of sustainability in fertilizer use. The emphasis on environmental safety and sustainable agricultural practices resonates with the current study's results, where a substantial proportion of respondents rated safety and nutrient content as critical factors. Adnan, Md Nordin, Rahman and Noor [20] noted that the adoption of safety measures could enhance productivity while addressing environmental concerns, which aligns the concerns for fertilizer safety seen among rice farmers in the present study.

3.4 Role of phosphorus in the plant:

The assessment of rice farmers' knowledge on the role of phosphorus in plant growth highlights a strong awareness of its importance in rice cultivation. Approximately 98.5% of farmers strongly agree or agree that phosphorus significantly enhances root growth in rice (Table 3). This aligns with studies by Okada, *et al.* [21], which demonstrated that phosphorus application improves root length distribution and overall water uptake in rice, especially under water-stress conditions. Phosphorus's role in stimulating root growth allows for more efficient water and nutrient absorption, crucial in phosphorus-deficient soils. A majority of farmers (86.7%) recognized the importance of phosphorus in achieving maximum tillering, a critical growth phase that influences yield. Deng, *et al.* [22] highlighted that under low phosphorus conditions, rice varieties with higher phosphorus use efficiency exhibited increased tillering, root biomass, and root-to-shoot ratios, emphasizing the nutrient's critical role in sustaining rice productivity even in suboptimal conditions. However, 9% of farmers still expressed disagreement, suggesting a need for targeted education to bridge gaps in understanding phosphorus's role in tillering and overall crop performance.

TABLE 3

FARMERS' PERCEPTION ON THE ROLE OF PHOSPHORUS IN THE PLANT

	Strongly agree (%)	Agree (%)	Disagree (%)	Strongly disagree (%)
Phosphorus increase root growth in rice	63.3	35.2	1	0.5
Phosphorus increase influence early maturity in rice	52.9	46.2	0.5	0.5
Phosphorus increase rice straw strength	51.4	46.7	1.4	0.5
Phosphorus increase crop quality and disease resistance.	41	53.8	5.2	0
Phosphorus is an essential element required for energy storage and transfer within the plant.	42.4	52.9	4.3	0.5
Phosphorus is a major component in ATP, the molecule that provides "energy" to the plant for such processes as photosynthesis, protein synthesis, nutrient translocation, nutrient uptake and respiration.	31.9	47.6	20.5	0
Phosphorus is a component of other compounds necessary for protein synthesis and transfer of genetic material (DNA, RNA).	35.2	44.8	15.7	4.3
Maximum tillering of rice plants also depends on Phosphorus availability in the soil	40.5	46.2	9	4.3

Farmers also acknowledged phosphorus's contribution to early maturity in rice, with 99.1% either strongly agreeing or agreeing. This understanding mirrors findings by Andrianary, *et al.* [23], who observed that phosphorus application shortens the time to heading, mitigating the effects of environmental stressors such as low temperatures, which can delay phenological development. Early maturity facilitated by adequate phosphorus application ensures timely harvesting, crucial in regions with unpredictable growing seasons. Regarding phosphorus's impact on rice straw strength, 98.1% of farmers agreed, reflecting an appreciation of its role in structural integrity. Strong straw is essential to prevent lodging, a phenomenon where plants fall over before harvest, drastically reducing yield. The ability of phosphorus to reinforce plant structure is also supported by Sanusan, *et al.* [24], who found that phosphorus application improves root density and shoot growth, enhancing overall plant stability.

A significant 94.8% of farmers also recognized phosphorus's role in enhancing crop quality and disease resistance, echoing the nutrient's broader benefits beyond growth enhancement. Phosphorus's role in energy storage and transfer was well recognized, with 95.3% of farmers agreeing. Phosphorus is a key component in ATP, the molecule essential for energy transfer in photosynthesis, nutrient uptake, and protein synthesis [25]. This biochemical function is fundamental to plant growth, and the farmers' awareness reflects a good understanding of phosphorus's critical role at the molecular level. However, there was slightly less agreement (79.5%) on phosphorus's role as a major component in ATP and its involvement in protein synthesis and genetic material transfer (DNA, RNA). This indicates a more complex understanding of phosphorus's biochemical functions, suggesting that further education might help bridge knowledge gaps about its molecular roles in rice plants.

The insights derived from farmers' perceptions and supported by literature emphasize the critical role of phosphorus in rice production, affecting root growth, tillering, maturity, structural integrity, and disease resistance. Bridging the knowledge gaps identified could further optimize phosphorus management practices among rice farmers, enhancing productivity and resilience under varying agro-ecological conditions.

3.5 Phosphorus deficiency symptoms in rice:

The assessment of rice farmers' knowledge on phosphorus deficiency symptoms reveals varying levels of awareness regarding critical indicators reflecting phosphorus shortages in plants. Most farmers recognized moderate to severe stunting (97.1%), small stem diameter (94.3%), and small, very erect, and dark green leaves (94.7%) as key symptoms of phosphorus deficiency (Table 4). These symptoms align with findings from literature that emphasize the impact of phosphorus deficiency on rice growth. For example, Rose, *et al.* [26] highlighted that phosphorus deficiency significantly reduces biomass accumulation in rice, causing visible stunting and affecting nutrient uptake patterns. This literature reinforces the farmers' observations of stunted growth as a primary sign of phosphorus stress. Another well-recognized symptom among farmers was the appearance of phosphorus deficiency in older leaves first, with 85.7% agreeing or strongly agreeing. This understanding is crucial because phosphorus, being a mobile nutrient, often displays its deficiency in older leaves before newer growth is affected, as discussed by Malhotra, *et al.* [27]. The symptom's visibility on older leaves underscores the importance of proper phosphorus management, as deficiency at critical growth stages can severely limit the plant's developmental processes, including root and shoot growth, photosynthesis, and overall productivity.

Farmers also exhibited a high level of awareness regarding the impact of phosphorus on tillering and plant development, with 89.1% acknowledging that reduced tillering and delayed development are signs of deficiency. This perception aligns with studies like Panda, Bhatt, Bastia, Patra and Anandan [1], which emphasize the role of phosphorus in early vegetative stages of rice, where it significantly influences root and shoot development. In phosphorus-deficient conditions, rice cultivars often exhibit reduced root volume, lower total root surface area, and decreased shoot dry weight, all of which contribute to limited tillering and delayed overall growth.

TABLE 4

FARMERS' PERCEPTION ON THE PHOSPHORUS DEFICIENCY SYMPTOMS

Phosphorus Deficiency Symptoms	Strongly agree (%)	Agree (%)	Disagree (%)	Strongly disagree (%)
Moderate to severe stunting	67.1	30	2.9	0
Small, very erect, dark green leaves	57.1	37.6	4.8	0.5
Small stem diameter	51.9	42.4	5.2	0.5
Reduced or no tillering and delayed plant development	44.3	44.8	9.5	1.4
Lack of vigorous growth after Nitrogen fertilization and flooding.	35.2	40.5	22.9	1.4
Phosphorus deficiency symptoms may appear in older leaves first.	43.3	42.4	10	4.3
Plant tissue testing is the best tool for diagnosis of phosphorus deficiency.	41.4	42.4	13.8	2.4

However, there was a notable knowledge gap among farmers regarding the lack of vigorous growth after nitrogen fertilization and flooding, with 22.9% disagreeing that this was linked to phosphorus deficiency. This misconception may arise from a limited understanding of the synergistic relationship between phosphorus and nitrogen in fostering robust plant growth. Chen, *et al.* [28] further highlighted that phosphorus deficiency could be mistakenly attributed to nitrogen, emphasizing the need for accurate diagnostic tools like plant tissue testing, which only 75.7% of farmers recognized as valuable. This knowledge gap points to the need to enlighten rice farmers in southeast Nigeria on the proper identification of the symptoms of P deficiency in rice.

3.6 Excessive application of phosphorus:

There is a strong awareness of the environmental implications associated with P mismanagement among the rice farmers in southeast Nigeria. The majority of respondents, 97.7%, agreed or strongly agreed that increased soil and water temperatures influence the cycling and release of phosphorus along the land-water continuum (Table 5). This assertion aligns with the P Transfer Continuum framework highlighted by Forber, *et al.* [29], which emphasizes that climate change effects such as rising temperatures and extreme weather events can increase P export and eutrophication risks in catchments. A significant portion of the farmers (95.7%) also acknowledged that more frequent extreme rainfall events might influence P transfers and losses. This perception is consistent with Lucas, *et al.* [30], who noted that extreme precipitation events could exacerbate P loss from agricultural soils to waterways, especially after fertilizer application. The unpredictability of these climate events complicates nutrient management, increasing the risk of P losses from agricultural lands to water bodies.

TABLE 5

FARMERS' PERCEPTION ON THE EXCESSIVE APPLICATION OF PHOSPHORUS

Excessive application of phosphorus	Strongly agree (%)	Agree (%)	Disagree (%)	Strongly disagree (%)
Increased soil and water temperatures will affect the cycling and release of phosphorus along the land–water continuum.	54.8	42.9	1.9	0.5
More frequent extreme rainfall events may affect phosphorus transfers and loss.	46.7	49	4.3	0
Increased phosphorus runoff contributes to the increased algal growth in the surrounding water bodies.	33.8	52.9	12.9	0.5
Increased phosphorus runoff reduces the quality of neighboring water (river, lake, etc.)	31.4	41.4	22.9	4.3

Similarly, 86.7% of farmers agreed or strongly agreed that increased P runoff contributes to algal growth in surrounding water bodies. This insight resonates with findings from Mardamootoo, Du Preez and Barnard [7], who identified P runoff as a critical factor in non-point source pollution and accelerated eutrophication of aquatic systems. However, 12.9% of farmers disagreed with this statement, highlighting a knowledge gap about the consequences of nutrient overuse on aquatic ecosystems. The

disagreement among some farmers may stem from a lack of understanding of how P runoff contributes to harmful algal blooms, which degrade water quality and restrict water use for recreational, industrial, and drinking purposes. Some of the rice farmers (22.9%) were unaware of the adverse effects of P runoff on water quality in rivers and lakes. This knowledge gap could hinder the adoption of sustainable practices aimed at reducing runoff. Beusen, *et al.* [31] documented that despite increased nutrient retention in freshwater systems due to human activities, river nutrient transport to the ocean has significantly increased, exacerbating water quality issues globally. The heightened P flux from agricultural landscapes to water bodies, driven by both anthropogenic factors and climate change, reinforces the urgency for targeted farmer education on the environmental costs of excessive P application.

Educating farmers about the environmental implications of P mismanagement is crucial for promoting better phosphorus stewardship. Sharpley, *et al.* [32] argue for greater coordination in P recycling at various scales, emphasizing the importance of efficient P use and minimizing reliance on chemical fertilizers through practices such as rhizosphere management and the 4R nutrient management approach (Right source, Right rate, Right time, Right place). This holistic approach can mitigate P losses and align agricultural productivity with environmental sustainability.

IV. CONCLUSION

The demographic and agricultural profile of rice farmers in southeast Nigeria reveals a predominantly male, middle-aged, and moderately educated population, with substantial farming experience and land ownership. While these farmers are engaged in semi-commercial rice farming and focused on maximizing yields, challenges related to literacy and education may hinder the adoption of modern agricultural practices. Fertilizer use, particularly chemical and compound types, is widespread, with phosphorus application practices varying by timing and method, indicating opportunities for more sustainable and balanced nutrient management strategies. Farmers demonstrate a good understanding of phosphorus's essential role in plant growth, maturity, and resilience, as well as the major symptoms of phosphorus deficiency, such as stunting and reduced tillering. However, there are minor knowledge gaps, particularly regarding the environmental impact of excessive phosphorus application and its contribution to water quality degradation. Addressing these gaps through targeted educational programs and promoting sustainable phosphorus management practices could enhance crop productivity while mitigating environmental risks.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

AUTHORS' DECLARATION

The authors hereby declare that the work presented in this article are original and that any liability for claims relating to the content of this article will be borne by them. The views shared in this publication is that of the authors and not of the funders.

FUNDING

CUP received funding from Tetfund (TETF/DR&D/CE/UNI/NSUKKA/BR/2024/VOL.I) and the African Plant Nutrition Institute (APNI 2022 Young African Phosphorus Fellowship Award) for this study.

DATA AVAILABILITY

The datasets generated during the current study are available from the corresponding author on reasonable request.

REFERENCES

[1] Panda, S.; Bhatt, B.B.; Bastia, D.; Patra, B.C.; Anandan, A. Multiple trait contribution towards phosphorus deficiency tolerance at species level in early vegetative stage of rice. *Indian Journal of Genetics and Plant Breeding* **2021**, *81*, 548-556, doi:10.31742/IJGPB.81.4.7.

[2] Bhatta, B.B.; Panda, R.K.; Anandan, A.; Pradhan, N.S.N.; Mahender, A.; Rout, K.K.; Patra, B.C.; Ali, J. Improvement of Phosphorus Use Efficiency in Rice by Adopting Image-Based Phenotyping and Tolerant Indices *Frontiers in plant science* **2021**, *12*, 717107, doi:10.3389/fpls.2021.717107.

[3] Fan, Y.; Lin, F.; Yang, L.; Zhong, X. Decreased soil organic P fraction associated with ectomycorrhizal fungal activity to meet increased P demand under N application in a subtropical forest ecosystem. . *Biology and Fertility of Soils* **2018**, *54*, 149–161.

[4] PwC. *Boosting rice production through increased mechanisation*; Abuja, Nigeria, 2018; p. 20.

[5] Liverpool-Tasie, S.; Olaniyan, B.; Salau, S.; Sackey, J. *A review of fertilizer policy issues in Nigeria*; International Food Policy Research Institute (IFPRI): Abuja, Nigeria, 2010.

[6] Alewell, C.; Ringeval, B.; Ballabio, C.; Robinson, D.A.; Panagos, P.; Borrelli, P. Global phosphorus shortage will be aggravated by soil erosion. . *Nature Communications* **2020**, *11*, 4546, doi:10.1038/s41467-020-18326-7.

[7] Mardamootoo, T.; Du Preez, C.C.; Barnard, J.H. Agricultural Phosphorus Management for Environmental Protection: A Review. *Journal of Geoscience and Environment Protection* **2021**, *9*, 48-81, doi:10.4236/gep.2021.98004.

[8] Cordell, D.; White, S. Sustainable Phosphorus Measures: Strategies and Technologies for Achieving Phosphorus Security. . *Agronomy* **2013**, *3*, 86-116, doi:10.3390/agronomy3010086.

[9] Bindraban, P.S.; Dimkpa, C.O.; Pandey, R. Exploring phosphorus fertilizers and fertilization strategies for improved human and environmental health. . *Biology and Fertility of Soils* **2020**, *56*, 299–317, doi:10.1007/s00374-019-01430-2.

[10] Mba, C.; Madu, A.; Ajaero, C.; Obetta, A. Patterns of rice production and yields in South Eastern Nigeria. *African Journal of Food, Agriculture, Nutrition and Development* **2021**, *21*, 18330-18348.

[11] Okeke, C.; Oluka, S. A survey of rice production and processing in South East Nigeria. *Nigerian Journal of Technology* **2017**, *36*, 227-234.

[12] Tavakol, M.; Dennick, R. Making sense of Cronbach's alpha. *Int J Med Educ* **2011**, *2*, 53-55, doi:10.5116/ijme.4dfb.8dfd.

[13] Myeni, L.; Moeletsi, M.; Thavhana, M.; Randela, M.; Mokoena, L. Barriers affecting sustainable agricultural productivity of smallholder farmers in the Eastern Free State of South Africa. *Sustainability* **2019**, *11*, 3003.

[14] Simpson, R.J.; Oberson, A.; Culvenor, R.A.; Ryan, M.H.; Veneklaas, E.J.; Lambers, H.; Lynch, J.P.; Ryan, P.R.; Delhaize, E.; Smith, F.A.; et al. Strategies and agronomic interventions to improve the phosphorus-use efficiency of farming systems. *Plant and Soil* **2011**, *349*, 89-120, doi:10.1007/s11104-011-0880-1.

[15] Nasution, F.J.; Hanum, H.; Ginting, J. Effect of dose and time application of phosphorus fertilizer on phosphorus availability, growth and production of rice (Oryza sativa l.). *AIP Conference Proceedings* **2021**, *2342*, doi:10.1063/5.0045727.

[16] Mazid-Miah, M.A.; Gaihre, Y.K.; Hunter, G.; Singh, U.; Hossain, S.A. Fertilizer Deep Placement Increases Rice Production: Evidence from Farmers' Fields in Southern Bangladesh. *Agronomy Journal* **2016**, *108*, 805-812, doi:https://doi.org/10.2134/agronj2015.0170.

[17] Li, L.; Wang, Y.; Nie, L.; Ashraf, U.; Wang, Z.; Zhang, Z.; Wu, T.; Tian, H.; Hamoud, Y.A.; Tang, X.; et al. Deep placement of nitrogen fertilizer increases rice yield and energy production efficiency under different mechanical rice production systems. *Field Crops Research* **2022**, *276*, 108359, doi:https://doi.org/10.1016/j.fcr.2021.108359.

[18] Acheampong, L.D.; Nsiah Frimpong, B.; Adu-Appiah, A.; Asante, B.O.; Asante, M.D. Assessing the information seeking behaviour and utilization of rice farmers in the Ejisu-Juaben municipality of Ashanti Region of Ghana. *Agriculture & Food Security* **2017**, *6*, 38, doi:10.1186/s40066-017-0114-8.

[19] Li, X.; Wu, X. The impact of social norms on rice farmers' behavior of organic fertilizers application: mediating effect of value perception and moderating effect of education level. *International Journal of Low-Carbon Technologies* **2021**, *16*, 1492-1503, doi:10.1093/ijlct/ctab074.

[20] Adnan, N.; Md Nordin, S.; Rahman, I.; Noor, A. Adoption of green fertilizer technology among paddy farmers: A possible solution for Malaysian food security. *Land Use Policy* **2017**, *63*, 38-52, doi:https://doi.org/10.1016/j.landusepol.2017.01.022.

[21] Okada, K.; Kondo, M.; Ando, H.; Kakuda, K.-i. Phosphorus application affects root length distribution and water uptake of upland rice in a column experiment. *Soil Science and Plant Nutrition* **2004**, *50*, 257-261, doi:10.1080/00380768.2004.10408475.

[22] Deng, Y.; Men, C.; Qiao, S.; Wang, W.; Gu, J.; Liu, L.; Zhang, Z.; Zhang, H.; Wang, Z.; Yang, J. Tolerance to low phosphorus in rice varieties is conferred by regulation of root growth. *The Crop Journal* **2020**, *8*, 534-547, doi:https://doi.org/10.1016/j.cj.2020.01.002.

[23] Andrianary, B.H.; Tsujimoto, Y.; Rakotonindrina, H.; Oo, A.Z.; Rabenarivo, M.; Ramifehiarivo, N.; Razakamanarivo, H. Phosphorus application affects lowland rice yields by changing phenological development and cold stress degrees in the central highlands of Madagascar. *Field Crops Research* **2021**, *271*, 108256, doi:https://doi.org/10.1016/j.fcr.2021.108256.

[24] Sanusan, S.; Polthanee, A.; Seripong, S.; Audebert, A.; Mouret, J.-C. Rates and timing of phosphorus fertilizer on growth and yield of direct-seeded rice in rain-fed conditions. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science* **2009**, *59*, 491-499, doi:10.1080/09064710802368694.

[25] Julia, C.C.; Rose, T.J.; Pariasca-Tanaka, J.; Jeong, K.; Matsuda, T.; Wissuwa, M. Phosphorus uptake commences at the earliest stages of seedling development in rice. *Journal of Experimental Botany* **2018**, *69*, 5233-5240, doi:10.1093/jxb/ery267.

[26] Rose, T.J.; Kretzschmar, T.; Liu, L.; Lancaster, G.; Wissuwa, M. Phosphorus Deficiency Alters Nutrient Accumulation Patterns and Grain Nutritional Quality in Rice. *Agronomy* **2016**, *6*, 52.

[27] Malhotra, H.; Vandana; Sharma, S.; Pandey, R. Phosphorus Nutrition: Plant Growth in Response to Deficiency and Excess. In *Plant Nutrients and Abiotic Stress Tolerance*, Hasanuzzaman, M., Fujita, M., Oku, H., Nahar, K., Hawrylak-Nowak, B., Eds.; Springer Singapore: Singapore, 2018; pp. 171-190.

[28] Chen, L.; Lin, L.; Cai, G.; Sun, Y.; Huang, T.; Wang, K.; Deng, J. Identification of Nitrogen, Phosphorus, and Potassium Deficiencies in Rice Based on Static Scanning Technology and Hierarchical Identification Method. *PLOS ONE* **2014**, *9*, e113200, doi:10.1371/journal.pone.0113200.

[29] Forber, K.J.; Withers, P.J.A.; Ockenden, M.C.; Haygarth, P.M. The Phosphorus Transfer Continuum: A Framework for Exploring Effects of Climate Change. *Agricultural & Environmental Letters* **2018**, *3*, 180036, doi:https://doi.org/10.2134/ael2018.06.0036.

[30] Lucas, E.; Kennedy, B.; Roswall, T.; Burgis, C.; Toor, G.S. Climate Change Effects on Phosphorus Loss from Agricultural Land to Water: A Review. *Current Pollution Reports* **2023**, *9*, 623-645, doi:10.1007/s40726-023-00282-7.

[31] Beusen, A.H.W.; Bouwman, A.F.; Van Beek, L.P.H.; Mogollón, J.M.; Middelburg, J.J. Global riverine N and P transport to ocean increased during the 20th century despite increased retention along the aquatic continuum. *Biogeosciences* **2016**, *13*, 2441-2451, doi:10.5194/bg-13-2441-2016.

[32] Sharpley, A.N.; Bergström, L.; Aronsson, H.; Bechmann, M.; Bolster, C.H.; Börling, K.; Djodjic, F.; Jarvie, H.P.; Schoumans, O.F.; Stamm, C.; et al. Future agriculture with minimized phosphorus losses to waters: Research needs and direction. *AMBIO* **2015**, *44*, 163-179, doi:10.1007/s13280-014-0612-x.