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Effects of phosphorus rich organic manure (PROM) on growth and yield of soybean in calcareous soil

Abstract. The phosphorus fixation and its availability are a major challenge not only in alkaline or calcareous soil but also in acidic soil. The stress of nutrient availability from soil is a major challenge for more phosphorus demanding leguminous crops like soybean. Using organic manure and rock phosphate in presence of phosphorus solubilising bacteria (PSB) plays a vital role not only by enhancing phosphorus availability but also by reducing stress of other nutrients too. The purpose of this study was to evaluate the impact of various phosphorus sources, including organic and inorganic inputs, on the growth parameters and productivity of soybean cultivated in calcareous soil conditions. The study found that applying 75% or 100% P_2O_5 through phosphorus rich organic manure or 100% via vermicompost significantly improved soybean growth, with larger leaves and plant height at days 28 and 56 after sowing. Phosphorus rich organic manure amendment for 100% P_2O_5 also resulted in the largest leaf area per plant (1,657.26 cm^2), leaf area index (7.37), and total chlorophyll content (1.23 $mg\ g^{-1}$). Additionally, 100% P_2O_5 through phosphorus rich organic manure led to significantly more pods per plant (46.33), seeds per pod (3.00), and seeds per plant (150.27). Subsequently, significantly higher grain (25.94 $q\ ha^{-1}$) and straw (35.16 $q\ ha^{-1}$) yield of soybean was achieved with the application of 100% P_2O_5 via phosphorus rich organic manure and which was followed by incorporation of 75% P_2O_5 via phosphorus rich organic manure or 100% P_2O_5 through vermicompost. Hence this could be a sustainable way of producing P-rich organic manure to

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improve the growth and yield attributes of soybean. The findings of this study can be beneficial to soil scientists, agronomist, farmers and agricultural enterprises working involved in legume production and other phosphorus demanding crops

Keywords: phosphorus organic sources; phosphorus inorganic sources; diammonium phosphate; single super phosphate; vermicompost

INTRODUCTION

Phosphorus is a major nutrient involved in energy translocation, root development, and flower initiation. It is taken up by plants in two forms – HPO_4^{2-} and H_2PO_4^- . Phosphorus affects plant metabolic processes like photosynthesis, translocation, transpiration, and storage of energy in the form of adenosine triphosphate and adenosine diphosphate.

Phosphorus (P) availability in Indian soils is limited, particularly in alkaline and acidic soils, where P fixation occurs. Only 15-20% of applied P is used by crops in the first year, with the rest contributing to the residual P pool (Nakeertha et al., 2023). Different forms of aluminium, iron, magnesium, and calcium bind the available P, which makes it unavailable to plants. P deficiency is most prevalent in soil types that are characterised by high levels of withering, calcareousness, and alkalinity. The economic and ecological viability of attempts at reclamation through the utilisation of phosphatic fertilisers is questionable, considering that the efficiency of these fertilisers when incorporated is remarkably poor. In highly calcareous soils, phosphorus availability is further restricted due to the development of insoluble calcium phosphate compounds, which reduce the nutrient's uptake by plants. The process of phosphate solubilisation, which is accompanied by the production of organic acids and acid phosphatases, is of paramount importance in the mineralisation of organic phosphorus in soil. The utilisation of rock phosphate, in conjunction with manure and phosphate-solubilising bacteria, has been demonstrated to ensure consistent performance. The application of these bacteria has been shown to enhance plant growth-promoting rhizobacteria (PGPR) activities, thereby strengthening resistance against disease pathogens. Phosphate solubilising bacteria like *Bacillus subtilis* and *Bacillus megaterium* play a crucial role in solubilising

the insoluble forms of phosphorus into soluble or plant available form (Khan et al., 2021). Recent studies by K. Sadvakasov & Ye. Islamov (2023) also highlighted the potential of *Bacillus subtilis* in microbial biotechnology, particularly its effective growth on alternative microbial substrates, which supports its application in sustainable agriculture.

Phosphorus-rich organic manure (PROM) offers a sustainable solution for enhancing the P use efficiency (PUE) in calcareous soils. PROM is created by enriching compost or farmyard manure (FYM) with rock phosphate and inoculating it with phosphate-solubilising microorganisms. The gradual mineralisation of organic P provides a slow-release, plant-available source of phosphorus. The Ministry of Agriculture (India) approved the use of PROM, recognising its potential to improve soil fertility and nutrient uptake in challenging soil conditions (Measures..., 2024). Recent studies suggest that applying PROM can markedly increase soybean growth and yield. Application of NPKM (30% nitrogen, phosphorus, and potassium + 70% manure) resulted in greater rice yields, PUE, P uptake, and overall balance (Hayatu et al., 2023). M. Ahmad et al. (2022) concluded that addition of 90 kg of P_2O_5 as single super phosphate or 100% acidulated rock phosphate was found superior for wheat yield and phosphorus nutrition compared to other mineral sources and control.

PROM is also gaining attention due to its ability to address P lockout issues in both alkaline and calcareous soils, making it a promising approach for improving crop productivity and soil health. Overall, the use of PROM, integrated with other nutrient management practices, can markedly improve phosphorus availability and soybean yields in highly calcareous soils. An investigation was performed to assess the growth and yield of soybean grown in highly calcareous

with application various sources of phosphorus. K. Noor *et al.* (2020) also concluded that the application of integrated use of organic manures resulted in a significant increase in yield components and maize yield, attributable to the incorporation of inorganic phosphorus sources, such as rock phosphate. The release of phosphorus from rock phosphate was found to be greater in combination with manure.

Therefore, the purpose of the present study was to explore the comparative effectiveness of PROM, vermicompost, and inorganic phosphorus sources in improving phosphorus availability, enhancing plant physiological traits, and increasing the productivity of soybean under the constraints of highly calcareous soil conditions.

MATERIALS AND METHODS

The experiment was conducted during kharif-2023 on alkaline (pH 8.18) and highly calcareous soil (12.47% CaCO₃) at the Post Graduate Research Farm, College of Agriculture, Pune. The soil, classified as Inceptisol (*Vertic Haplustepts* family), was medium-deep black, 70-80 cm deep, and dominated by smectite clay. Initial soil testing revealed a low organic carbon content (0.62%), with available nitrogen, phosphorus, and

potassium levels at 113.50 kg ha⁻¹, 10.79 kg ha⁻¹, and 536 kg ha⁻¹, respectively. The diethylene tri-amine penta acetic acid (DTPA)-extractable micronutrients were also measured, showing 1.18 mg kg⁻¹ Fe, 3.08 mg kg⁻¹ Mn, 2.28 mg kg⁻¹ Zn, and 2.24 mg kg⁻¹ Cu. PROM was prepared by using partially decomposed compost of soybean waste at 1,000 kg in high density polyethylene bags. Subsequently, phosphorus solubilising bacteria in liquid form at 2 lit t⁻¹ of partially decomposed compost was thoroughly mixed and allowed to incubate for 72 hours (Plate-1). Rock phosphate in powder form (size < 0.5mm) at 250 kg per tonne of partially decomposed compost of soybean waste was thoroughly mixed. Total 5-6 turnings at an interval of 15 days were carried out and moisture level was maintained at 40-45%. After 75-80 days, phosphorus rich organic manure was found ready and representative sampling was performed accordingly to assess nutrient status. Vermicompost was also prepared by using partially decomposed compost of soybean straw along with *Eisenia fetida* earthworm species in high-density polyethylene polybags. The composite sample of vermicompost and FYM were analysed for nutrient status (Table 1).

Table 1. Proximate analysis of PROM, FYM, and vermicompost

Seq. No.	Parameter	Unit	PROM	FYM	Vermicompost
1	pH (1: 10)	–	7.18	7.49	6.91
2	EC	(dSm ⁻¹)	1.74	1.66	2.12
3	Moisture	(%)	24.02	23.5	25.45
4	Organic Carbon	(%)	21.06	22.26	30.79
5	Total N	(%)	0.78	0.69	1.48
6	Total P	(%)	14.57	0.39	0.79
7	Total K	(%)	0.37	0.38	0.81
8	Total Fe	(ppm)	10,550	186	388
9	Total Mn	(ppm)	600	35.7	65.7
10	Total Zn	(ppm)	125	14.8	18.3
11	Total Cu	(ppm)	30	4.39	15.2
12	Total Ca	%	13.63	–	–
13	Total Mg	%	0.52	–	–
14	Total B	(ppm)	30	–	–
15	C:N ratio	–	24:1	39:1	20:1
16	C:P ratio	–	1.44:1	57.07:1	38.97:1

Source: compiled by the authors

The soybean variety 'KDS-726' (*Phule Sangam*) was used as the investigated crop for the experiment. PROM was formulated at the Vermicompost Yard, Division of Soil Science, College of Agriculture, Pune. The recommended fertiliser dose (50:75:45 kg ha⁻¹ of N, P₂O₅, and K₂O) was applied, except for the control plots. Phosphorus was provided from various sources, including PROM and vermicompost as organic sources, and Diammonium Phosphate (DAP) and Single Super Phosphate (SSP) as inorganic sources. Nitrogen and potassium were supplied through urea and muriate of potash, respectively. PROM, FYM, and vermicompost were applied at the time of sowing, and their proximate analysis was conducted before the experiment (Table 1).

P-rich organic manure and vermicompost were analysed for total nitrogen (N) by H₂SO₄ along with digestion mixture (K₂SO₄:CuSO₄ in 10:1 ratio) using macro-Kjeldhal method (Herlich, 1990), while phosphorus (P), potassium and other micronutrients were estimated by digesting 1 g dry manure sample with 10 mL tri-acid mixture (9:3:1 HNO₃:HClO₄: H₂SO₄) at 180-200°C. The P content in the acid digest was determined by means of the vanadomolybdate-phosphate yellow colour method, utilising a spectrophotometer. Meanwhile, the K content was determined by means of a flame photometer. A randomised block design (RBD) with analysis of variance (ANOVA) was employed to assess treatment effects on all studied characteristics (Panse & Sukhatme, 1985). All experimental procedures involving plants were conducted following institutional, national, and international ethical standards. No endangered or protected plant species were used in the study (Statement..., 2025).

RESULTS AND DISCUSSIONS

Effects of various sources and levels of phosphorus on growth of soybean in calcareous soil

The findings showed that periodical number of leaves and plant height (28 and 56 days after sowing (DAS)) of soybean grown in calcareous soil were significantly influenced by phosphorus application through PROM, vermicompost, and phosphatic fertilisers (Table 2, Figs. 1-2). The count of leaves on soybean plants at 28 and 56 DAS, as influenced by phosphorus application via PROM, vermicompost, and phosphatic fertilisers, ranged within 4.81-5.80 and 13.58-19.80, respectively. However, the plant height ranged within 14.40-19.80 cm on 28 DAS and 45.87-53.20 cm on 56 DAS. Application of 100% P₂O₅ through PROM (5.80), 75% P₂O₅ through PROM (5.80), 100% P₂O₅ through vermicompost (5.60), 100% P₂O₅ through DAP (5.47), and 50% P₂O₅ through PROM (5.47) were found significantly superior over 100% P₂O₅ through SSP (5.20), RDF (5.13), and control (4.81) on 28 DAS. Furthermore, these superior treatments were found to be statistically on par with each other. Significantly greater number of leaves (19.80) on 56 DAS was reported with application of 100% P₂O₅ through PROM, which was found to be statistically on par with rest of treatments except absolute control (13.58). Addition of 100% P₂O₅ through PROM yielded significantly greater (19.80 cm) plant height, which was found to be statistically on par with all the treatments under study except RDF and control. However, remaining treatments comprising phosphorus application either at 50% or 75% or yet 100% through either PROM, DAP, SSP, or vermicompost yielded statistically on-par results in terms of plant height of soybean. Analogous findings for plant height were reported on 56 DAS for soybean.

Table 2. Effects of phosphorus through PROM and phosphatic fertilisers on morphological features of soybean in calcareous soil

Seq. No.	Treatment	Count of leaves		Plant height (cm)	
		28 DAS	56 DAS	28 DAS	56 DAS
1	Absolute Control	4.81	13.58	14.40	45.87
2	RDF (NPK)	5.13	16.20	18.07	46.00
3	50% P ₂ O ₅ : PROM	5.47	18.33	18.87	47.20
4	75% P ₂ O ₅ : PROM	5.80	19.47	19.60	51.00
5	100% P ₂ O ₅ : PROM	5.80	19.80	19.80	53.20

Table 2, Continued

Seq. No.	Treatment	Count of leaves		Plant height (cm)	
		28 DAS	56 DAS	28 DAS	56 DAS
6	100% P ₂ O ₅ : DAP	5.47	18.60	19.40	47.93
7	100% P ₂ O ₅ : SSP	5.20	17.33	18.40	46.07
8	100% P ₂ O ₅ : Vermicompost	5.60	18.93	19.53	48.87
	SE+	0.15	1.01	0.22	1.95
	CD at 5%	0.44	3.05	0.67	5.91

Note: SE: Standard error, CD at 5% : Critical difference at 5% significance level, Recommended dose of fertilisers (RDF), (N – Nitrogen, P – Phosphorus, and K – Potassium), P-rich organic manure (PROM), Diammonium phosphate (DAP), Single super phosphate (SSP), Days after sowing (DAS)

Source: compiled by the authors

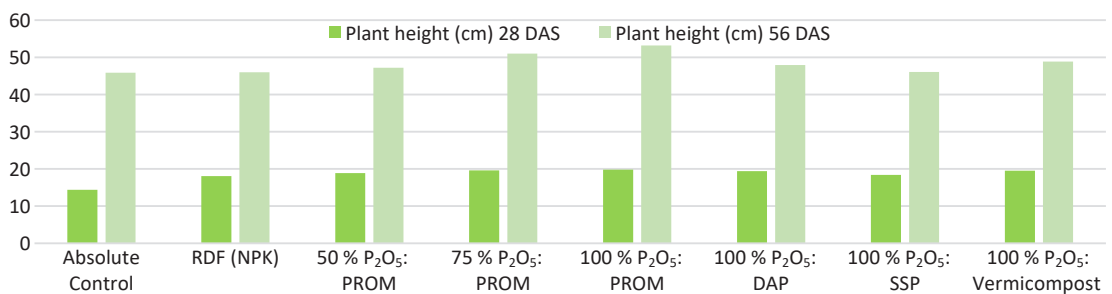


Figure 1. Plant height

Note: RDF: Recommended dose of fertilisers (N – Nitrogen, P – Phosphorus, and K – Potassium), P-rich organic manure (PROM), Diammonium phosphate (DAP), Single super phosphate (SSP), days after sowing (DAS)

Source: compiled by the authors

As for the interactive effects of phosphorus application through PROM and phosphatic fertilisers, data revealed that application of phosphorus at 75% or 100% through PROM and vermicompost or DAP yielded prominently greater number of leaves and plant height in calcareous soil. This might be explained by the application of PROM which might have greater content of available P₂O₅. The PSB present in PROM might have solubilised the unavailable forms of calcium-fixed phosphate by releasing organic acid like gluconic, fumaric, succinic, lactic, and propionic acids, leading to lowering the pH of the rhizosphere, which directly solubilised to available form. R. Boje *et al.* (2024) revealed that the number of pods plant⁻¹, filled pods plant⁻¹, nodulation, protein, and oil content in soybean were greatly improved when 78 kg P₂O₅ ha⁻¹ was applied through SSP: 100 kg ha⁻¹ + PROM: 600 kg ha⁻¹. Same treatment also produced maximum seed yield (22.35 q ha⁻¹),

stover yield (30.52 q ha⁻¹), nutrient content, and uptake in seed and stover by the crop.

Application of phosphorus through SSP + PROM and seed inoculation with *Aspergillus awamori* + *Pseudomonas striata* is a rewarding approach in maximising crop productivity (Yadav *et al.*, 2017). R. Singh *et al.* (2018) also reported that plant height, number of primary and secondary branches per plant, and number of leaves per plant increased significantly with increasing level of phosphorus up to 80 kg ha⁻¹ + PSB. Co-application of residual reactive phosphate rock with *Rhizobium* and soluble P-bacteria reported significantly greater plant height of soybean on 30 and 90 DAS. U. Ade *et al.* (2018) also reported analogous findings. In addition, the provision of phosphorus by PROM is accompanied by the provision of a substantial quantity of nutrients such as N, K, Ca, Mg, and some metallic micronutrients. This results in increased vegetative growth,

as evidenced by an increase in the number of leaves and plant height. It could be summarised that application of phosphorus at the rate

of either 75% or 100% through P-rich organic manure was found superior for the plant height and number of leaves.

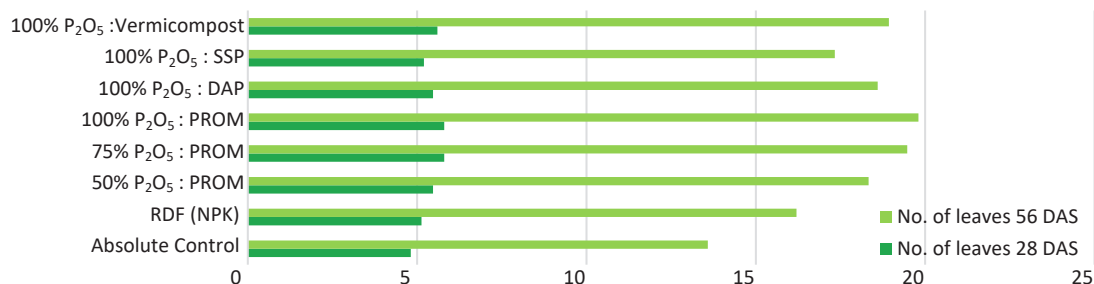


Figure 2. Periodical number of leaves

Note: RDF: Recommended dose of fertilizers (N – Nitrogen, P – Phosphorus and K – Potassium), P-rich organic manure (PROM), Diammonium phosphate (DAP), Single super phosphate (SSP)

Source: compiled by the authors

Leaf area plant⁻¹, leaf area index and total chlorophyll

Leaf area plant⁻¹, leaf area index and total chlorophyll content in soybean grown in calcareous soil was influenced significantly by the application of P₂O₅ through PROM, vermicompost, and phosphatic fertilisers. Application of PROM, vermicompost, and phosphatic fertilisers to soybean in calcareous soil produced varied leaf area plant⁻¹, leaf area index, and chlorophyll, which ranged within 1,040.64-1,657.26 cm², 4.63-7.37, and 0.98-1.23 mg g⁻¹ of fresh tissue, respectively (Table 3; Figs. 3-4). Significantly greater leaf area plant⁻¹ (1,657.26 cm²), leaf area index (7.37), and total chlorophyll (1.23 mg g⁻¹ of fresh tissue) were reported with the addition of 100% P₂O₅: PROM which was followed by 75% P₂O₅: PROM. In case of vermicompost application for the substitution of 100% P₂O₅ reported greater leaf area plant⁻¹ (1,497.36 cm²), leaf area index (6.65), and total chlorophyll (1.12 mg g⁻¹ of fresh tissue) than RDF (1,260.52 cm², 5.60, and 0.99 mg g⁻¹ of fresh tissue). Further application of 100% P₂O₅: DAP

yielded greater leaf area plant⁻¹ (1,461.96 cm²), leaf area index (6.50), and chlorophyll (1.12 mg g⁻¹ of fresh tissue) than 100% P₂O₅ through SSP.

Maximum leaf area, leaf area index, and chlorophyll content were reported with P application through PROM which might be explained by the fact that P-rich manure not only supplies P but also a considerable amount of other nutrients involved in chlorophyll synthesis. K. Boubekri *et al.* (2023) reported analogous findings. The study examined the plant growth-promoting role of phosphorus-solubilising bacteria and associated microbes, hypothesising that these might have synthesised gibberellin, resulting in superior leaf area and leaf area index. Greater photosynthetic rates in PROM phosphorus-supplied treatments are attributed to higher nutrient availability from calcareous soil, which leads to increased leaf area. P. Lokhande *et al.* (2023) also concluded that application of a liquid organic formation like panchagavya increased chlorophyll content due to greater population of photosynthetic bacteria.

Table 3. Effect of PROM and phosphatic fertilisers on leaf area, Leaf area index (LAI), and total chlorophyll of soybean in calcareous soil

Seq. No.	Treatment	Leaf area plant ⁻¹ (cm ²)	Leaf area index	Total Chlorophyll (mg g ⁻¹ of fresh tissue)
1	Absolute Control	1,040.64	4.63	0.92
2	RDF (NPK)	1,260.52	5.60	0.99
3	50% P ₂ O ₅ : PROM	1,437.26	6.39	1.08
4	75% P ₂ O ₅ : PROM	1,624.38	7.22	1.13

Table 3, Continued

Seq. No.	Treatment	Leaf area plant ⁻¹ (cm ²)	Leaf area index	Total Chlorophyll (mg g ⁻¹ of fresh tissue)
5	100% P ₂ O ₅ : PROM	1,657.26	7.37	1.23
6	100% P ₂ O ₅ : DAP	1,461.96	6.50	1.12
7	100% P ₂ O ₅ : SSP	1,358.85	6.04	1.01
8	100% P ₂ O ₅ : Vermicompost	1,497.36	6.65	1.12
	SE+	40.76	0.18	0.09
	CD at 5%	123.63	0.55	0.27

Note: SE : Standard error, CD at 5% : Critical difference at 5% significance level, RDF: Recommended dose of fertilisers (N – Nitrogen, P – Phosphorus, and K – Potassium), P-rich organic manure (PROM), Diammonium phosphate (DAP), Single super phosphate (SSP)

Source: compiled by the authors

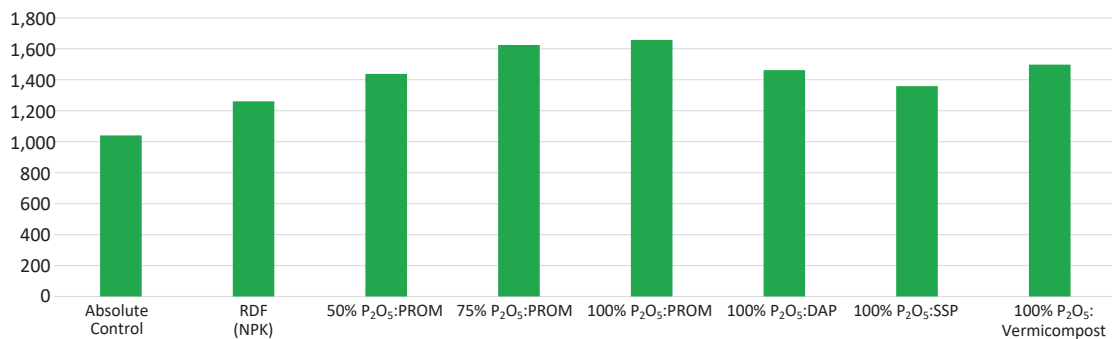


Figure 3. Leaf area per plant (cm²)

Note: RDF: Recommended dose of fertilisers (N – Nitrogen, P – Phosphorus, and K – Potassium), P-rich organic manure (PROM), Diammonium phosphate (DAP), Single super phosphate (SSP)

Source: compiled by the authors

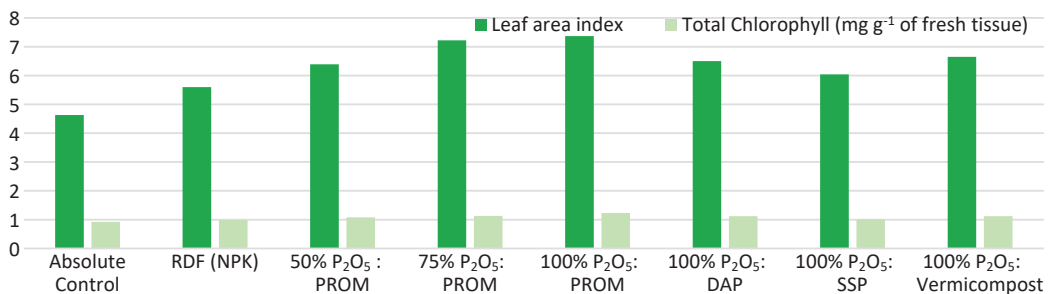


Figure 4. Leaf area index and total chlorophyll

Note: RDF: Recommended dose of fertilisers (N – Nitrogen, P – Phosphorus, and K – Potassium), P-rich organic manure (PROM), Diammonium phosphate (DAP), Single super phosphate (SSP)

Source: compiled by the authors

The organic acids diffused in soil at the time of decomposition of organic matter present in PROM might have reduced P exchange sites through chelation and released more

plant available phosphorus in calcareous soil there by higher root exploration in soil resulted into greater nutrient uptake, as well as greater leaf area, leaf area index, and chlorophyll.

Plant height, chlorophyll, and 100 grain weight of soybean were significantly impacted by different levels of P_2O_5 at 0, 30, 60, and 120 kg ha⁻¹ with broadcast and band application (Moreira et al., 2020). These findings suggest that optimising phosphorus sources and application methods can substantially enhance physiological traits and nutrient uptake efficiency in soybean cultivated under challenging soil conditions.

Effect of various sources and levels of phosphorus on yield characteristics of soybean in calcareous soil

Data presented in Table 4 and Figure 5 present significant variation in the number of pods

plant⁻¹, seeds pod⁻¹, seeds plant⁻¹ of soybean in calcareous soil as influenced by P_2O_5 application through PROM, vermicompost, and phosphatic fertilisers. Significantly greater number of pods plant⁻¹ (46.33), seeds pod⁻¹ (3.00), and seed plant⁻¹ (150.27) were noticed with application of 100% P_2O_5 : PROM which was followed and statistically on par with 75% P_2O_5 : PROM, 100% P_2O_5 vermicompost, and 50% P_2O_5 : PROM. Lower number of pod plant⁻¹, seeds pod⁻¹ and seeds plant⁻¹ were observed in control treatment where no fertilisers were added. Yield characteristics of soybean, particularly in calcareous soil, depends on nutrient availability and soil pH.

Table 4. Effects of PROM and phosphatic fertilisers on yield characteristics of soybean in calcareous soil

Seq. No.	Treatment	Pods per plant	Seeds per pod	Seeds per plant
1	Absolute Control	27.20	2.80	92.33
2	RDF (NPK)	39.80	2.93	132.40
3	50% P_2O_5 : PROM	41.47	2.93	136.27
4	75% P_2O_5 : PROM	45.87	3.00	146.73
5	100% P_2O_5 : PROM	46.33	3.00	150.27
6	100% P_2O_5 : DAP	44.20	2.93	144.27
7	100% P_2O_5 : SSP	40.87	2.93	134.73
8	100% P_2O_5 : Vermicompost	45.67	2.93	145.60
	SE+	1.92	0.03	5.66
	CD at 5%	5.82	0.11	17.17

Note: SE: Standard error, CD at 5%: Critical difference at 5% significance level, RDF: Recommended dose of fertilisers (N – Nitrogen, P – Phosphorus, and K – Potassium), P-rich organic manure (PROM), Diammonium phosphate (DAP), Single super phosphate (SSP)

Source: compiled by the authors

S. Arintonang & L. Sidauruk (2020) reported greater number of branches, pods, and weight of seeds per plant in soybean with vermicompost P application treatment. The researchers further discussed the increased number of pods in soybeans following P-substituted vermicompost treatment. This phenomenon could be attributed to the higher and more available form of nutrients supplied by organic manure. It can be hypothesised that the presence of further organic manure may have resulted in the release of low-molecular-weight organic acids. This, in turn, may have led to an enhancement of N fixation and an increase in N absorption by the leaves. This may have positively influenced Mg absorption from the soil. The addition of further

P-solubilising bacteria to soil through PROM resulted in the enhancement of bacterial population. This is likely to have led to a greater release of plant growth-promoting substances, such as auxins, gibberellins, and cytokines, which may have subsequently resulted in a greater number of pods per plant. These findings are in agreement with the results reported by P. Lokhande et al. (2023). The researchers also reported enhanced leaf area, chlorophyll, and number of pods with the application of vermicompost and organic formulations. Further application of PROM and vermicompost for P substitution stimulates release of microbial origin organic acids dominantly gluconic acid resulted into reduction of soil reaction in rhizosphere which

leads to more availability of P and other nutrients too resulted into more growth and yield contributing characters. A. Bamagoos *et al.* (2021) also reported inoculation of calcareous soil with P-SB (a 1:1 mixture of two *Pseudomonas sp.*; *Ps. mallei* and *Ps. cepaceae*) significantly exceeded leguminous compost, humic acid, or even leguminous compost + humic acid for the positive results obtained. P-SB facilitated nutrient solubility (e.g., N, K, Fe, and Mn), including conversion of insoluble phosphorous into a form available in the tested soil due to increased soil enzymatic activities (e.g., phosphatases and phytases). This mechanism, combined with a decrease in soil calcium carbonate content and an increase in cation exchange capacity (CEC) and organic matter (OM) content, increased the availability of various nutrients to plants, including P, in the soil, which contributed to the increased plant output in case of *Phaseolus vulgaris*.

Yield characteristics of soybean such as the number of pods⁻¹, number of seeds pod⁻¹, and number of seeds plant⁻¹ were on par for P₂O₅ application either with SSP or DAP. However, a

greater count of pods plant⁻¹, seeds pod⁻¹, and seeds plant⁻¹ were observed with P₂O₅ application through DAP. This could be attributed to a better fixation of P applied through SSP as compared to DAP. These findings agree with those reported by A. Jamal *et al.* (2023). The researchers reported that most of the applied P fertiliser was found to be fixed to the surfaces of calcite, thereby becoming unavailable in the rhizosphere. Further abundance of CaCO₃ along with alkaline pH lowers solubility and availability of P in rhizosphere (Aswitha *et al.*, 2024). Neutralisation of CaCO₃ content due to organic acid release resulted into lowering the pH causes release of available nutrients in rhizosphere. M. Khan *et al.* (2021) concluded that combined application of rock phosphate, poultry manure, and *Bacillus Spp.* MN-54 showed most effective for increasing shoot and root length to the tune of 37.5% and 42.6% in chickpea. The researchers explained that incorporation of manure along with *Bacillus Spp.* MN-54 helped to improve nutritional status and availability of nutrients by supplying macro and micronutrients leads to greater number of pods in chickpea.

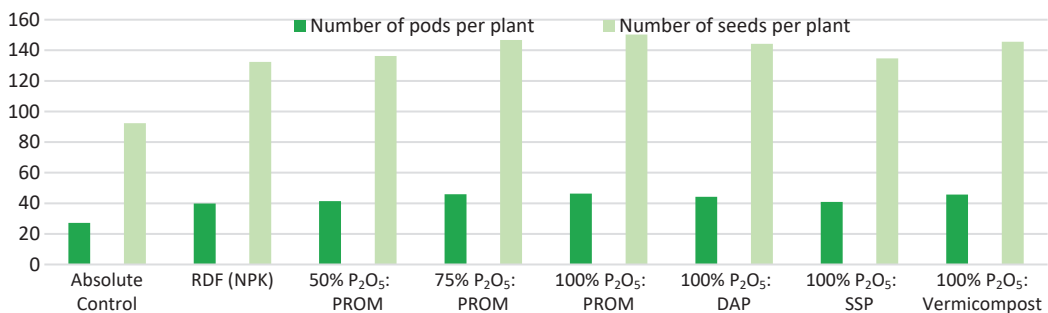


Figure 5. Soybean yield characteristics

Note: RDF: Recommended dose of fertilisers (N – Nitrogen, P – Phosphorus, and K – Potassium), P-rich organic manure (PROM), Diammonium phosphate (DAP), Single super phosphate (SSP)

Source: compiled by the authors

Effect of various sources and levels of phosphorus on grain and straw yield of soybean in calcareous soil

Grain and straw yield of soybean grown on highly calcareous soil, as influenced by levels of P₂O₅ incorporation through PROM, vermicompost, SSP, and DAP, were noted at the harvest stage of soybean. Application of P₂O₅ through various organic and inorganic sources significantly

influenced grain and straw yield of soybean (Table 5; Fig. 6). Data indicated that grain yield of soybean ranged within 19.38-25.94 q ha⁻¹ while straw yield – within 26.33-35.16 q ha⁻¹ in various treatments of phosphorus application. Significantly greater grain (25.94 q ha⁻¹) and straw (35.16 q ha⁻¹) yield of soybean was observed with 100% P₂O₅ application through PROM and this treatment was followed by and statistically on

par with 75% P₂O₅ (25.00 and 32.66 q ha⁻¹), 100% P₂O₅ vermicompost (24.69 and 32.00 q ha⁻¹) and 100% P₂O₅ through DAP (24.38 and 31.66 q ha⁻¹). Use of either 75% or 100% P₂O₅ through PROM

and 100% P₂O₅ through vermicompost resulted in almost 27-33% increase over control while 17% over RDF for grain yield of soybean grown in highly calcareous soil.

Table 5. Effect of PROM and phosphatic fertilisers on grain and straw yield of soybean in calcareous soil

Sr. No.	Treatment	Yield (q ha ⁻¹)	
		Grain	Straw
1	Absolute Control	19.38	26.33
2	RDF (NPK)	22.13	26.91
3	50% P ₂ O ₅ ; PROM	23.75	28.25
4	75% P ₂ O ₅ ; PROM	25.00	32.66
5	100% P ₂ O ₅ ; PROM	25.94	35.16
6	100% P ₂ O ₅ ; DAP	24.38	31.66
7	100% P ₂ O ₅ ; SSP	22.44	27.83
8	100% P ₂ O ₅ ; Vermicompost	24.69	32.00
	SE+	0.69	1.06
	CD at 5%	2.01	3.22

Note: SE: Standard error, CD at 5%: Critical difference at 5% significance level, RDF: Recommended dose of fertilisers (N – Nitrogen, P – Phosphorus, and K – Potassium), P-rich organic manure (PROM), Diammonium phosphate (DAP), Single super phosphate (SSP)

Source: compiled by the authors

The presence of calcium carbonate (CaCO₃) in soil, when the pH is alkaline, can restrict the availability of phosphorus, iron, zinc, and potassium. Subsequently, the added phosphatic fertiliser is rapidly transformed into an unavailable form, which has the effect of reducing the plant's usable form of P in the rhizosphere. Phosphorus-enriched compost incorporated for soybean in highly calcareous soil produced higher yield which might be attributed to a greater availability of P and other nutrients in soil. Among inorganic fertilisers, 100% P₂O₅ through SSP application produced lower yield (22.44 q ha⁻¹) than that of DAP (24.38 q ha⁻¹). Single super phosphate is a calcium phosphate that is applied in soil with a high calcium carbonate content and an alkaline pH. This may result in the restriction of solubilisation of phosphorus, which is rapidly converted into insoluble complexes of tricalcium phosphate.

The organic acids like fumaric, succinic, formic, propionic, gluconic, etc., released under the application of PROM via phosphate solubilising bacteria and decomposition of organic manure, resulted in lowering the soil pH near rhizosphere, leading to the conversion of insoluble phosphorus into soluble form. In addition,

these phenomena have been demonstrated to accelerate mineralisation rates, not only for P, but also for micronutrients. The further plant growth-promoting effect of PSB (*Bacillus megaterium* and *Bacillus thuringiensis*) and other microorganisms present in the PROM might have played a role in higher microbial-oriented nutrient availability. This, in turn, could have resulted in increased nutrient uptake, higher photosynthetic rate and higher chlorophyll synthesis, which could have led to an increase in yield. P. Bagade *et al.* (2025) also reported analogous findings. The utilisation of organic manure, which is abundant in phosphorus, has been demonstrated to have a substantial impact on the soil's biological condition, owing to its role as a nutrient source for microbes. This increase in microbial population consequently stimulates heightened levels of biological activity within the rhizosphere. In conjunction with organic components such as fluvic and humic acid, these microbes may have retained nutrients through a process of chelation, thereby enhancing nutrient availability to plants. This approach contrasts with the conventional methods of leaching, fixation, and precipitation of nutrients.

Application of either 75% or 100% P_2O_5 through PROM and 100% P_2O_5 via vermicompost improved leaf area, chlorophyll, yield, and yield characteristics, which might be attributed to greater solubility of calcium-fixed phosphorus by PSB. Subsequent addition of manure might have enhanced release of organic acids during decomposition, lowering the rhizosphere pH and increasing solubilisation of fixed and precipitated P in calcareous soil. The experiment yielded results that lend further credence to the hypothesis that the suppression of pH changes can exert a substantial influence on the physical, chemical, and biological characteristics of soil, thereby engendering conditions conducive to optimal root growth and enhanced access to the soil. This can engender an increase in the yield of soybeans.

P applied via SSP may not have been available to plants due to its alkaline calcareous nature, resulting in smaller yield compared to PROM and vermicompost. P application through SSP might have increased the Ca content in calcareous soil that might have enhanced $CaCO_3$ and alkanisation, resulting in less microbial activity, subsequently leading to poor nutrient availability. Furthermore, PROM and vermicompost not only supplied P, but also provides significant amount of other essential nutrients contributing to improvement in growth and yield features resulted into higher yield. PSB and beneficial microflora added via PROM and vermicompost might have secreted plant growth promoting constituents leads to positive growth over SSP and DAP application.

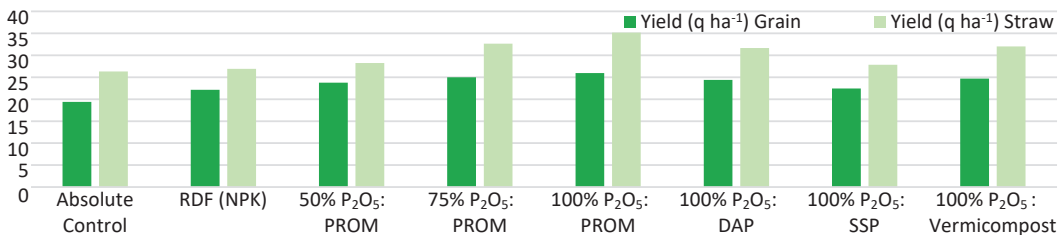


Figure 6. Grain and straw yield of soybean

Note: RDF: Recommended dose of fertilisers (N – Nitrogen, P – Phosphorus, and K – Potassium), P-rich organic manure (PROM), Diammonium phosphate (DAP), Single super phosphate (SSP)

Source: compiled by the authors

It was hypothesised that the application of P, derived from organic matter, has enhanced the quality of the soil. This improvement has been demonstrated by an increase in soil porosity and water-holding capacity, alongside a reduction in soil pH. The impact of this enhanced soil quality has been shown to result in a decrease in nutrient fixation, an increase in microbial population and activity, and an enhancement in enzyme synthesis. These changes have collectively led to a higher availability of nutrients. The outcome of this experiment is in agreement with the findings reported by K. Khan *et al.* (2023). Results of the present study are also uniform with K. Aswitha *et al.* (2024). The researchers found that among many P-activators like FYM, SSP and DAP, vermicompost and P rich organic manure were found to be the best P-activators in calcareous soil. Husnain *et al.* (2021) also concluded that the residual effect of reactive rock phosphate in combination

with Rhizobium and P solubilising bacteria resulted in a reported increase in soybean yield of 40.9% in the absence of reactive rock phosphate and microbes. T. Dev *et al.* (2020) reported that the efficiency of rock phosphate as a source of phosphorus for crop production is enhanced by increased solubility due to the application of farmyard manure (FYM) and phosphate-solubilising bacteria (PSB). The researchers further concluded that the combined application of phosphate-solubilising bacteria (PSB) and farmyard manure (FYM) enhanced the mineralisation of organic phosphorus, thereby increasing soil phosphorus availability, promoting plant growth, and improving the dry matter yield of soybean. P. Lokhande *et al.* (2023) also concluded that addition of 30:60:30 kg ha⁻¹ N, P_2O_5 , and K_2O to soybean in combination with Beejamruth seed treatment, Jeevaamrut (soil application at 500 L ha⁻¹ on 30 and 45 DAS) and two foliar sprays

of panchyagavya at 3% reported significantly greater leaf area, chlorophyll, yield characteristics, and yield amount itself. The combined application of rhizobia inoculant, P-fertiliser, and organic manure increased grain yield fourfold, whereas the combined application of rhizobia inoculant, P-fertiliser, and cattle manure increased grain yield threefold. Harvest index, phosphorus agronomic efficiency, and rainwater use efficiency were relatively greater with the manure (prepared from poultry manure, rice husks, and urban waste) treatment combinations than with solely cattle-based manure combinations and the control treatment. The application of rhizobia inoculant, P-fertiliser in combination with manure (poultry manure, urban waste, and rice husks) was profitable with value-cost ratio of 2 as compared to the combination of cattle manure which had a value cost ratio of 0.40. The findings revealed that manure offers a better option of improving soybean response to rhizobia inoculant and P-fertiliser and can enhance rainwater use efficiency. However, the long-term benefit must be quantified (Ulzen *et al.*, 2020). In summary, numerous studies confirmed that the combined application of organic manure, phosphorus fertilisers, and microorganisms such as phosphate-solubilising bacteria and inoculants markedly enhances phosphorus availability in calcareous soils, improves soil physicochemical properties, boosts plant productivity, and increases soybean yield. This integrated approach shows promise for sustainable agriculture and improving resource use efficiency under challenging agroecological conditions.

CONCLUSIONS

In conclusion, the study showed that phosphorus application through PROM, vermicompost, and phosphatic fertilisers significantly influenced soybean growth in calcareous soil. Application of 100% P₂O₅ through PROM and vermicompost, as well as 75% P₂O₅ through PROM, resulted in superior plant height, chlorophyll and leaf count. The presence of PSB in PROM may have contributed to solubilising unavailable forms of calcium-fixed phosphate, influencing plant growth. These findings highlighted the potential of phosphorus application to improve soybean growth through PROM to improve

soybean growth and yield. Furthermore, application of P₂O₅ through PROM, vermicompost, and phosphatic fertilisers significantly influenced leaf area plant⁻¹, leaf area index, and total chlorophyll content in soybean. The highest values of leaf area plant⁻¹, leaf area index, and total chlorophyll were reported with the addition of 100% P₂O₅ through PROM. Notably, the application of 100% P₂O₅ through phosphorus-rich organic manure resulted in a significantly greater number of pods plant⁻¹ (46.33), seeds pod⁻¹ (3.00), and seed plant⁻¹ (150.27), followed by 75% P₂O₅ via PROM, 100% P₂O₅ vermicompost, and 50% P₂O₅ : PROM treatments. Furthermore, the study supported the hypothesis that the application of PROM and vermicompost creates favourable conditions for root growth, leading to a greater yield of soybean in alkaline calcareous soil, as evidenced by the improved grain and straw yield, better availability of nutrients, improved soil pH, and enhanced microbial population and activity. The study demonstrated that phosphorus application through PROM and vermicompost significantly improved the grain and straw yield of soybean in highly calcareous soil. The use of organic matter-based P application resulted in greater availability of nutrients, improved soil pH, and enhanced microbial population and activity, and positive growth over inorganic fertiliser application. This rock phosphate-based organic manure further needs to be assessed in various types of soils and crops to maintain and improve soil health and quality. The findings of the presented study can be used to produce P-rich organic base manure which will maintain soil sustainability. This approach warrants further investigation across diverse soil types, climatic conditions, and crop species to validate its broader applicability and long-term impact on soil health and productivity.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Вплив фосфоровмісного органічного добрива (PROM) на ріст і врожайність сої на карбонатних ґрунтах

Анотація. Фіксація фосфору та його доступність є серйозною проблемою на лужних і карбонатних ґрунтах. Обмежена доступність поживних речовин у ґрунті є значним викликом для фосфорозалежних бобових культур, таких як соя. Проте використання органічного добрива та фосфориту за участі фосфат-розчинювальних бактерій (PSB) відіграє важливу роль не лише у підвищенні вмісту фосфору, а й у зниженні стресу. Метою дослідження було оцінити вплив різних джерел фосфору, включаючи органічні та неорганічні добрива, на параметри росту та продуктивність сої, що вирощується в умовах вапняного ґрунту. Дослідження показало, що застосування 75 або 100 % P_2O_5 через PROM або 100 % через вермикомпост значно покращувало ріст сої, зокрема збільшувалася кількість листків і висота рослин на 28-й та 56-й день після сівби. Використання PROM з 100 % P_2O_5 дало найвищі показники листової поверхні ($1657,26 \text{ cm}^2$), індексу листової поверхні (7,37) та загального вмісту хлорофілу ($1,23 \text{ mg g}^{-1}$). Крім того, застосування 100 % P_2O_5 через PROM призвело до значного збільшення кількості стручків на рослині (46,33), насінин у стручку (3,00) та насінин на рослині (150,27). Також значно вищу врожайність зерна (25,94 ц/га) та соломи (35,16 ц/га) сої забезпечило внесення 100 % P_2O_5 через PROM, за яким ішло внесення 75 % через PROM або 100 % через вермикомпост. Отже, виробництво фосфоровмісного органічного добрива може бути сталим підходом для підвищення росту та врожайності сої. Результати дослідження можуть бути використані агрономами, фахівцями з ґрунтознавства та агрохімії, а також фермерами і сільськогосподарськими підприємствами, які працюють із карбонатними (кальцієвими) ґрунтами для підвищення ефективності використання фосфорних добрив і покращення врожайності сої

Ключові слова: органічні джерела фосфору; неорганічні джерела фосфору; діамонійфосфат; простий суперфосфат; біогумус