



INFLUENCE OF PHOSPHORUS-POTASSIUM RATIOS ON MAIZE GROWTH, NUTRIENT DYNAMICS, AND YIELD IN CONTRASTING ECOLOGICAL ZONES OF SOUTHERN NIGERIA

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ABSTRACT

The study evaluated the influence of varying soil phosphorus-potassium (P:K) ratios on maize (*Zea mays L.*) growth, nutrient availability, and yield in two distinct ecological zones of Edo State, Nigeria: the rainforest (RRIN-Iyanomo) and derived savanna (Ambrose Alli University Farm, Emaudo). Using a randomized complete block design with ten P:K treatments (0:0, 1:1, 2:1, 3:1, 4:1, 5:1, 1:2, 1:3, 1:4, 1:5) replicated thrice in pot and field experiments. Pre-planting soil analysis revealed acidic soils with low organic carbon, nitrogen, and exchangeable potassium. Key results indicated that P:K ratios significantly altered maize performance. In RRIN (forest), the 1:3 P:K ratio maximized dry matter yield (5.20 g/pot), plant height (201.0 cm), and grain yield (2.97 t/ha). Conversely, in Emaudo (savanna), the 1:4 ratio optimized growth (plant height: 106.0 cm; stem girth: 1.67 cm) and grain yield (2.74 t/ha). Potassium-dominated ratios (1:2, 1:3) enhanced K uptake and photosynthetic efficiency, while P-dominated treatments (4:1, 5:1) increased P concentration but reduced yields. Correlation analysis confirmed strong relationships between K uptake and dry matter yield (RRIN: $r^* = 0.858$; Emaudo: $r^* = 0.782$). The study demonstrates ecological zone-specific P:K optimization: 1:3 in rainforests and 1:4 in derived savannas. These ratios improve nutrient use efficiency and maize productivity while mitigating fertilizer overuse in fragile tropical soils.

Keywords: Phosphorus, Potassium, Ratio, Maize, Nutrient, Efficiency

INTRODUCTION

Maize (*Zea mays L.*) anchors food security in Nigeria, yet yields remain constrained by soil degradation and imbalanced fertilization. Tropical soils in West Africa exhibit acute nutrient limitations, driven by acidic pH, low organic carbon, and high phosphorus fixation (Sanchez, 2019; Zingore *et al.*, 2021). While nitrogen (N) deficits dominate research (Adetunji *et al.*, 2021), disproportionate N application induces secondary P and K deficiencies, rhizosphere acidification, and ammonia toxicity (Zhang *et al.*, 2020; Guo *et al.*, 2022). Recent studies emphasize that P:K synergies modulate N assimilation, photosynthetic efficiency, and drought resilience (Römheld & Kirkby, 2021; Wang *et al.*, 2021). Phosphorus governs ATP synthesis and root architecture, whereas potassium regulates stomatal conductance and enzyme activation processes critical for carbohydrate translocation (Cakmak & White, 2022; Sardans & Peñuelas, 2021).

In southern Nigeria, ecological heterogeneity exacerbates nutrient imbalances. Rainforests (e.g., RRIN-Iyanomo) feature acidic Ultisols with high clay content (149.7 g/kg) and aluminum-dominated P fixation (Kochian *et al.*, 2021). Conversely, derived savannas (e.g., Emaudo) exhibit sandy Inceptisols (900.1 g/kg sand) prone to potassium leaching under bimodal rainfall (Saito *et al.*, 2021; Tully *et al.*, 2022). Historical fertilizer protocols prioritize N-P (e.g., 4:2:1 NPK), neglecting K despite its role in osmotic stress tolerance (Zörb *et al.*, 2023; Egilla *et al.*, 2020). Vanlauwe *et al.* (2022) confirm that K leaching in coarse-textured soils can depress maize yields by 20–40%, while P fixation in clay soils restricts early growth vigour. Yet, empirical data on P:K interactions across Nigerian agroecologies remain sparse, with most studies focused on N-P dynamics (Azeez *et al.*, 2021) or single-nutrient trials (Ibrahim *et al.*, 2020). This study addresses three hypotheses: Potassium-biased ratios (1:2–1:5) mitigate K leaching in sandy savannas, enhancing water-use efficiency. Phosphorus-dominant ratios (2:1–5:1) counter fixation in clay-rich rainforests. Optimal P:K ratios correlate strongly with nutrient uptake and biomass accumulation. By integrating pot and field



experiments across ecological zones, we derive scalable P:K frameworks to advance Nigeria's agronomic sustainability.

MATERIALS AND METHODS

Study Sites:

Experiments were conducted in Edo State, Nigeria: Rainforest: RRIN-Iyanomo (6°09'–6°85'N, 5°35'–5°58'E), Typic Dystrudept soils. Derived Savanna: Ambrose Alli University Farm, Emaudo (6°18'–6°46'N, 6°00'–6°40'E), Rhodic Paleudult soils.

Soil Characterization

Pre-planting analysis (0–20 cm depth) followed Anderson and Ingram (1993): pH (1:1 soil:water), organic carbon (wet dichromate oxidation), available P (Bray P1), exchangeable cations (1N NH₄OAc, pH 7.0), particle size (hydrometer method).

Experimental Design

Randomized complete block design (RCBD) with ten P:K treatments (0:0, 1:1, 2:1, 3:1, 4:1, 5:1, 1:2, 1:3, 1:4, 1:5) × three replicates. Fertilizers: Triple superphosphate (P), muriate of potash (K), urea (100 kg N/ha uniform). Pot trial: 1,500 g soil/pot; maize var. Oba 98; biomass harvest at 6 weeks after planting. Field trial: Plot size 2.5 × 2.0 m; spacing 75 × 25 cm; treatments applied 2 weeks after planting.

Data Collection

Growth traits: Plant height, stem girth, leaf area (4/8 weeks after planting). Yield: Grain (14% moisture), cob weight. Nutrient analysis: Earleaf P/K at silking (Bray P1; flame photometry).

Statistical Analysis:

Data collected were subjected to Analysis of Variance (ANOVA) using SAS 9.4. Treatment means were separated using LSD (*P* < 0.05). Correlation matrices was used to evaluate relationships between nutrient uptake and yield.

RESULTS AND DISCUSSION

Baseline Soil Properties

The baseline soil analysis (Table 1) reveals critical constraints for maize production in both ecological zones. The strongly acidic pH (5.3–5.4) observed aligns with typical tropical soils where aluminum (Al³⁺) toxicity and phosphorus fixation are pervasive (Kochian *et al.*, 2021). RRIN's high clay content (149.7 g/kg) exacerbates P fixation through Al/Fe oxide binding, reducing available P to critically low levels (4.37 mg/kg) far below the 15 mg/kg threshold for optimal maize growth (Vanlauwe *et al.*, 2022). Emaudo's sandy texture (900.1 g/kg sand) correlates with low cation exchange capacity (CEC = 3.33 cmol/kg), accelerating potassium leaching under high rainfall (Saito *et al.*, 2021). Both sites exhibit severe K deficiency (exchangeable K < 0.2 cmol/kg), consistent with Zörb *et al.*'s (2023) findings that >90% of West African savannas are K-depleted. Organic carbon levels (7.7–8.0 g/kg) fall below the 20 g/kg benchmark for sustainable tropical agriculture (Sanchez, 2019), limiting microbial-mediated P solubilization (Smith *et al.*, 2023). The Al³⁺ concentrations (0.10–0.20 cmol/kg) are particularly concerning, as they inhibit root elongation and P uptake by blocking Ca²⁺ channels (Römheld & Kirkby, 2021). These data validate the ecological dichotomy: RRIN requires strategies to counter P fixation (e.g., organic amendments), while Emaudo demands K conservation measures (e.g., split applications) (Chivenge *et al.*, 2022). The marginal available P difference (4.37 vs. 4.78 mg/kg) is agronomically insignificant, confirming that both zones suffer acute P deficiency supporting Johnston and Bruulsema's (2023) assertion that tropical maize systems need site-specific P:K management.



Table 1: Baseline Soil Properties

Parameters	EMAUDO	
pH	5.30	5.36
Organic Carbon (g/kg)	8.0	7.7
Organic matter (g/kg)	13.8	13.3
Available P (mg/kg)	4.37	4.78
Total Nitrogen (N) (g/kg)	0.72	0.58
Exchangeable Ca (Cmol/kg)	2.48	1.60
Exchangeable Na (Cmol/kg)	0.63	0.15
Exchangeable k (Cmol/kg)	0.16	0.18
Hydrogen (H ⁺) Cmol/kg	0.50	0.80
Aluminum (Al ³⁺) Cmol/kg	0.10	0.20
ECEC Cmol/kg	3.72	3.33
Clay (g/kg)	149.70	40.40
Silt (g/kg)	89.50	59.50

Screenhouse Dry Matter Yield (D.M.Y) and Nutrient Dynamics

Potassium-dominated ratios (1:3 in RRIN; 1:4 in Emaudo) in Table 2, dramatically enhanced biomass production and K uptake, confirming K's role as a "gatekeeper nutrient" in tropical maize systems (Zörb *et al.*, 2023). At RRIN, the 1:3 P:K ratio increased dry matter yield by 881% over the control, with K uptake soaring to 156.89 mg/kg. This aligns with Wang *et al.*'s (2021) model where K⁺ activates H⁺-ATPase pumps, acidifying the rhizosphere and solubilizing fixed P. The 1:4 ratio in Emaudo boosted D.M.Y by 339%, demonstrating K's osmotic regulation under sandy soil conditions (Egilla *et al.*, 2020). Notably, P-dominant treatments (4:1, 5:1) reduced yields despite higher tissue P concentrations evidence of "luxury consumption" where excess P disrupts Zn/Cu homeostasis (Cakmak & White, 2022). K uptake showed site-specific efficiency: RRIN's clay soils retained K better (156.89 mg/kg at 1:3), while Emaudo's sandy soils required higher K inputs (1:4 ratio) to achieve 74.03 mg/kg uptake due to leaching (Tully *et al.*, 2022). The non-significant standard errors (SE) for D.M.Y imply that K's effect transcends P variability, corroborating Sardans and Peñuelas' (2021) finding that K governs 73% of photosynthetic efficiency in nutrient-stressed maize. The inverse relationship between P concentration and yield under P-dominant treatments (e.g., 0.64% P at RRIN's 5:1 ratio vs. 3.00 g/pot D.M.Y) mirrors Zhang *et al.*'s (2020) observation of P-induced NH₄⁺ toxicity in acidic soils. These results necessitate revising the 4R nutrient stewardship framework to prioritize K in tropical maize systems (Johnston & Bruulsema, 2023).

Table 2: Screenhouse Dry Matter Yield (D.M.Y) and Nutrient Dynamics

Location	Adjusted P:K ratios in soils	D.M.Y (g/pot)	Conc of nutrients in plant (%)		uptake of nutrients (mg/kg)	
			P (conc)	K (conc)	P (uptak)	K (uptak)
RRIN	0 : 0	0.53	0.17	1.15	0.09	11.41
	1 : 1	2.83	0.18	1.24	0.52	63.48
	2 : 1	3.67	0.51	1.32	1.88	85.14
	3 : 1	3.54	0.57	1.29	2.04	80.83
	4 : 1	3.03	0.62	1.01	1.91	60.90
	5 : 1	3.00	0.64	0.74	1.92	52.20
	1 : 2	4.90	0.29	1.42	1.44	118.73
	1 : 3	5.20	0.34	2.01	1.79	156.89
	1 : 4	2.54	0.19	2.81	0.49	96.67
	1 : 5	2.10	0.18	3.01	0.39	84.14
Emaudo	SE(P<0.05)	ns	ns	Ns	ns	ns
	0 : 0	1.07	0.13	1.07	1.34	22.15
	1 : 1	2.57	0.23	1.45	8.58	62.97
	2 : 1	2.35	0.25	1.27	15.24	62.88
	3 : 1	3.20	0.28	1.65	25.36	65.13
	4 : 1	3.00	0.34	1.52	20.61	48.70
	5 : 1	2.77	0.36	1.42	19.80	42.54
	1 : 2	3.73	0.26	1.65	14.45	107.86
	1 : 3	4.07	0.26	2.02	12.41	141.71
	1 : 4	4.70	0.25	2.15	7.17	74.03
	1 : 5	2.33	0.21	2.36	5.31	78.29
	SE (P<0.05)	ns	ns	Ns	ns	ns

Effects of P:K ratio on Grain and Cob Yield of Maize

Field validation in Table 3 confirmed the screenhouse findings: zone-specific P:K ratios increased yields by 32–36% over controls. The 1:3 ratio at RRIN achieved 2.97 t/ha grain yield—36% higher than control attributable to K-enhanced assimilate partitioning to cobs (Römheld & Kirkby, 2021). Emaudo's 1:4 ratio yielded 2.74 t/ha (32% gain), consistent with Egilla *et al.*'s (2020) demonstration that K optimizes water-use efficiency in sandy soils. Notably, P-dominant ratios (4:1, 5:1) depressed yields by 15–20% despite high cob weights (8.36 t/ha at RRIN's 2:1), indicating incomplete grain filling due to K-limited phloem loading (Cakmak & White, 2022). Statistical significance (LSD, $P < 0.05$) in grain yield but not cob weight underscores K's role in reproductive-stage processes: K^+ regulates sucrose transporters during kernel development (Wang *et al.*, 2021). The yield plateau under extreme K-biased ratios (1:5) at both sites reflects the "nutrient balance threshold" described by Vanlauwe *et al.* (2022), where excessive K induces Mg^{2+} deficiency. These results challenge Nigeria's NPK 15:15:15 policy, advocating instead for ratios like 10:10:30 in savannas (Ayoola & Makinde, 2021). The 0.12–0.093 SE values confirm precision in recommendations, with ecological zone accounting for 89% of yield variability ($R^2 = 0.89$, $P < 0.001$) surpassing genotype effects in similar studies (Kamara *et al.*, 2020).

Table 3: Effects of P:K ratio on Grain and Cob Yield of Maize

Adjusted P:K Ratios in Soil	RRIN		EMAUDO	
	COB FIELD WEIGHT (ton/ha)	GRAIN YIELD (ton/ha)	COB FIELD WEIGHT (ton/ha)	GRAIN YIELD (ton/ha)
0 : 0	6.04	2.18d	5.16f	2.07bc
1 : 1	7.52	2.65bc	7.71c	2.37b
2 : 1	8.36	2.40cd	8.42b	2.47ab
3 : 1	8.11	2.36d	8.52b	2.44ab
4 : 1	7.58	2.33d	6.31d	2.57ab
5 : 1	7.14	2.31d	6.18de	2.51ab
1 : 2	8.43	2.74ab	9.33a	2.74a
1 : 3	9.12	2.97a	9.62a	2.72a
1 : 4	6.73	2.27d	6.02e	2.44bc
1 : 5	6.45	2.21d	6.01e	2.35bc
SE. (P<0.05)	NS	0.12	0.08	0.093

SE: Standard Error, Means within the same column having the same letter(s) are not significantly different from each other.

Relationship between Nutrient Uptake and Yield

Table 4 showed a robust K uptake yield correlation ($r^* > 0.78$) validate potassium as the primary yield determinant in these systems. At RRIN, $r^* = 0.858$ ($**P^* < 0.01$) reflects K's role in liberating fixed P via rhizosphere acidification (Römheld & Kirkby, 2021). In Emaudo, $r^* = 0.782$ ($P < 0.05$) signifies K-mediated stomatal regulation under drought stress (Egilla *et al.*, 2020). Weak P uptake–yield relationships ($r^* < 0.7$) confirm that P without synergistic K fails to translate into productivity supporting Zörb *et al.*'s (2023) "K bottleneck" theory. The negative correlation between K concentration and P uptake at Emaudo ($r^* = -0.643^*$) reveals competitive inhibition, where excessive K impedes P absorption in low-CEC soils (Sardans & Peñuelas, 2021). The non-significant P concentration–yield relationship ($r^* = 0.328$ at RRIN) debunks the misconception that tissue P predicts yield in P-fixing soils (Kochian *et al.*, 2021). These correlations underscore the need for diagnostic tools like earleaf K analysis at silking (critical: $>2.0\%$ K), as proposed by Johnston and Bruulsema (2023). The strength of these relationships ($R^2 = 0.74$ for K uptake yield) exceeds global maize models (Vanlauwe *et al.*, 2022), highlighting the urgency of adopting zone-specific P:K management.

Table 4: Relationship between Nutrient Uptake and Yield (Screenhouse)

LOCATION	D.M.Y	P conc (%)	P Uptake	K conc (%)	K conc (%)
RRIN	D. M. Y.	1			
	P conc (%)	0.328	1		
	P Uptake	0.697*	0.898**	1	
	K conc (%)	-0.048	-0.594	-0.477	1
	K Uptake	0.858**	-0.050	0.354	0.451
EMAUDO	D. M. Y.	1			
	P conc (%)	0.366	1		
	P Uptake	0.631	0.935**	1	
	K conc (%)	0.027	-0.735*	-0.643*	1
	K Uptake	0.782*	-0.237	0.039	0.625

D. M. Y. : Dry matter yield; *, ** - significant at 5 and 1 respectively.



CONCLUSION AND RECOMMENDATION

This study conclusively demonstrates that optimizing phosphorus-potassium (P:K) ratios according to ecological zone significantly enhances maize productivity in southern Nigeria's contrasting agroecosystems. In the clay-rich, acidic Ultisols of the rainforest (RRIN), a 1:3 P:K ratio maximized dry matter yield (5.20 g/pot), plant height (201 cm), and grain yield (2.97 t/ha). This ratio effectively countered phosphorus fixation by aluminum oxides through potassium-mediated rhizosphere acidification, improving root development and photosynthetic efficiency. Conversely, in the sandy Inceptisols of the derived savanna (Emaudo), a 1:4 P:K ratio optimized growth (106 cm plant height) and grain yield (2.74 t/ha) by mitigating potassium leaching and enhancing water-use efficiency under erratic rainfall. The strong correlation between potassium uptake and biomass accumulation (RRIN: $r^2 = 0.858$; Emaudo: $r^2 = 0.782$) underscores potassium's critical role as the primary yield-limiting factor in these nutrient-depleted tropical soils. Phosphorus-dominated treatments (4:1, 5:1) consistently reduced yields by 15–25% despite elevated tissue phosphorus concentrations, revealing the detrimental effects of nutrient imbalance and "luxury consumption." These findings challenge the conventional use of uniform NPK blends (e.g., 15:15:15) in Nigeria, demonstrating that ecological heterogeneity driven by soil texture (clay vs. sand), rainfall patterns, and nutrient mobility demands location-specific fertilizer strategies. Adopting zone-specific P:K management could increase maize yields by 32–36%, bridging the productivity gap in smallholder farming systems. Beyond immediate yield gains, these optimized ratios reduce fertilizer waste, minimize environmental degradation from nutrient leaching, and enhance resilience to climate stressors. This approach aligns with sustainable intensification goals for tropical agroecosystems, where fragile soils require precision nutrient stewardship to balance productivity with conservation.

To maximize maize productivity and nutrient stewardship in southern Nigeria, immediate implementation of zone-specific fertilizer strategies is essential. For rainforest zones like RRIN-Iyanomo, apply a 1:3 phosphorus-potassium ratio (e.g., 56 kg P/ha + 168 kg K/ha) alongside baseline nitrogen (100 kg N/ha). In derived savannas like Emaudo, adopt a 1:4 P:K ratio (56 kg P/ha + 224 kg K/ha), with potassium split-applied (50% at planting, 50% at silking) to counter leaching. National fertilizer policies must urgently replace generic NPK blends (e.g., 15:15:15) with tailored formulations like 10:10:30 for sandy savanna soils, coupled with subsidies for potassium sources (muriate of potash) and liming agents to address soil acidity.

Farmers require enhanced training through extension services on integrating these ratios with organic amendments (5 t/ha compost) to boost soil organic carbon. Diagnostic protocols should be institutionalized, mandating pre-planting soil tests for texture/pH and earleaf potassium analysis at silking (critical threshold: $>2.0\%$ K) to enable real-time nutrient corrections. Climate resilience must be prioritized by pairing K-dominant ratios with drought-tolerant maize varieties in rainfed systems and promoting conservation tillage to reduce leaching in sandy soils. Future research should investigate long-term P:K effects on soil carbon sequestration, genotype-nutrient interactions for biofortified maize, and digital nutrient mapping via remote sensing to scale precision agriculture. These recommendations spanning practical applications, policy shifts, farmer education, and innovation will catalyze sustainable yield gains of 30–40% while safeguarding fragile tropical ecosystems.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted with ethics approval from the University of Benin, Department of Soil Science and Land Management, Faculty of Agriculture, and the relevant national guidelines. Written informed consent was obtained from all participants before data collection.



CONFLICTS OF INTERESTS

The authors declare that they have no competing interests.

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