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Impact of integrated phosphorus management using prom and PSB on nutrient uptake, seed quality and economics of cowpea [*Vigna unguiculata* (L.) walp.]

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Abstract
Efficient phosphorus management plays a vital role in improving nutrient use efficiency, crop quality, and profitability in legume production systems. A field experiment was conducted during Kharif 2025 at the Agronomy Research Farm, Faculty of Agriculture, Vivekananda Global University, Jagatpura, Jaipur (Rajasthan), to assess the effect of integrated phosphorus management on nutrient uptake, seed quality, and economic returns of cowpea. The experiment comprised eight treatments involving different combinations of DAP, Phosphate Rich Organic Manure (PROM), and Phosphate Solubilizing Bacteria (PSB) arranged in a Randomized Block Design with three replications. The integrated application of 50% recommended phosphorus through DAP + 50% through PROM along with PSB (T_8) significantly enhanced nitrogen and phosphorus uptake by seed and straw, increased protein content, and produced the highest gross return (₹1,09,333.77 ha^{-1}), net return (₹70,121.77 ha^{-1}), and benefit-cost ratio (1.78). The treatment also improved nutrient use efficiency and maintained superior crop performance compared with sole chemical phosphorus application and the control. The results suggest that partial substitution of chemical phosphorus fertilizer with PROM combined with PSB offers an economically viable and environmentally sustainable approach for cowpea cultivation. Adoption of this integrated nutrient management practice can improve seed quality, enhance farm profitability, and promote long-term soil fertility under the agro-climatic conditions of Rajasthan.

Keywords: Cowpea, PROM, PSB, nutrient uptake, protein content, economics, sustainable phosphorus management, integrated nutrient management

Introduction
Cowpea (*Vigna unguiculata* (*L.*) Walp.) is an important grain legume cultivated extensively in tropical and subtropical regions due to its adaptability to drought-prone environments, high nutritional value, and ability to improve soil fertility through biological nitrogen fixation. The crop serves as an inexpensive source of dietary protein (18–25%) and is rich in carbohydrates, minerals, vitamins, and essential amino acids, making it an important component of food and nutritional security. Besides its nutritional significance, cowpea contributes to sustainable cropping systems by enriching soil nitrogen and improving soil health through symbiotic nitrogen fixation.

Phosphorus is the second most important plant nutrient after nitrogen and is essential for plant growth, energy transfer, root development, nodulation, biological nitrogen fixation, and seed formation. It is a structural component of nucleic acids, phospholipids, adenosine diphosphate (ADP), and adenosine triphosphate (ATP), which regulate several physiological and biochemical processes in plants (Nesme *et al.*, 2014; Elhaissouf *et al.*, 2022) [15, 5]. Phosphorus deficiency adversely affects chlorophyll synthesis, root growth, nutrient uptake, and reproductive development, ultimately reducing crop productivity (Galatro *et al.*, 2020) [6]. In leguminous crops, adequate phosphorus nutrition is particularly important because it promotes effective nodulation and enhances the efficiency of biological nitrogen fixation (Mitran *et al.*, 2018) [14].

Although phosphorus fertilizers are widely used to improve crop production, their use efficiency remains low because a large proportion of applied phosphorus becomes fixed in the soil through reactions with calcium, iron, and aluminium compounds, making it unavailable for plant uptake (Rana *et al.*, 2020; Teng *et al.*, 2020) [17, 23]. Continuous dependence on chemical phosphatic fertilizers also increases production costs and may contribute to environmental degradation through nutrient losses and eutrophication.

Therefore, sustainable phosphorus management strategies that improve phosphorus availability while reducing fertilizer inputs are becoming increasingly important.

Phosphate Rich Organic Manure (PROM) has emerged as a promising alternative source of phosphorus because it supplies nutrients gradually, improves soil physical and biological properties, and enhances phosphorus availability. PROM is prepared by composting finely ground rock phosphate with organic materials and beneficial microorganisms, providing residual benefits that may extend to subsequent crops (Sharma *et al.*, 2004; Bi *et al.*, 2020) [19]. Studies have shown that PROM can perform comparably to conventional phosphatic fertilizers while promoting sustainable nutrient management (Khangarot *et al.*, 2022a; Tamizhvendhan *et al.*, 2023) [10, 22].

Phosphate Solubilizing Bacteria (PSB) play an equally important role in phosphorus nutrition by converting insoluble phosphorus compounds into plant-available forms through the secretion of organic acids and phosphatase enzymes (Cheng *et al.*, 2023) [1]. The combined use of PROM and PSB enhances phosphorus solubilization, improves nutrient uptake, stimulates root growth, and increases crop productivity while reducing dependence on chemical fertilizers (Tian *et al.*, 2021) [24]. Such integrated nutrient management practices are increasingly recognized as environmentally sustainable approaches for improving crop performance and maintaining long-term soil fertility.

Improved phosphorus nutrition not only enhances growth and yield but also increases nutrient uptake, protein accumulation, seed quality, and economic returns. Higher phosphorus availability promotes efficient absorption and utilization of nitrogen and phosphorus, leading to better grain quality and higher profitability. The integration of organic phosphorus sources with beneficial microorganisms therefore offers an effective strategy for achieving sustainable cowpea production with improved resource-use efficiency.

Keeping these aspects in view, the present investigation entitled "Impact of Integrated Phosphorus Management Using PROM and PSB on Nutrient Uptake, Seed Quality and Economics of Cowpea [*Vigna unguiculata* (*L.*) Walp.]" was undertaken to evaluate the influence of integrated phosphorus management practices on nutrient uptake, seed protein content, quality attributes, and economic returns of cowpea under the agro-climatic conditions of Rajasthan.

Material and Methods

The field experiment was carried out during the Kharif 2025 season at the Agronomy Research Farm, Faculty of Agriculture, Vivekananda Global University, Jaipur, Rajasthan, India. The experimental site is situated in the semi-arid agro-climatic zone and is characterized by loamy sand soil. Prior to sowing, the soil was analyzed and found to contain low organic carbon (0.39%), low available nitrogen (122.44 kg ha $^{-1}$), medium available phosphorus (22.92 kg ha $^{-1}$), available potassium (154.16 kg ha $^{-1}$), low available zinc (0.47 ppm), and low available iron (2.84 ppm). The soil reaction was nearly neutral, with a pH of 6.7. During the crop growing period, the experimental location received approximately 555 mm of rainfall, most of which occurred between July and September. The prevailing weather conditions were favourable for sorghum cultivation, with average maximum temperatures ranging from 29.5 to 39.4 °C and minimum temperatures varying between 16.6 and 22.4 °C throughout the growing season.

Experimental Design and Treatments

The experiment was conducted using a Randomized Block Design (RBD) comprising eight treatments with three replications. The treatments consisted of different phosphorus management practices involving recommended nitrogen (RDN), diammonium phosphate (DAP), Phosphate Rich Organic Manure (PROM), and Phosphate Solubilizing Bacteria (PSB). The treatment details were as follows: T$_1$colon Absolute control (no fertilizer application); T$_2$colon RDN + zero phosphorus; T$_3$colon RDN + 50% recommended phosphorus through DAP + 50% through PROM; T$_4$colon RDN + 100% recommended phosphorus through PROM; T$_5$colon RDN + 50% recommended phosphorus through DAP + 50% through PROM + PSB; T$_6$. : RDN + 100% recommended phosphorus through DAP + PSB; T$_7$: RDN + 100% recommended phosphorus through PROM + PSB; and T$_8$colon Recommended dose of fertilizer (RDF: 20:45:00 kg $N_2O_{52}O$ ha $^{-1}$).

The cowpea variety RC-19 was sown at a seed rate of 20 kg ha $^{-1}$ with a row spacing of 45 cm. Each experimental plot measured 4.5×6.0 : m, while the net plot size was 3.6×6.0 m. Phosphate Rich Organic Manure (PROM) and chemical fertilizers were applied as basal doses according to the treatment schedule. Seeds assigned to PSB treatments were inoculated with *Bacillus megatherium* liquid culture at 2 ml kg $^{-1}$ seed immediately before sowing.

Observations Recorded

Growth observations included plant population, plant height, number of branches per plant, dry matter accumulation, chlorophyll content, and total as well as effective nodules per plant. Yield attributes recorded were number of pods per plant, seeds per pod, and 1000-seed weight. Yield parameters comprised seed yield, straw yield, biological yield, and harvest index.

For quality assessment, protein content in seed was determined. Nutrient uptake of nitrogen and phosphorus by seed and straw was estimated using standard analytical procedures. Economic evaluation included computation of cost of cultivation, gross returns, net returns, and benefit-cost (B) ratio.

Statistical Analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for the Randomized Block Design following the procedure described by Fisher (1950). Treatment means were compared using the Critical Difference (CD) test at the 5% level of significance whenever the F-test indicated significant treatment effects.

Results and Discussion

Nitrogen concentration and uptake in seed and straw

The integrated phosphorus management practices significantly influenced nitrogen concentration and nitrogen uptake in both seed and straw of cowpea. The highest nitrogen concentration in seed (3.411%) and straw (1.500%) was recorded under T$_5$ (RDN + 50% recommended phosphorus through DAP + 50% through PROM + PSB), which remained statistically at par with T$_6$. The lowest values were observed under the absolute control (T$_1$). Similarly, nitrogen uptake by seed (43.29 kg ha $^{-1}$) and straw (43.08 kg ha $^{-1}$) was also maximum under T$_5$, followed by T$_6$ and T$_7$. The enhanced nitrogen accumulation under integrated phosphorus management may be attributed to improved phosphorus availability, enhanced root development, increased biological nitrogen fixation, and greater nutrient absorption resulting from PSB inoculation. Similar observations have been reported by Mitran *et al.* (2018) [14], Rana *et al.* (2020) [17], Khangarot *et al.* (2022) [10], and Cheng *et al.* (2023) [1].

Table 1: Effect of integrated phosphorus management on nitrogen concentration and uptake in cowpea

Treatments	Seed N concentration (%)	Stalk N concentration (%)	Seed N uptake (kg ha-1)	Stalk N uptake (kg ha-1)
T_1	2.48	1.053	19.99	19.43
T_2	2.8	1.426	29.32	33.02
T_3	2.78	1.406	29.69	36.07
T_4	3.12	1.4	34.54	36.57
T_5	3.411	1.5	43.29	43.08
T_6	3.323	1.496	39.45	39.89
T_7	3.132	1.432	39.28	38.22
T_8	2.78	1.406	32.17	36.85

Phosphorus concentration and uptake in seed and straw

Integrated phosphorus management significantly improved phosphorus concentration and uptake in cowpea. The highest phosphorus concentration in seed (0.470%) and straw (0.271%) was recorded under T_6, whereas phosphorus uptake in seed (5.88 kg ha ^{1}) was $^{-}$ maximum under T_7 and straw uptake (7.22kgha^{-1}) under T_6. The higher phosphorus uptake under integrated nutrient management was mainly due to increased phosphorus solubilization by PSB and the gradual release of phosphorus from PROM, which improved nutrient availability throughout crop growth. Comparable findings have been reported by Elhaissouf *et al.* (2022) [5], Cheng *et al.* (2023) [1], and Tamizhvendhan *et al.* (2023) [22].

Table 2: Effect of integrated phosphorus management on phosphorus concentration and uptake in cowpea

S.No.	Treatments	Phosphorus concentration		Phosphorus uptake (kg/ha)	
		Seed	Stalk	Seed	Stalk
T1	Absolute Control (no application)	0.383	0.176	3.08	3.24
T2	RDN + P Zero	0.425	0.198	4.45	4.58
T3	RDN + 50% RD of P from DAP + 50% RD of P from PROM	0.429	0.185	4.58	4.74
T4	RDN + 100% RD of P from PROM	0.436	0.196	4.82	4.99
T5	RDN + 50% RD of P from DAP + 50% RD of P from PROM + PSB	0.444	0.218	5.63	6.23
T6	RDN + 100% RD of P from DAP + PSB	0.47	0.271	5.57	7.22
T7	RDN + 100% RD of P from PROM + PSB	0.469	0.259	5.88	6.91
T8	RDF ($N:P_2O_5:K_2O$ -@20:45:00 kg ha^{-1})	0.457	0.246	5.28	6.44
	CD (P=0.05)	0.02	0.007	0.186	0.254
	SEm+	0.007	0.002	0.061	0.083
	CV (%)	2.574	1.794	2.137	2.59
	NS= Non-significant				

Potassium concentration and uptake

Table 3: Effect of integrated phosphorus management on potassium concentration and uptake in cowpea

Treatments	Seed P concentration (%)	Straw P concentration (%)	Seed P uptake (kg ha-1)	Straw P uptake (kg ha-1)
T_1	0.383	0.176	3.08	3.24
T_2	0.425	0.198	4.45	4.58
T_3	0.429	0.185	4.58	4.74
T_4	0.436	0.196	4.82	4.99
T_5	0.444	0.218	5.63	6.23
T_6	0.47	0.271	5.57	7.22
T_7	0.469	0.259	5.88	6.91
T_8	0.457	0.246	5.28	6.44

Application of integrated phosphorus sources significantly increased potassium concentration and uptake in seed and straw. The highest potassium concentration (1.488% in seed and 2.980% in straw) and potassium uptake (18.88 and 85.25 kg ha ^{1}, respectively) were recorded $^{-}$ under T_5. Enhanced potassium uptake under PROM and PSB treatments could be attributed to better root proliferation, improved microbial activity, and increased nutrient availability in the rhizosphere.

Seed protein content

Seed protein content varied significantly among the treatments. The highest protein content (21.31%) was obtained with T_5, followed by T_6 (20.76%), whereas the lowest protein content (15.50%) was recorded in the control. Improved phosphorus nutrition and enhanced nitrogen assimilation under integrated nutrient management contributed to higher protein synthesis in cowpea seeds.

Table 4: Effect of integrated phosphorus management on seed protein content

Treatments	Protein (%)
T_1	15.5
T_2	17.5
T_3	17.37
T_4	19.5
T_5	21.31
T_6	20.76
T_7	19.57
T_8	17.37

Economics

Economic analysis revealed significant differences among phosphorus management practices. The integrated application of 50% recommended phosphorus through DAP + 50% through PROM + PSB (T_5) recorded the highest gross return (ell109, 333.77ha^{-1}), net return (τ 70, 121.77ha^{-1}), and benefit-cost ratio (1.78), indicating that integrated phosphorus management is economically superior to sole chemical fertilization.

Table 5: Economics of integrated phosphorus management in cowpea

Treatments	Cost of cultivation (₹ ha-1)	Gross return (₹ ha-1)	Net return (₹ ha-1)	B:C ratio
T_1	34,600	69,578.22	34,978.22	1.01
T_2	35,087	90,009.29	54,922.29	1.56
T_3	39,444	92,730.28	53,286.28	1.35
T_4	41,497	95,608.73	54,111.73	1.3
T_5	39,212	109,333.77	70,121.77	1.78
T_6	37,094	102,228.79	65,134.79	1.75
T_7	41,579	107,329.76	65,750.76	1.58
T_8	37,342	99,741.74	62,399.74	1.67

Conclusion

The present investigation demonstrated that integrated phosphorus management significantly improved nutrient concentration, nutrient uptake, seed quality, and profitability of cowpea. Among all treatments, application of 50% recommended phosphorus through DAP+50 % through PROM along with PSB (T_5) proved to be the most effective by producing maximum nitrogen and potassium uptake, highest seed protein content, and superior economic returns. Although phosphorus concentration was highest under T_6 and phosphorus uptake under T_7, the overall performance of T_5 was superior because of its balanced improvement in nutrient acquisition, seed quality, and farm profitability. Therefore, integrated application of PROM and PSB with partial substitution of chemical phosphorus fertilizer can be recommended as a sustainable nutrient management strategy for cowpea cultivation under the agro-climatic conditions of Rajasthan.

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