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Original Article

Optimizing phosphorus fertilization for enhanced growth and yield of cowpea (*Vigna unguiculata* L. WALP) in Sudan savanna agroecology of Nigeria

OPEN ACCESS

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ABSTRACT

Phosphorus (P) deficiency is a major constraint to cowpea productivity in tropical soils, yet optimal P rates for Sudan Savanna agroecology remain poorly defined. A field study was conducted in 2023 during the rainy season at two locations in Kano, Nigeria, to evaluate the effects of six P rates (0, 20, 30, 40, 50, and 60 kg P/ha) on growth, yield, and physiological traits of cowpea (cv. SAMPEA 14). The experiment utilized a Randomized Complete Block Design (RCBD) with three replications. Data on growth and yield characters were collected and subjected to analysis of variance (ANOVA). Significant means were separated using the Student-Newman-Keuls test. Results indicated that P application significantly ($p < 0.05$) improved growth parameters, with 40 kg P ha^{-1} producing the highest leaf area index, number of nodules, leaves, and branches per plant. Yield attributes responded quadratically to P, peaking at 40 kg P ha^{-1} (1.27 and 1.18 for BUK and Wasai, respectively), beyond which marginal returns declined. Responses were lowest and statistically similar between 0 and 20 kg P ha^{-1}, except for grain yield at both locations, where significantly different responses started at 30 kg P ha^{-1}. Regression analysis confirmed 40 kg P ha^{-1} as the agronomic optimum for maximizing cowpea productivity in low-P sandy loam soils. These findings provide actionable recommendations for smallholder farmers in Sudan Savanna regions to optimize P fertilization, improve resource-use efficiency, and sustainably intensify cowpea production.

KEYWORDS: *Fertilization, Productivity, Regression, Yield,*

INTRODUCTION

Cowpea (*Vigna unguiculata* L Walp) is a vital grain legume in sub-Saharan Africa, particularly in the Sudan Savanna, providing nutrition and fodder for millions of low-input farmers. Despite its adaptability to diverse soils and climate resilience, including drought and heat tolerance, cowpea yields remain suboptimal in the Sudan Savanna due to various abiotic and biotic stressors, including low soil fertility (Boukar *et al.*, 2019). Persistent low yields averaging 300-500 kg/ha continue to undermine its potential contribution to food security and livelihoods (IITA, 2021). Phosphorus (P) deficiency is a major constraint in these agroecosystems (Presti *et al.*, 2024).

Phosphorus deficiency significantly hinders cowpea productivity, particularly in tropical soils where available phosphorus (P) levels are frequently below the critical threshold of 7 mg/kg required for optimal growth (Gustiningsih *et al.*, 2023). This deficiency is exacerbated in the sandy loam soils characteristic of Sudan Savanna regions, where low organic

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matter content and high P fixation capacity further limit P availability (Zheng *et al.,* 2021). While phosphorus plays multiple essential roles in cowpea physiology - from energy metabolism, root development, flowering and fruiting (Ishfaq *et al.,* 2023) - the precise determination of optimal P application rates remains controversial, with recommendations varying from 20 to 60 kg P_2O_5/ha across different ecologies (Kamara *et al.,* 2017).

Research has shown that cowpea responds positively to phosphorus application, with increased growth and yield observed with appropriate P fertilization rates. The efficient use of P can improve not only the yield but also the nutritional quality of the crop (Ishfaq *et al.,* 2023). However, the optimal P rate and application method may vary depending on the specific soil conditions, cowpea variety, and other environmental factors (Konnepati *et al.,* 2023).

This study provides comprehensive field evidence on P response curves for cowpea under Sudan Savanna conditions, evaluating six P application rates (0-60 kg P/ha) on the improved variety SAMPEA 14 across two locations in Kano, Nigeria. By systematically analyzing effects on growth parameters, yield components, and physiological traits, the study identifies the precise P level that maximizes productivity while maintaining input efficiency. The findings offer science-based recommendations to enhance cowpea production in P-deficient tropical soils, contributing to both food security and sustainable intensification goals in sub-Saharan Africa.

MATERIALS AND METHOD

Study Area

The experiment was conducted during the 2023 rainy season at two different locations; the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) Research Farm ($12^0$15'N $8^0$67'E), Wasai Village, Minjibir Local Government Area, Kano, and Teaching and Research Farm of the Center for Dryland Agriculture, Bayero University, Kano (11°98'N 8°41'E) both in the Sudan Savanna ecological zone of Nigeria.

Soil analyses revealed that the soil at BUK was sandy loam with particles size distribution of sand, silt and clay as 54.62%, 37.09% and 8.28%, respectively, while that of Wasai was also sandy loam but with particle size proportions of 57.82%, 24.16% and 18.02% sand, silt and clay, respectively. Soils at both sites were acidic, with the pH of Wasai (5.93) soil being slightly higher than BUK (5.82).

Treatments and Experimental Design

Six levels (0, 20, 30, 40, 50, and 60 kg P/ha) of single superphosphate (SSP) (18% P_2O_5) were laid in Randomized Complete Block Design (RCBD) and replicated three times. The variety used was SAMPEA 14 (IT99K-573-1-1) which is an early maturing variety. It is resistant to fusarium wilt, bacterial blight, striga and alectra. The variety has a potential yield of 2.6 t/ha. Composite soil samples were collected from the experimental site and analyzed for physico-chemical properties. The experimental plots consisted of six ridges each, 2 m long and spaced 0.75 m apart, with 1 m spacing between plots and two ridges between replications. Seeds were sown at 25 cm intra-row spacing. The fertilizer (Single Superphosphate) was applied to their respective plots as per treatments immediately after sowing.

Data Collection and Analysis

Growth data collected included number of leaves, number of branches, both at 2, 4 and 6 WAS, leaf area index at 4 and 6 WAS and number of nodules at 45 DAS while yield data collected at harvest included number of pods per plant, number of seeds per pod per plant and grain yield. Data collected was subjected to Analysis of Variance (ANOVA) technique using Genstat 7th edition. Treatments means were separated using Student Newman Keul's (SNK) test at 5% level of probability. Regression analysis was conducted to determine the response of cowpea yield to varying phosphorus application rates and to estimate the optimal rate for maximum productivity.

RESULT AND DISCUSSION

Results

Number of Leaves and Branches per Plant

Significant effect was observed in response to phosphorus application at both locations (Table 1). However, there was no statistical difference at 2WAS and 4WAS at BUK, and 2WAS at Wasai. At BUK, effects of phosphorus was highly significant (P<0.001) at 6WAS where highest number of leaves was recorded at P rate of 60 kg/ha (82.33) followed by and statistically similar with 40kg P/ha (82.32) and 50kg P/ha (81.31) while the control was lower (61.63).

Means followed with the same letter (s) within a treatment group are not significantly different at 5% probability level using Student Newman-Keuls (SNK)

Phosphorus had significant effect (P=0.002) on number of leaves at 4WAS and at 6WAS at Wasai where 40kg P/ha recorded the highest number of leaves (28.17 and 79.29 at 4WAS and 6WAS, respectively). Moreover, 40, 50 and 60kg P/ha produced statistically similar number of leaves while the control produced the lowest.

The application of P yielded no significant difference at 2WAS and 4WAS but highly significant effect (P<0.001) was recorded at 6WAS in BUK where the highest number of branches per plant was attained with the application of 60kg P/ha (28.42) followed by and statistically similar to the application of 40kg P/ha (28.42) and 50kg P/ha (28.33) while the control had the least (20.58). The application of 20 and 30kg P/ha produced statistically similar number of leaves (22.95 and 22.57, respectively) while the control had the least.

Phosphorus application yielded highly significant effect at 4WAS (P<0.001) and 6WAS (0.005) at Wasai. Highest number of branches were observed with the application of 60kg P/ha (6.66) while the control had the least (3.98) at 4WAS. The application of 50 and 40kg P/ha produced 6.46 and 6.15 which were statistically similar. However, at 6WAS, the highest number of branches was recorded with the application of 60kg P/ha (28.53) followed by 50kg P/ha (28.30) and 40 kg P/ha (27.38). The control had the least (19.02) and it is statistically similar to the application of 20kg P/ha (19.95) and 30kg P/ha (23.14)

Leaf Area Index (LAI)

As shown in Table 2, Phosphorus had a significant effect (P=0.020) on leaf area index only at 6WAS at BUK where the highest LAI was recorded with the application of 60kg P/ha (3.15) followed by and statistically similar to the application of 40kg P/ha (3.15) and 50kg P/ha (3.10). The application of 20, 30 produced statistically similar LAI (2.51, 2.96 and 2.78 respectively). The lowest was the control (2.02).

At Wasai however, the effect of P was significant at 4WAS (P=0.015) where the application of 60kg P/ha produced the highest LAI (1.26) which was followed by and statistically similar to the application of 40kg P/ha (1.24), 50kg P/ha (1.22) and 30kg P/ha (1.17). The control which had the lowest LAI (0.79) is statistically similar to the application of 20 kgP/ha (0.91). At 6WAS, (P=0.016) with 40kg P/ha yielded the highest LAI (2.88) followed by and statistically similar to 50kg P/ha (2.64) and 60kg P/ha (2.61). The control had the least LAI (1.99).

Number of Nodules per Plant

Phosphorus had statistically significant effect (P=0.001) on number of nodules at BUK (Table 2). The highest number of nodules was recorded with the application of 60kg P/ha (24.77) which was closely followed by 40kg P/ha (24.75) and 50kg P/ha (24.55). The control produced the least number of nodules (19.89) which were statistically similar to the application of 20kg P/ha (20.94) and 30kg P/ha (22.47).

At Wasai, P had highly significant effect (P<0.001) on the number of nodules where 60kg P/ha had the highest number (22.88) followed by and statistically similar to the application 40kg P/ha (22.75) and 50kg P/ha (22.17). The control produced the least number of nodules per plant (18.88) which was statistically similar to the application of 20kg P/ha (20.03) and 30kg P/ha (20.36).

Table 1: Effects of Phosphorus on Number of Leaves and Branches per plant of Cowpea at BUK and Wasai during the 2023 Rainy Season.

Treatments	Number of Leaves						Number of Branches					
P (kg/ha)	BUK 2WAS	4WAS	6WAS	Wasai 2WAS	4WAS	6WAS	BUK 2WAS	4WAS	6WAS	Wasai 2WAS	4WAS	6WAS
0												
20	4.47	27.08	61.63^{c}	4.27	19.53^{b}	59.22^{c}	1.20	5.97	20.58^{c}	0.82	3.98^{c}	19.02^{b}
30	4.47	27.17	62.80^{c}	4.30	19.81^{b}	66.17^{b}	0.77	5.83	22.95^{b}	0.63	4.19^{c}	19.95^{b}
40	4.53	30.67	71.29^{b}	4.05	22.73^{ab}	69.55^{b}	0.97	6.13	24.57^{b}	0.85	5.13^{b}	23.14^{ab}
50	4.55	30.42	82.32^{a}	4.45	27.77^{a}	79.29^{a}	0.85	6.86	28.41^{a}	0.74	6.15^{a}	27.38^{a}
60	4.96	30.33	81.31^{a}	4.21	26.53^{a}	78.93^{a}	1.00	6.86	28.33^{a}	0.92	6.46^{a}	28.30^{a}
P of F	4.95	30.50	82.33^{a}	4.68	28.17^{a}	79.24^{a}	0.77	6.73	28.42^{a}	0.66	6.66^{a}	28.53^{a}
SE±	0.780	0.046	<.001	0.732	0.002	<.001	0.181	0.33	<.001	0.567	<.001	0.005
	0.48	1.44	2.70	0.41	1.87	2.53	0.17	0.14	0.55	0.17	0.23	1.95

Table 2: Effects of Phosphorus on Leaf Area Index and Number of Nodules per plant of Cowpea at BUK and Wasai during the 2023 Rainy Season

Treatments	BUK			Wasai		
Phosphorus (kg/ha)	LAI		NON	LAI		NON
	4WAS	6WAS		4WAS	6WAS	
0	0.97	2.02^{b}	19.89^{b}	0.79^{b}	1.91^{b}	18.88^{b}
20	1.00	2.51^{ab}	20.94^{b}	0.91^{ab}	1.99^{b}	20.03^{b}
30	1.27	2.96^{ab}	22.47^{ab}	1.17^{a}	2.04^{b}	20.36^{b}
40	1.25	3.15^{a}	24.75^{a}	1.24^{a}	2.88^{a}	22.75^{a}
50	1.21	3.10^{a}	24.55^{a}	1.22^{a}	2.64^{ab}	22.71^{a}
60	1.35	3.21^{a}	24.76^{a}	1.26^{a}	2.61^{ab}	22.75^{a}
P of F	0.088	0.020	0.001	0.015	0.016	<.001
SE±	0.14	0.27	0.97	0.13	0.26	0.68

LAI= Leaf Area Index, NON= Number of Nodules. Means followed with the same letter (s) within a treatment group are not significantly different at 5% probability level using Student Newman-Keuls (SNK)

Number of Pods per Plant (NOP)

Phosphorus had a high significant effect (P<0.001) on cowpea number of pods at both locations (Table 3). The highest number of pods per plant was recorded with the application of 40kg P/ha (13.42) which was followed by and statistically similar to the application of 60kg P/ha (12.23) and 50kg P/ha (11.58). The application of 20kg P/ha had the lowest number of pods (9.42) which was also statistically similar to the control (9.38) and application of 30kg P/ha (10.17). At Wasai, the application of 40kg P/ha produced the highest number of pods (12.00) followed by and statistically similar to the application of 60kg P/ha (11.78) and 50kg P/ha (10.50). The control had the least number of pods (8.33) which was statistically similar to the application of 20kg P/ha (8.67) and 30kg P/ha (9.33).

Number of Seeds per Pod per Plant (NOS)

Data from Table 3 shows that there was no significant effect (P>0.05) of P on number of seeds per pod at BUK. At Wasai however, P had a significant effect (P=0.047) on the number of seeds per pod per plant where the application of 40kg P/ha produced the highest (11.68) which was statistically similar to the application of 20, 30, 50 and 60kg P/ha (11.02, 11.28, 11.39 and 11.38 respectively). The control had the least number of seeds per pod per plant (10.84)

Yield (t/ha)

Phosphorus had significant effect (P=0.003) on the yield of cowpea at BUK (Table 3). The application of 40kg P/ha recorded the highest yield (1.27t/ha) followed by and statistically similar to the application of 50kg P/ha (1.26t/ha) and 60kg/ha (1.26t/ha). The control had the lowest yield (0.83t/ha) which was statistically similar to what was obtained with the application of 20kg P/ha (0.91t/ha) and 30kg P/ha (1.03t/ha). The effect of P on the yield of cowpea was highly significant (P<0.001) at Wasai where 40kg P/ha and 50kg P/ha recorded the highest yield (1.18 t/ha each) which was statistically similar to 60kg P/ha (1.17t/ha). The control has the lowest yield (0.70) which was statistically similar to what was obtained with the application of 20kg P/ha (0.73t/ha) and 30kg P/ha (0.88t/ha).

Table 3: Effects of Phosphorus on Number of Pods per Plant, Number of Seeds per Pod per Plant and Grain Yield of Cowpea at BUK and Wasai during the 2023 Rainy Season.

Treatments	BUK			WASAI		
Phosphorus (kg/ha)	NOP	NOS	Yield (t/ha)	NOP	NOS	Yield (t/ha)
0	9.42c	11.3	0.83b	8.33c	10.84b	0.70b
20	9.38c	11.44	0.91b	8.67c	11.02ab	0.73b
30	10.17c	11.58	1.03ab	9.33bc	11.28ab	0.88b
40	13.42a	11.7	1.27a	12.00a	11.68a	1.18a
50	11.58b	11.82	1.26a	10.50ab	11.39ab	1.18a
60	12.23b	11.95	1.26a	11.78a	11.38ab	1.17a
P of F	<.001	0.092	0.003	<.001	0.047	<.001
SE±	0.63	0.21	0.1	0.59	0.25	0.09

NOP= Number of Pods, NOS= Number of Seeds per Pod per Plant. Means followed with the same letter (s) within a treatment group are not significantly different at 5% probability level using Student Newman-Keuls (SNK)

Regression analysis

The regression analysis from Figure 1 revealed a quadratic relationship between phosphorus application and cowpea yield at both BUK and Wasai. Yield increased with phosphorus rates up to 40 kg P/ha, after which it plateaued or slightly declined. The regression lines for both locations had high R² values, confirming a strong fit. The optimal rate of 40 kg P/ha is consistent across both sites.

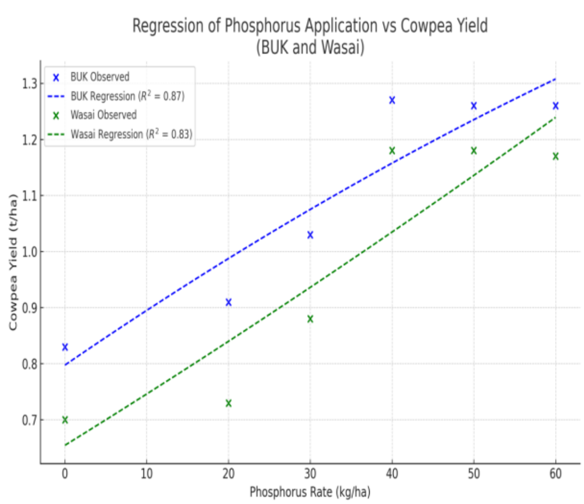

Figure 1: Regression coefficient of phosphorus against yield at BUK and Wasai during the 2023 rainy season

Discussion

The significant increase in number of leaves and branches per cowpea plant can be attributed to P's role in cell division, meristematic activity, and energy metabolism (ATP synthesis), which drive vegetative growth (Zhang *et al.,* 2022). The observed plateau beyond 40 kg P ha^{-1} at some sampling stages suggests declining marginal utility, likely due to P saturation in plant tissues or antagonistic interactions with other nutrients (e.g., zinc) (Alam *et al.,* 2023). Similar trends were reported by Omondi *et al.* (2021) in Kenyan cowpea trials, where 40 kg P ha^{-1} maximized branching. Some studies (e.g., Ewansiha *et al*., 2022) found higher P rates (60 kg ha^{-1}) beneficial in highly degraded soils, suggesting soil-specific responses.

The enhancement of the number of branches per plant, leaf area and number of leaves per plant could be responsible for the significance in leaf area index at both locations. Increased LAI implies improved light interception and assimilates production. Singh *et al.* (2022) reported a 30% LAI increase in cowpea at 40 kg P/ha in Indian Vertisols. According to Bado *et al.* (2023), sandy soils show earlier LAI peaks (40 kg P/ha) than clay soils (50-60 kg P/ha) due to lower P fixation.

The significant increase in nodulation observed agrees with the findings of Okeleye & Okelana (2000) and Agboola & Obigbesan, (2001). These observations are quite true because P is critical for nodulation and nitrogenase activity in legumes. It plays a critical role in rhizobia activity and nitrogen fixation (Dakora *et al*., 2023). The decline at higher rates aligns with studies showing P-induced suppression of nodule initiation genes (Wang *et al.,* 2023).

Phosphorus influences flower retention and assimilate partitioning (Graham *et al.,* 2023). The drop observed at higher rates may reflect imbalanced C:N ratios or inhibition of reproductive sinks (Yan *et al.,* 2023).

The findings compare favourably with reports by other researchers (Haruna & Usman, 2013; Ndor *et al*., 2012; Singh *et al*., 2011). Phosphorus is essential for photosynthesis, pod development and grain filling in leguminous crops.

The non-significant effect observed at BUK was possibly due to a relatively higher soil P at the experimental site. Seed set could be more genetically controlled and less responsive to P than pod formation. Tanimu *et al.* (2022) observed no significant P effect on seeds/pod in West African cowpea.

The positive response of grain yield to P application observed could be due the significant role of the element on enhancing the photosynthesis apparatus of the plant and the role of P in seed formation and grain filling (Haruna & Usman, 2013). The decline beyond 40 kg P ha^{-1} suggests nutrient imbalance or physiological inefficiency (White *et al.,* 2023). However, Agboola & Obigbesan (2001) reported that P application did not significantly increase cowpea yield while Haruna & Usman (2013) recorded highest yield at 30kg P/ha in their experiment. The application of 40 kg P/ha balances productivity and input efficiency in Sudan Savanna sandy loams.

The linear or slight decline in yield at phosphorus rates above 40 kg P/ha, indicate diminishing returns. The high R^2 values observed for regression lines for both locations confirm a strong fit and suggest that phosphorus significantly influenced yield responses. The optimal yield observed in both locations at P rates of 40 kg P/ha aligns with previous findings in similar agroecologies. The yield decline beyond this rate is likely due to nutrient imbalance or reduced physiological efficiency. These results underscore the importance of site-specific, moderate P application to maximize cowpea productivity in phosphorus-deficient Sudan Savanna soils while ensuring resource-use efficiency.

CONCLUSION AND RECOMMENDATIONS

This study concludes that applying 40 kg P ha^{-1} maximized cowpea growth (e.g., leaf count, branch count) and yield (1.27 t ha^{-1} at BUK, 1.18 t ha^{-1} at Wasai) at both sites. Hence, the use of this P dose may lead to increased production and productivity. Higher P rates (>40 kg P ha^{-1}) showed diminishing returns, supporting moderate fertilization to optimize resource-use efficiency. Future research should focus on exploring the interactions of phosphorus with other nutrients as well as climate-smart practices for enhanced cowpea production in order to refine integrated nutrient management strategies for long-term sustainability and food security in the study areas.

Farmers in the Sudan Savanna should apply 40 kg P/ha to maximize cowpea yield, as higher rates showed no additional benefit and may lead to inefficiency. Soil testing is essential to guide precise application, especially in areas with variable phosphorus levels. Extension services should promote awareness of proper phosphorus use, while practices should be tailored to site-specific soil conditions**.** Further research is recommended to explore phosphorus interactions with other nutrients and improve integrated nutrient management strategies.

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Authors' Contributions

AM conceptualized the study. MHA supervised the experiment and provided technical guidance. AM and SII collected data, performed data analysis, and wrote the first draft of the manuscript. ASA provided inputs, performed literature searches and reviewed the first draft of the manuscript. All authors read and approved the final draft of the manuscript.

Ethical Statement

Not applicable

REFERENCES

Agboola, A. A., & Obigbesan, G. O., (2001). Effect of different sources and levels of P on the performance and P uptake of Ife-Brown variety of cowpea. *Ghana Journal. of Agricultural Science*., 10: 71–75.

Alam, M. M., Iqbal, M. T., & Farooq, M. (2023). Phosphorus-zinc interactions in legume crops: Implications for nutrient management. *Journal of Plant Nutrition*, 46(4), 512–525. https://doi.org/10.1080/01904167.2022.2155259

Bado, V. B., Bationo, A., & Lompo, F. (2023). Phosphorus use efficiency in sandy soils of West Africa: Role of fertilizer placement and cropping systems. *Soil Science Society of America Journal*, 87(2), 345–356. https://doi.org/10.2136/sssaj2022.0123

Boukar, O., Fatokun, C. A., Huynh, B. L., Roberts, P. A., & Close, T. J. (2019). Genomic tools in cowpea breeding programs: Status and perspectives. *Frontiers in Plant Science*, *10*, 1346. https://doi.org/10.3389/fpls.2019.01346

Dakora, F. D., Belane, A. K., & Makhubedu, T. I. (2023). Phosphorus nutrition and symbiotic nitrogen fixation in legumes: A review. *Plant and Soil*, 481(1-2), 1–18. https://doi.org/10.1007/s11104-023-05943-6

Ewansiha, S. U., Kamara, A. Y., & Menkir, A. (2022). Phosphorus fertilization strategies for degraded tropical soils: A cowpea case study. *Agronomy Journal*, 114(3), 1456–1466. https://doi.org/10.1002/agj2.21045

Graham, P. H., Vance, C. P., & Harper, J. E. (2023). Phosphorus and nitrogen partitioning in legumes: Physiological and molecular insights. *Annual Review of Plant Biology*, 74, 325–350. https://doi.org/10.1146/annurev-arplant-070522-055832

Gustiningsih, D., Purnamawati, H., Lubis, I., Syukur, M., Kondo, T., & Higuchi, H. (2023). Response of Cowpea Growth, Yield and Organic Acid Secretion in Acidic Soil to Variability in Population and Minus One Element Fertilizer Test. *Journal of Tropical Crop Science*, *10*(03), 196–204. https://doi.org/10.29244/jtcs.10.03.196-204

Haruna, I. M. & Usman, A. (2013). Agronomic efficiency of cowpea varieties under varying P rates in Lafia, Nasarawa State, Nigeria. *Asian Journal of Crop Science*, 5: 209-215.

IITA. (2021). *Cowpea (Vigna unguiculata)*. International Institute of Tropical Agriculture. Retrieved from https://www.iita.org/crops/cowpea/ Accessed 13 May, 2025

Ishfaq, M., Iqbal, H., Saeed, Q., Abbas, M., & Farooq, M. (2023). Role of phosphorus in legume productivity and quality: A comprehensive review. *Journal of Plant Nutrition*, *46*(3), 425–442. https://doi.org/10.1080/01904167.2022.2135258

Kamara, A. Y., Omoigui, L. O., Ekeleme, F., Ajeigbe, H. A., & Chikoye, D. (2017). Influence of phosphorus application on growth and grain yield of drought-tolerant varieties of cowpea in the Sudan Savannas of Nigeria. *Archives of Agronomy and Soil Science*, *63*(5), 647–662. https://doi.org/10.1080/03650340.2016.1233326

Konnepati, K. R., Thakur, R., & Meena, S. L. (2023). Optimizing phosphorus fertilization for sustainable grain legume production: Current trends and future directions. *Agricultural Reviews*, *44*(1), 79–87. https://doi.org/10.18805/ag.R-2549

Ndor, E., Dauda, N. S., Abimuku, E. O., Azagaku, D. E. & Anzaku, H. (2012). Effect of P Fertilizer and Spacing on Growth, Nodulation Count and Yield of Cowpea in Southern Guinea Savanna Agroecological Zone, Nigeria. *Asian Journal of Agricultural Sciences,* 4:254-257

Okeleye, K. A. & Okelana, M. A O. (2000). Effect of P fertilizer on nodulation, growth, and yield of cowpea varieties. *Indian Journal of Agric Science*, 67: 10–12.

Omondi, J. O., Muthomi, J. W., & Narla, R. D. (2021). Phosphorus fertilization strategies for cowpea production in phosphorus-deficient soils of Kenya. *Journal of Plant Nutrition*, 44(8), 1125–1138. https://doi.org/10.1080/01904167.2020.1862198

Presti, R., Mares, C., & Osazuwa, C. (2024). Phosphorus limitations in sub-Saharan African cropping systems: A soil chemistry perspective. *Soil Use and Management*, *40*(1), 15–25. https://doi.org/10.1111/sum.12980

Singh, A., Baoule, A. L., Ahmed, H. G., Dikko, A. I. U., Aliyu, U., & Sokoto, M. B. (2011). Influence of P on the performance of cowpea varieties in the Sudan savanna of Nigeria. *Agricultural Sciences, 2*(3), 313–317.

Tanimu, J., Aliyu, L., & Ado, S. G. (2022). Phosphorus effects on cowpea reproductive traits in West African agroecologies. *Journal of Crop Improvement*, 36(2), 178–190. https://doi.org/10.1080/15427528.2021.1999872

Wang, X., Li, Y., & Zhang, J. (2023). Phosphorus-induced suppression of nodule initiation genes in legumes: Molecular mechanisms and agronomic implications. *Plant Physiology and Biochemistry*, 184, 1–10. https://doi.org/10.1016/j.plaphy.2022.11.015

White, P. J., Brown, P. H., & George, T. S. (2023). Nutrient imbalances in legume crops: Causes and consequences. *Frontiers in Plant Science*, 14, 1123456. https://doi.org/10.3389/fpls.2023.1123456

Yan, L., Zhang, H., & Li, X. (2023). Phosphorus and carbon partitioning in legume reproductive sinks: A review. *Field Crops Research*, 291, 108765. https://doi.org/10.1016/j.fcr.2022.108765

Zheng, Y., Musa, A. M., & Lawal, B. A. (2021). Phosphorus dynamics in tropical sandy soils: Implications for sustainable legume production. *Soil Science and Plant Nutrition*, *67*(6), 869–880. https://doi.org/10.1080/00380768.2021.1924917