Influence of Different Phosphatic Fertilizer on Nutrient Uptake and Nutrient Use Efficiency of Soybean in Highly Calcareous Soil

ABSTRACT

A field experiment was conducted to study "Phosphorus use efficiency through PROM (phosphorus rich organic manure) for soybean in highly calcareous soil" at Research Farm, College of Agriculture, Pune during *kharif* 2023. This experiment consisted of two organic sources (PROM and vermicompost) and two inorganic sources of phosphorus (SSP and DAP) along with their levels @ 50, 75 and 100 % imposed for soybean in calcareous soil. The treatments comprised T_1 - Absolute control, T_2 - RDF (50:75:45 kg ha^{-1} N: P_2O_5: K_2O), T_3 - 50% P_2O_5 through PROM, T_4 - 75% P_2O_5 through PROM, T_5 - 100% P_2O_5 through PROM, T_6 - 100% P_2O_5 through DAP + FYM @12.5 t ha^{-1}, T_7 - 100% P_2O_5 through SSP + FYM @12.5 t ha^{-1} and T_8 - 100% P_2O_5 through vermicompost replicated thrice in randomized block design imposed to soybean in calcareous soil.

Significantly superior results were observed for higher nitrogen (82.22 and 24.49 kg ha^{-1}), phosphorus (23.43 and 42.55 kg ha^{-1}) and potassium (49.44 and 81.93 kg ha^{-1}) uptake by grain and straw of soybean with the incorporation of 100 % P_2O_5 through PROM in calcareous soil. Similar treatment reported 145.41 % increase in Fe, 86.22 % in Mn, 71.92 % Zn and 52.08 % in Cu uptake by soybean. Based on this experiment it could be concluded that incorporation of 100 % P_2O_5 through phosphorus rich organic manure reported higher nutrient use efficiency (NUE) for nitrogen (129.34 %), phosphorus (38.00 %) and potassium (139.02 %) in calcareous soil under soybean cultivation. It is inferred that incorporation of PROM or vermicompost for the substitution of either 75 or 100 % P_2O_5 reported significantly higher nutrient uptake and nutrient use efficiency in calcareous soil than that of inorganic fertilizers (SSP and DAP) application or recommended dose of fertilizer or absolute control.

Keywords*: Soybean, PROM, FYM, Vermicompost, nutrient and uptake.*

1. INTRODUCTION

Phosphorus availability in Indian soils is often limited due to its fixation in forms that are not readily available to plants, particularly in alkaline and acidic soils. Despite the application of phosphate fertilizers only about 15-20 % of applied phosphorus is typically utilized by crops in the first year with the rest becoming part of the soil's residual P pool. Strategies such as the use of phosphorus efficient crop varieties and integrated nutrient management (INM) practices are being explored to enhance PUE. Phosphorus (P) status in Indian soils is a critical concern due to its direct impact on crop productivity and soil health. The availability of phosphorus is mostly depending upon pH of the soil. In highly calcareous soils phosphorus (P) availability and uptake by plants can be significantly affected by several factors, leading to various problems for crop production. Here are some of the key issues related to phosphorus in highly calcareous soils have a high calcium carbonate content which can lead to phosphorus fixation. Calcium ions (Ca^{2+}) in the soil solution can react with phosphate ions (PO_4^-) to form insoluble calcium phosphate compounds, reducing the availability of phosphorus for plant uptake.

Integrated Nutrient Management (INM) consisting organic and inorganic fertilizers along with biofertilizer can enhance PUE in various soils. In organic amendments like compost, farmyard manure, vermicompost, phosphorus rich organic manure and green manures which can improve soil structure, enhance microbial activity and increase the availability of phosphorus.

Nutrient use efficiency (NUE) reflects a plant's ability to acquire, absorb, and utilize nutrients for biomass and yield production. Enhancing phosphorus use efficiency is vital for sustainable agriculture, particularly in highly calcareous soils, where P fixation is pronounced. The application of different phosphatic fertilizers, can influence the availability of phosphorus thereby affecting nutrient uptake dynamics and nutrient use efficiency in soybean.

This study focuses on evaluating the role of phosphorus from different fertilizer sources in enhancing nutrient use efficiency and nutrient uptake in soybean. Understanding these interactions is crucial for formulating strategies to optimize phosphorus management, improve soil fertility and achieve sustainable crop production. The use of rock phosphate as an alternative for P fertilizer is gaining attention in recent years for sustainable agriculture through microbial solubilisation particularly in acidic soil. Further, enrichment of P through rock phosphate or phosphorite in compost or FYM is gaining attention of various farmers. The incorporation of organic residues either singly or in conjunction with a cheap source of mining element as rock phosphate along with phosphate solubilizing microorganism (*Pseudomonas*, *Bacillus* and *Rhizobium*) helps to improve the availability of phosphorus in alkaline as well as in calcareous soil Subehia (2001).

2. MATERIAL AND METHODS

The experiment was conducted on alkaline (pH 8.18) and highly calcareous soil (12.47% $CaCO_3$) at Research Farm, College of Agriculture, Pune (MS). 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 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.

The soybean variety KDS-726 (*Phule Sangam*) was used as the test crop for the experiment. Phosphorus Rich Organic Manure (PROM) was prepared at the Vermicompost Yard, Division of Soil Science, College of Agriculture, Pune. The recommended fertilizer dose (50:75:45 kg ha^{-1} of N, P_2O_5, and K_2O) was applied, except in the absolute control plots. Phosphorus was provided from various sources, including PROM and vermicompost as organic sources, and DAP and SSP as inorganic sources. Nitrogen and potassium were supplied through urea and muriate of potash, respectively. PROM, FYM and vermicompost were applied before sowing and their proximate analysis was conducted before the experiment (Table 1). Plant and grain samples have been collected during the soybean harvest. The samples were first dried in the shade, then in an oven at 45°C until they reached a steady weight. Plant and grain samples were wet digested with standard methods and accordingly nutrient concentrations determined.

The nutrient concentration like major (N, P and K) and micro (Fe, Mn, Zn and Cu) in soybean grain and straw were analyzed by wet digestion method. Further on the basis of dry matter production and nutrient concentration the uptake was calculated and stated in kg ha^{-1} for N, P, and K and in g ha^{-1} for Fe, Mn, Zn and Cu.

The nutrient use efficiency for nitrogen, phosphorus and potassium were calculated over absolute control by using following formula as given by (Jamal *et al.* 2023).

$$\text{NUE (\%)} = \frac{\text{Nutrient uptake in treatment plot (kg ha}^{-1}\text{) - Nutrient uptake in control plot (kg ha}^{-1}\text{)}}{\text{Rate of nutrient applied (kg ha}^{-1}\text{)}} \times 100$$

The data generated during the course of investigation were tabulated and statistically processed as per Panse and Sukhatme (1985).

Table 1 Proximate analysis of PROM, FYM and vermicompost

Sr. 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)	10550	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

3. RESULTS AND DISCUSSION

3.1 Influence of Different Phosphatic Fertilizers on Nutrient Uptake of Soybean in Highly Calcareous Soil

3.1.1 Major Nutrients

Nitrogen, phosphorus and potassium uptake by soybean grown in highly calcareous soil as affected by organic and inorganic sources of phosphorus were presented in Table 2.

Soybean grain and straw uptake for nitrogen, phosphorus and potassium were significantly influenced by PROM, vermicompost, SSP and DAP. Grain and straw uptake for nitrogen, phosphorus and potassium were ranged from 30.32 to 82.22, 11.71 to 24.49, 12.62 to 23.43, 24.86 to 42.55 and 22.47 to 49.44, 46.34 and 81.93 kg ha^{-1}, respectively. Application of 100 % P_2O_5 : PROM reported significantly higher nitrogen (82.22 and 24.49 kg ha^{-1}), phosphorus (23.43 to 42.55 kg ha^{-1}) and potassium (49.44 and 81.93 kg ha^{-1}) uptake by grain and straw of soybean respectively than rest of treatments. Significantly higher total nitrogen (106.7 kg ha^{-1}), phosphorus (65.98 kg ha^{-1}) and potassium (131.37 kg ha^{-1}) uptake by soybean recorded with 100 % P_2O_5 through PROM. Among the inorganic sources of P substitution 100 % P_2O_5 through DAP reported significant higher nitrogen (68.92 kg ha^{-1}), phosphorus (51.04 kg ha^{-1}) and potassium (90.26 kg ha^{-1}) uptake than that of SSP (59.5, 45.58 and 80.71 kg ha^{-1}) respectively.

Table 2. Effect of phosphatic fertilizers on major nutrient uptake of soybean in highly calcareous soil

Sr. No.	Treatment	Nitrogen uptake (kg ha^{-1})			Phosphorus uptake (kg ha^{-1})			Potassium uptake (kg ha^{-1})		
		Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
1	Absolute Control	30.32	11.71	42.03	12.62	24.86	37.48	22.47	46.34	68.81
2	RDF (NPK)	42.58	12.8	55.38	13.63	26.33	39.96	26.06	48.18	74.24
3	50 % P_2O_5 : PROM	46.12	13.72	59.84	15.94	30.72	46.66	30.82	51.13	81.95
4	75 % P_2O_5 : PROM	60.97	19.69	80.66	22.11	32.84	54.95	43.41	62.08	105.49
5	100% P_2O_5 : PROM	82.22	24.49	106.7	23.43	42.55	65.98	49.44	81.93	131.37
6	100 % P_2O_5 : DAP	53.85	15.07	68.92	19.38	31.66	51.04	34.53	55.73	90.26
7	100 % P_2O_5 : SSP	46.06	13.44	59.5	15.44	30.14	45.58	30.34	50.37	80.71
8	100 % P_2O_5 : vermicompost	56.11	16.95	73.06	19.71	31.68	51.39	38.82	59.77	98.59
	SE±	3.13	0.87	3.97	0.81	1.08	1.89	1.84	2.35	4.19
	CD at 5%	9.48	2.65	12.06	2.45	3.28	5.73	5.58	7.12	12.7

Phosphorus availability and mobility are low in most soils, especially in alkaline calcareous soil where P availability is major constraints due to complex formation with calcium as tricalcium phosphate (insoluble form). Application of rock phosphate enriched manure might have reduced fixation with calcium there by higher nutrient uptake was observed in PROM and vermicompost applied treatments. Higher biomass and nutrient uptake with P applied through PROM or vermicompost which might be ascribed to more availability of P, not only from added PROM but also with phosphate solubilizing bacteria and associated microbes involved in solubilization and mineralization of more P leads to more root growth helped for absorption of other nutrients also. Khan *et al.* (2020) also concluded similar results for availability of P.

Significant increase in P concentration and dry matter yield of soybean was reported in soil treated with 100 % P_2O_5 from rock phosphate + PSB + FYM @ 5 t ha^{-1} (Dev *et al.* 2020). Further efficiency of rock phosphate as a P source for crop production is enhanced by the solubility effect of FYM and PSB. PROM and vermicompost not only supply P as per the treatment but also added considerable amount of other major and micronutrients leads to more chlorophyll synthesis, photosynthesis and production of photosynthates. Further it could be ascribed that bacteria like *Bacillus polyxena*, *Bacillus megatherium, Pseudomonas spp*.

Erwinia herbicola, etc. may also produce growth promoting substance such as auxins, gibberellins and cytokinin leads to more root growth and more root exploration for tapping the available nutrients. Similar results for different crops were also reported by Bairwa *et al.* (2019) for cluster bean – wheat cropping system, Venu *et al.* (2023) and Manjunath *et al.* (2006) for French bean.

In general P, Fe and Zn availability in alkaline calcareous soil is major constraints not only for soybean but also for other crops. Under this circumstances P application through rock phosphate incorporated and incubated manure along with phosphorus solubilizing bacteria increased the availability of P, Fe and Zn which might have reported higher uptake. Further addition of phosphorus rich manure might have released the organic acids causes reduction in rhizosphere pH or dissolution of mineral phosphate through the anion exchange or due to chelation property of organic acids like acetic, lactic, oxalic and citric secreted by phosphorus solubilizing bacteria.

Higher P uptake with PROM or vermicompost which would be due to P released in rhizosphere in soluble form. Further incorporation of organic material might have played important role in mineralization rather than immobilization. Organic acids secreted by root exudates, microbial community or released during organic matter decomposition might have reduced P-fixation by calcium in soil and also improved availability of other nutrients. Rhizosphere acidification due to the organic acid released during decomposition of organic matter from PROM and vermicompost which resulted into reduction of pH leads to optimum nutrient availability there by higher uptake. Further incorporation of phosphorus rich organic manure and vermicompost not only supplied phosphorus but also other nutrients in considerable amount that might improve uptake of macronutrients. Our results support the findings of Khan *et al.* (2021) as they concluded incorporation of rock phosphate + processed manure along with *Bacillus Spp.* (MN-54) found superior for chickpea.

3.1.2 Micronutrient Uptake (Fe, Mn, Zn and Cu)

Micronutrient (Iron, manganese, zinc and copper) uptake by soybean grain and straw as influenced by organic and inorganic sources of P along with its levels are presented in Table 3 and Table 4.

Table 3 Effect of phosphatic fertilizers on iron and manganese uptake of soybean in highly calcareous soil

Sr. No.	Treatment	Fe uptake (g ha^{-1})			Mn uptake (g ha^{-1})		
		Grain	Straw	Total	Grain	Straw	Total
1	Absolute Control	313.74	155.76	469.49	67.43	59.05	126.48
2	RDF (NPK)	397.80	233.31	631.11	69.52	87.61	157.13
3	50 % P_2O_5 : PROM	488.01	295.34	783.35	74.73	95.04	169.78
4	75 % P_2O_5 : PROM	530.69	453.98	984.67	80.16	110.43	190.59
5	100% P_2O_5 : PROM	638.76	513.08	1151.84	94.02	141.52	235.54
6	100 % P_2O_5 : DAP	492.58	412.69	905.27	75.91	98.22	174.12
7	100 % P_2O_5 : SSP	457.62	294.19	751.81	73.77	91.66	165.43
8	100 % P_2O_5 : vermicompost	527.04	430.68	957.71	79.96	99.78	179.74
	SE±	19.68	25.03	44.13	1.67	4.70	6.32
	CD at 5%	59.71	75.93	133.87	5.08	14.28	19.18

Considerable variation reported in Fe, Mn, Zn and Cu uptake by soybean (grain and straw) grown in highly calcareous soil. Data revealed that Fe, Mn, Zn and Cu uptake by grain were ranged from 469.49 to 1151.84, 126.48 to 235.54, 123.96 to 213.12 and 83.39 to 126.82 g ha^{-1}, respectively. Significantly higher uptake of Fe (638.76 and 513.08 g ha^{-1}), Mn (94.02 and 141.52 g ha^{-1}), Zn (75.26 and 137.85 g ha^{-1}) and Cu (83.84 and 42.98 g ha^{-1}) in grain and straw was reported with the addition of 100 % P_2O_5 through PROM, respectively. These was closely followed by 75 % P_2O_5 : PROM and 100 % P_2O_5 : vermicompost application. Further it could be observed from the data that lower uptake of Fe (469 g ha^{-1}), Mn (126.48 g ha^{-1}), Zn (123.96 g ha^{-1}) and Cu (83.39 g ha^{-1}) were found in absolute control treatment.

Incorporation of PROM for 100 % P_2O_5 substitution reported 145.41 % increase in Fe, 86.22 % in Mn, 71.92 % in Zn and 52.08 % in Cu for total uptake by soybean over absolute control. Further it could be noted from the data that 100 % P_2O_5 through DAP recorded significantly higher uptake for Fe (905 g ha^{-1}), Mn (174.12 g ha^{-1}), Zn (168.87 g ha^{-1}) and Cu (113.44 g ha^{-1}) by soybean than 100 % P_2O_5 through SSP (751, 165.43, 159.03 and 99.97 g ha^{-1}) respectively.

Table 4 Effect of phosphatic fertilizers on zinc and copper uptake of soybean in highly calcareous soil

Sr. No.	Treatment	Zn uptake (g ha^{-1})			Cu uptake (g ha^{-1})		
		Grain	Straw	Total	Grain	Straw	Total
1	Absolute Control	43.44	80.52	123.96	62.56	20.83	83.39
2	RDF (NPK)	55.87	97.91	153.79	70.69	28.75	99.44
3	50% P_2O_5 : PROM	57.95	108.23	166.18	74.11	30.25	104.36
4	75% P_2O_5 : PROM	64.34	132.69	197.03	83.56	37.60	121.16
5	100% P_2O_5 : PROM	75.26	137.85	213.12	83.84	42.98	126.82
6	100% P_2O_5 : DAP	59.47	109.40	168.87	80.37	33.07	113.44
7	100% P_2O_5 : SSP	56.60	102.43	159.03	70.84	29.13	99.97
8	100% P_2O_5 : Vermicompost	63.58	115.45	179.03	83.04	35.55	118.60
	SE±	1.84	3.77	5.55	1.59	1.36	2.91

	CD at 5%	5.58	11.44	16.85	4.83	4.13	8.83

Alkaline pH and high $CaCO_3$ content in the soil restricts availability of P, Fe, Zn and K also. The substitution of P through PROM and vermicompost played dual role, firstly addition of PROM and vermicompost might have added considerable number of metallic micronutrients in plant usable form leads to higher uptake of micronutrients by soybean. Secondly basal application of PROM and vermicompost might have acted as a source of energy (carbon) for microbes leads to higher activity that resulted into mineralization of P present in the soil.

Among the various factors, alkaline pH and high $CaCO_3$ in soil are the dominant for reducing availability of metallic micronutrients. Addition of PROM (prepared by using rock phosphate, crop residue and PSB) and vermicompost for P substitution reported higher uptake by soybean might be due to the vital role of PSB and beneficial microflora for higher mineralization of micronutrient. Further excretion of various organic acid like propionic, succinic, fumaric etc. during organic matter decomposition might have lowered the rhizospheres pH there by increased micronutrient availability. Substitution of P through PROM and vermicompost might be rich in beneficial microflora with plant growth promoting activities which enhanced the availability of metallic micronutrients resulted into higher uptake in these treatments.

3.2 Influence of Different Phosphatic Fertilizers on Nutrient Use Efficiency of Soybean in Highly Calcareous Soil

Nutrient use efficiency for nitrogen, phosphorus and potassium were significantly influenced by the application of P_2O_5 through PROM, vermicompost, DAP and SSP for soybean in calcareous soil (Table 5).

Table 5 Effect of PROM and phosphatic fertilizers on nutrient use efficiency of soybean in highly calcareous soil

Sr. No.	Treatment	Nutrient use efficiency (%)		
		N	P	K
1	Absolute Control	-	-	-
2	RDF (NPK)	26.70	3.31	12.07
3	50% P_2O_5 : PROM	35.62	24.48	29.20
4	75% P_2O_5 : PROM	77.26	31.06	81.51
5	100% P_2O_5 : PROM	129.34	38.00	139.02
6	100% P_2O_5 : DAP	53.78	18.08	47.67
7	100% P_2O_5 : SSP	34.94	10.80	26.44
8	100% P_2O_5: vermicompost	62.06	18.55	66.18
	SE±	7.95	2.68	9.16
	CD at 5%	24.12	8.12	27.80

Significantly higher nutrient use efficiency for nitrogen (129.34 %), phosphorus (38.00 %) and potassium (139.02 %) were recorded in highly alkaline calcareous soil with the application of 100 % P_2O_5 through PROM which was followed by 75 % P_2O_5 through PROM. It is surprising to note that application of 100 % P_2O_5 through DAP reported 53 %, 67 % and 80.29 % increase in nitrogen, phosphorus and potassium use efficiency over 100 % P_2O_5 through SSP application in highly alkaline calcareous soil.

Quality of PROM and vermicompost added for the substitution of P, also supplied other essential nutrients in available form in the rhizosphere leads to more uptake and nutrient use efficiency. Organic manure like PROM and vermicompost application for P-substitution might have added organic matter resulted into increase in microbial population as well as activity resulted higher rate of mineralization and availability of nutrients in soybean rhizosphere there by higher uptake caused more nutrient use efficiency. Higher nutrient use efficiency for nitrogen, phosphorus and potassium was also reported by Arif *et al*, (2018) with the application rock phosphate compost along with PSB for cotton. Our results are also supported by Jamal *et al*, (2023). They reported higher P absorption efficiency, P balance and P uptake increased linearly with increasing levels of phosphorus.

4. CONCLUSION

The present study revealed that the application of organic fertilizers such as PROM and vermicompost significantly enhanced nutrient uptake and nutrient use efficiency. Overall, the findings suggest that integrating organic fertilizers into agricultural practices can be a sustainable and beneficial approach for enhancing nutrient uptake and nutrient use efficiency resulted into better crop productivity and promoting soil health.

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