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Response of phosphorus levels and bio-fertilizers on growth and yield of Pigeonpea (*Cajanus cajan* L)

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ABSTRACT

A field study entitled “Response of phosphorus levels and bio-fertilizers on growth and yield of Pigeonpea (*Cajanus cajan* L)” was carried out on well-prepared sandy clay loam soil and a RBD design with a factorial concept was used. The experiment consisted of four levels of phosphorus viz., Control (P_0), 40 kg P_2O_5 ha⁻¹ (P_1), 50 kg P_2O_5 ha⁻¹ (P_2) and 60 kg P_2O_5 ha⁻¹ (P_3) and three biofertilizer viz., No inoculation (BF_0), Rhizobium @ 10 gm/kg seed (BF_1) and PSB @ 10 gm/kg seed (BF_2). Studies on the estimation of soil reaction (pH), electrical conductivity (EC), Organic carbon, and available nutrients, such as nitrogen, phosphorus, and potassium (NPK), were carefully conducted.

The application of phosphorus at 60 kg P_2O_5 ha⁻¹ consistently demonstrated significant positive effects on the growth, yield attributes, and productivity of pigeon pea. This level of phosphorus led to the highest plant height across all growth stages (40, 80, and 120 DAS), the maximum number of branches and root nodules per plant, and the most favourable yield components, including pods per plant, seeds per pod, and 1000-grain weight. Consequently, it resulted in the highest grain and stover yields, along with improved harvest index and protein content. Economically, the 60 kg P_2O_5 ha⁻¹ treatment yielded the greatest gross monetary return (GMR), net monetary return (NMR), and benefit-cost (B:C) ratio, underscoring its agronomic and financial viability for pigeon pea cultivation.

Similarly, the use of biofertilizer BF_2 (PSB @ 10 g/kg seed) significantly enhanced plant growth and yield parameters. This treatment promoted better plant height and branching, and achieved higher grain and stover yields compared to other biofertilizer treatments. Although Rhizobium @ 10 g/kg seed recorded a slightly higher harvest index and protein content, BF_2 was superior in overall yield performance. In terms of economics, Rhizobium inoculation resulted in higher GMR, NMR, and B:C ratio, indicating its potential for cost-effective cultivation. Thus, the integrated use of phosphorus at 60 kg P_2O_5 ha⁻¹ and biofertilizer seed treatment, particularly PSB or Rhizobium, can be recommended for optimising growth, yield, and profitability in pigeon pea production. Therefore, phosphorus @ 60 kg/ha and biofertilizer BF_2 (PSB @ 10 g/kg seed) should be opted for to achieve a higher production of pigeon pea crop in the existing agroclimatic conditions of Balaghat.

Keywords: Organic, Branches, Bio-fertilizers, Grains, Pod, Seed index, Stover yield

Introduction

Pigeon pea (*Cajanus cajan* L.) is the world's most widely cultivated pulse crop providing adequate protein for more than million peoples in the world. After chickpea, pigeon pea is the second most important pulse crop in India. Pigeon pea has a high nutritional value because of its 22.3% Protein, 1.7% Fat, 3.5% Minerals, 1.5% Fiber and 57.6% Carbohydrate content. Apart from cooked preparations, fresh pigeon peas can also be served in salads as a diet food or can be eaten raw. Pigeon pea is one of the important pulse crop which ranks sixth in terms of area and production in the world as compared to other legumes such as beans, chickpeas and it is consumed in different ways than others.

Globally, pigeon pea covers an area of 6.02 million hectares with the production of 5.32 million tonnes and the productivity of 883 kg/ha (FAO, 2022) [1]. In India, pigeon pea is grown over an area of about 4.06 million hectares with the production of 3.31 million tonnes and productivity of 814 kg/ha. Total area coverage under pigeon pea in Uttar Pradesh is 0.35 million hectares with the production of 0.36 million tonnes and the productivity of 1039 kg/ha (GOI, 2022) [2]. In early growth stage, plants may show very poor growth and exhibit nutritional disorder that make leaves and stems to change their colour. Poor plant growth and the nutritional disorder is caused by nitrogen deficiency. For that reason, plant cannot easily utilize soil nitrogen under low temperature conditions. On the other hand, it is considered that nitrogen deficiency is related to the poor nodule formation and low nitrogen fixation activity of the rhizobia in the nodules. Here, Bio-fertilizers are known to play an important role in increasing availability of nitrogen and phosphorus besides improving biological fixation of atmospheric nitrogen and enhance phosphorus availability to crop. Therefore, introduction of efficient biofertilizers such as Rhizobium, PSB through doing seed inoculation with them, may help in boosting up of production and consequently more nitrogen fixation for the crop in the soil which

is poor in nitrogen. Being a legume crop, major portion of nitrogen requirement of the crop is met through biological nitrogen fixation (Khajuria *et al.*, 2023) [3].

The main cause of this crop's low yield is insufficient and uneven fertilization, which has a negative impact on plant and soil health in addition to decreasing productivity. Because of this imbalance, shoot growth may be inhibited, resulting in dull or dark leaves. Applying fertilizers in sufficient amounts—especially phosphorus—is essential to resolving these problems. An essential plant nutrient and a crucial component of crop production is phosphorus.

Because it aids in root development, contributes to the production of phosphates and phosphoproteins, and is involved in energy-fixing and -releasing activities in plants, phosphorus is a crucial mineral element for grain legumes. Ade *et al.* (2018) [4] observed that pigeon peas responded significantly to phosphate supplementation. In the majority of Indian soils, it is often a major limiting nutrient for plant growth. The recovery efficiency of phosphorus in crops is typically 10–30% because only a portion of the phosphorus added by fertilizers is used by the plants and a significant portion is transformed into insoluble fixed forms.

Phosphorus is an important mineral element for grain legumes as it helps in root development, participates in the synthesis of phosphates and phosphoproteins and takes part in energy-fixing and releasing processes in plants. The significant response of pigeon pea to phosphate nutrition has been reported by Ade *et al.* (2018) [4]. It is frequently a major limiting nutrient for plant growth in most Indian soils. Only a part of the phosphorus supplemented through fertilizers is utilized by the plants and a large portion of it is converted into insoluble fixed forms, the recovery efficiency of phosphorus in crops of is generally 10–30%. Phosphorus plays a vital role in photosynthesis, respiration, energy storage, energy transfer, cell division cell elongation and several other processes within plant system (Rakshit *et al.*, 2015) [5].

Phosphorus is a vital nutrient for pulse crops, playing a critical role in enhancing seed germination, cell division, flowering, fruiting, and the synthesis of essential compounds such as fats and starch. It supports numerous biochemical activities within the plant. Additionally, phosphorus promotes root proliferation and nodulation, which are crucial for nutrient uptake and biological nitrogen fixation. The improved yield observed in pulse crops can be attributed to phosphorus's influence on root development, energy transformation, and metabolic processes. These effects collectively lead to an efficient translocation of photosynthates towards sink development, ultimately contributing to higher crop productivity (Singh *et al.*, 2012) [6]. Phosphorus has novel function of special importance in the process of energy storage and transfer. Response of phosphorus in pigeonpea has been reported by many researchers (Kumar *et al.*, 2006; Singh *et al.*, 2008) [7, 8].

In India's sustainable agriculture system, bio-fertilizers—a part of integrated nutrient management—are regarded as an economical, environmentally benign, and renewable source of non-bulky, inexpensive plant nutrient augmenting fertilizers. Therefore, given the current high cost of chemical fertilizers, the role of biofertilizers takes a unique significance. The purpose of inoculating pulse seeds with phosphate-soluble bacteria and Rhizobium is to increase the quantity of these bacteria in the rhizosphere and significantly enhance the availability of N and P for plant growth.

Bio-fertilizers, a component of integrated nutrient management and are considered to be cost effective, eco-friendly and renewable source of non-bulky, low cost plant nutrient supplementing fertilizers in sustainable agriculture system in India. Therefore, the role of bio-fertilizers assumes a special significance in present context of very high costs of chemical fertilizers. The seed of pulses are inoculated with Rhizobium and Phosphate solubilizing bacteria with an objective of increasing their number in the rhizosphere and substantial increase in the N and P availability for the plant growth. Rhizobium belongs to family Rhizobiaceae and is symbiotic in nature. It is a gram negative and motile bacterium with nonsporulating rods. Rhizobium incorporated in plant rhizosphere through seed treatment probably induced

more amount of nitrogen fixation in nodules of plants and solubilisation of fixed nitrogen from non-available to the exchangeable pool which imparts more vegetative growth (Khajuria *et al.*, 2023) [3]

Materials and Methods

The experiment was carried out at the Research farm of the Department of Agronomy, School of Agriculture Science, Technology & Research, Sardar Patel University, Balaghat (M.P.). The experiment was conducted in a randomised complete block design, factorial concept with three replications. Different phosphorus levels and biofertilizers will be allocated to the plots according to the treatments. The seed rate used as 20 kg/ha for sowing with 60.0 x 20.0 cm row-to-row and plant-to-plant distance.

The experiment involved twelve treatment combinations to evaluate the effects of varying phosphorus levels and seed inoculations with biofertilizers on crop performance. The treatments included: T1 – control with no phosphorus and no inoculation (P_0 BF₀), T2 – control with Rhizobium @ 10 g/kg seed (P_0 BF₁), and T3 – control with Phosphate Solubilizing Bacteria (PSB) @ 10 g/kg seed (P_0 BF₂). At 40 kg P_2O_5 /ha, treatments included T4 – without inoculation (P_1 BF₀), T5 – with Rhizobium (P_1 BF₁), and T6 – with PSB (P_1 BF₂). At 50 kg P_2O_5 /ha, the treatments were T7 – without inoculation (P_2 BF₀), T8 – with Rhizobium (P_2 BF₁), and T9 – with PSB (P_2 BF₂). At the highest level, 60 kg P_2O_5 /ha, the treatments included T10 – without inoculation (P_3 BF₀), T11 – with Rhizobium (P_3 BF₁), and T12 – with PSB (P_3 BF₂). This structured design enabled the assessment of the individual and combined effects of phosphorus and biofertilizer treatments on plant growth, nutrient uptake, and yield. The gross and net plot size was 5.00 m x 3.00 m and 4.50 m x 2.10 m, respectively. The fertiliser grades were applied as per the treatments. All the other agronomic practices were applied uniformly to all the treatments. The experiment will consist of the following factors along with their respective levels.

Results and Discussion

Phosphorus is a key macronutrient essential for vital physiological processes in plants, including energy transfer (ATP), cell division, and early root development (Mengel *et al.*, 2001) [9]. In the present study, increasing phosphorus levels from 0 to 60 kg P_2O_5 /ha significantly enhanced the growth of pigeonpea (*Cajanus cajan*), as evident in parameters such as plant height, number of branches, and overall plant vigour. Plants under the control treatment (P_0) showed restricted growth due to phosphorus deficiency, which limited root proliferation and nutrient absorption (Hinsinger, 2001) [10]. Higher phosphorus levels, particularly at 60 kg P_2O_5 /ha (P_3), resulted in robust vegetative growth due to improved root activity and nutrient uptake, confirming the findings of Singh *et al.* (2012) [11] and Fageria *et al.* (2011) [12], who reported similar growth enhancement in legumes under adequate phosphorus supply.

Phosphorus application significantly influenced the yield and its components in pigeonpea, including pods per plant, seeds per pod, and 100-seed weight. These improvements are attributed to phosphorus's critical role in enzyme activation and energy metabolism during the reproductive stages (Fageria *et al.*, 2011) [12]. The highest yield was obtained with the application of 60 kg P_2O_5 /ha, indicating that sufficient phosphorus availability enhances flowering, pod setting, and grain filling. Lower phosphorus levels led to poor yield performance due to impaired nutrient use efficiency (Tiwari *et al.*, 2014) [13]. These results are supported by Singh *et al.* (2012) [11], who found a direct relationship between increasing phosphorus rates and higher grain yield in pigeonpea, making phosphorus management an essential factor in sustainable legume production.

Phosphorus plays a vital role in protein synthesis by enhancing nitrogen assimilation and supporting various biochemical pathways (Fageria *et al.*, 2011) [12]. In pigeonpea, seed protein content increased steadily with higher phosphorus levels, with the highest protein concentration recorded at 60 kg P_2O_5 /ha. This is due to improved nitrogen fixation and efficient nutrient uptake, which are facilitated

by better root development under phosphorus-rich conditions (Singh *et al.*, 2012) [11]. Tiwari *et al.* (2014) [13] also reported that phosphorus promotes enzymatic and metabolic activities necessary for amino acid and protein formation in legumes. Therefore, adequate phosphorus not only boosts productivity but also improves the nutritional quality of pigeonpea seeds.

Biofertilizers such as *Rhizobium* and *Phosphate Solubilizing Bacteria* (PSB) have proven beneficial in improving pigeonpea growth and yield by enhancing nutrient availability. *Rhizobium* aids in atmospheric nitrogen fixation, supplying an essential nutrient for plant growth, while PSB increases the bioavailability of phosphorus in the rhizosphere by solubilizing bound phosphate (Gaur, 1990; Kumar *et al.*, 2013) [14, 15]. Application of these biofertilizers resulted in better plant height, branching, and yield parameters when compared to uninoculated controls. Singh *et al.* (2014) [16] found that biofertilizer-inoculated pigeonpea exhibited significantly higher biomass and grain yield. Additionally, Bhattacharyya *et al.* (2012) [17] reported synergistic effects when biofertilizers were combined with chemical phosphorus, highlighting their potential in sustainable nutrient management.

The use of *Rhizobium* and PSB also positively influenced the protein content of pigeonpea seeds. *Rhizobium* increased nitrogen availability through fixation, promoting greater protein synthesis, while PSB enhanced phosphorus-mediated metabolic functions critical to amino acid formation (Kumar *et al.*, 2013) [15]. The combined inoculation significantly improved seed protein levels over the control, corroborating findings by Singh *et al.* (2014) [16] and Bhattacharyya *et al.* (2012) [17]. Economically, biofertilizers offer cost-effective solutions by reducing the dependency on expensive chemical fertilizers. According to Tiwari *et al.* (2014) [13], phosphorus application, especially in combination with biofertilizers, improved net returns and benefit-cost ratios in pigeonpea farming. Hence, the integration of biofertilizers not only supports yield and protein enhancement but

also contributes to sustainable and profitable cultivation practices (Singh *et al.*, 2016) [18].

Conclusion

The application of phosphorus at 60 kg P₂O₅ ha⁻¹ consistently demonstrated significant positive effects on the growth, yield attributes, and productivity of pigeon pea. This level of phosphorus led to the highest plant height across all growth stages (40, 80, and 120 DAS), the maximum number of branches and root nodules per plant, and the most favorable yield components including pods per plant, seeds per pod, and 1000-grain weight. Consequently, it resulted in the highest grain and stover yields, along with improved harvest index and protein content. Economically, the 60 kg P₂O₅ ha⁻¹ treatment yielded the greatest gross monetary return (GMR), net monetary return (NMR), and benefit-cost (B:C) ratio, underscoring its agronomic and financial viability for pigeon pea cultivation.

Similarly, the use of biofertilizer BF₂ (PSB @ 10 g/kg seed) significantly enhanced plant growth and yield parameters. This treatment promoted better plant height and branching, and achieved higher grain and stover yields compared to other biofertilizer treatments. Although *Rhizobium* @ 10 g/kg seed recorded a slightly higher harvest index and protein content, BF₂ was superior in overall yield performance. In terms of economics, *Rhizobium* inoculation resulted in higher GMR, NMR, and B:C ratio, indicating its potential for cost-effective cultivation. Thus, the integrated use of phosphorus at 60 kg P₂O₅ ha⁻¹ and biofertilizer seed treatment, particularly PSB or *Rhizobium*, can be recommended for optimising growth, yield, and profitability in pigeon pea production.

Therefore, phosphorus @ 60 kg/ha and biofertilizer BF₂ (PSB @ 10 g/kg seed) should be opted for to achieve a higher production of pigeon pea crop in the existing agroclimatic conditions of Balaghat.

Table 1. Response of phosphorus levels and bio-fertilizers on growth and yield of Pigeonpea

Treatment	Plant height (cm)	Branches/plant	Root nodules/plant	Pods/plant	Seeds/pod	1000-seed wt. (g)	Seed yield/plant (g)	Seed yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)	Protein (%)	B:C ratio
P ₀ BF ₀	114.63	15.34	15.88	153.24	2.73	92.9	10.58	983.67	3335.78	20.8	15.9	1.04
P ₀ BF ₁	124.22	16.87	19.73	164.5	3.47	96.63	9.87	889.88	3861.13	22.78	15.09	1.1
P ₀ BF ₂	124.61	17.93	22.2	164.8	3.33	96.4	12.2	1082.51	3878.25	21.04	16.4	1.02
P ₁ BF ₀	125.44	18.13	23.87	168.77	3.53	97.21	12.68	1295.6	3905.57	23.68	17.21	1.26
P ₁ BF ₁	126.92	18.33	25.87	171.26	3.73	97.35	14.04	1182.2	4175.71	25.79	17.35	1.32
P ₁ BF ₂	139.73	17.73	22	170.16	3.73	96.94	13.69	1462.23	4204.88	23.21	16.94	1.25
P ₂ BF ₀	135.88	19.87	27.47	182.13	3.93	97.78	17.45	1523.34	4247.93	26.33	17.78	1.42
P ₂ BF ₁	143.61	19.27	25.67	181.46	4.2	98.79	17.01	1392.93	4261.12	26.24	18.79	1.45
P ₂ BF ₂	136.56	18.2	27.07	184.86	4.27	97.68	16.92	1533.74	4306.64	24.7	18.89	1.39
P ₃ BF ₀	150.64	20.93	30	185.53	4.07	99.37	18.19	1959.62	4144.46	30.72	19.13	1.5
P ₃ BF ₁	151.32	18.67	28.82	189.4	5.2	100.91	19.47	1686.21	4418.07	30.49	20.86	1.52
P ₃ BF ₂	146.74	19.49	29.24	189.26	4.33	98.87	19.53	1987.34	4528.14	27.97	20.29	1.47
SEm± (P)	1.2	0.25	0.49	0.49	0.1	0.47	0.45	28.88	22.16	0.17	0.46	0.03
CD (P = 0.05) (P)	3.53	0.74	1.45	1.44	0.28	1.39	1.31	84.69	65.01	0.5	1.35	0.09

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