Journal of Basic and Applied Research International

Volume 30, Issue 6, Page 36-44, 2024; Article no.JOBARI.12471
ISSN: 2395-3438 (P), ISSN: 2395-3446 (O)

Influence of Different Sources and Levels of Phosphorus on Nutrient Use Efficiency (NUE) and Properties of Low Calcareous Soil

Pranali Meshram [a++*], Abhay Patil [a#], Anand Jadhav [a#], Avinash Gosavi [a†] and Praful Bagade [a++]

[a] *Division of Soil Science, College of Agriculture, Pune (MS), Mahatma Phule Krishi Vidyapeeth, Rahuri, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.56557/jobari/2024/v30i68937

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://prh.ikprress.org/review-history/12471

Original Research Article

Received: 02/09/2024
Accepted: 04/11/2024
Published: 08/11/2024

ABSTRACT

A field experiment was conducted during *kharif* season of 2023 at Post Graduate Instructional Farm, College of Agriculture, Pune to study the impact of different phosphorus sources and levels on soybean growth and nutrient uptake in low calcareous soil. The experiment was laid out in randomized block design having eight treatments with three replications. 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** -

---

[++] *M.Sc. (Agri) Student;*
[#] *Assistant Professor of Soil Science;*
[†] *Associate Professor of Soil Science;*
**Corresponding author: E-mail: pranali.meshram2709@gmail.com;*

Cite as: *Meshram, Pranali, Abhay Patil, Anand Jadhav, Avinash Gosavi, and Praful Bagade. 2024. "Influence of Different Sources and Levels of Phosphorus on Nutrient Use Efficiency (NUE) and Properties of Low Calcareous Soil". Journal of Basic and Applied Research International 30 (6):36-44. https://doi.org/10.56557/jobari/2024/v30i68937.*

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. The soil of experimental site was clay loam in texture. The findings of the present investigation revealed that the higher nutrient use efficiency was registered in treatment 100% P_2O_5 through SSP + FYM @12.5 t ha^{-1} (16.25 kg kg^{-1}). The application of 100% P_2O_5 through PROM recorded higher nutrient use efficiency (13.31 kg kg^{-1}) over RDF (11.52 kg kg^{-1}). In respect of agronomic nutrient use efficiency, 100% P_2O_5 through SSP + FYM @12.5 t ha^{-1} registered higher nitrogen (40 kg grain kg $nutrient^{-1}$), phosphorus (26 kg grain kg $nutrient^{-1}$) and potassium efficiency (44 kg grain kg $nutrient^{-1}$) to soybean crop. The agronomic efficiency of nitrogen, phosphorus and potassium was observed higher in treatment 100% P_2O_5 through PROM over treatment RDF.

After harvest of crop the soil pH was remained unaffected while the electrical conductivity of soil was significantly higher in 100 % P_2O_5 through vermicompost and PROM to soybean crop. The application of 100% P_2O_5 either through vermicompost or PROM recorded at par organic carbon content in soil (0.66% and 0.64% respectively). The application of 100% P_2O_5 through PROM significantly reduced calcium carbonate (6.29%) in soil.

The 100% P_2O_5 through SSP + FYM @12.5 t ha^{-1} showed higher available nitrogen in soil (297.33 kg ha^{-1}) while the application of 100% P_2O_5 through DAP + FYM @12.5 t ha^{-1} exhibited higher level of available phosphorus and potassium content in soil (41.33 and 745.33 kg ha^{-1}, respectively). Further, the application of 100% P_2O_5 through vermicompost was also significantly superior in available micronutrients like iron (5.7 mg kg^{-1}), manganese (9.9 mg kg^{-1}), zinc (4.6 mg kg^{-1}) and copper (10.4 mg kg^{-1}).

The application of 100% P_2O_5 through PROM registered significantly higher available nitrogen (287.33 kg ha^{-1}), available phosphorus (37.33 kg ha^{-1}), available potassium (737.67 kg ha^{-1}), available micronutrients *viz*. iron (5.4 mg kg^{-1}), manganese (9.2 mg kg^{-1}), zinc (4.4 mg kg^{-1}) and copper (10.4 mg kg^{-1}) over recommended dose of fertilizers.

In general, the integration of organic fertilizers, FYM, PROM and vermicompost, with chemical fertilizers can significantly enhance nutrient use efficiency, soil nutrient content, improve soil health and increase soybean yield in low calcareous soils.

Keywords: Soybean; PROM; FYM; vermicompost; nutrient use efficiency (NUE); soil properties.

1. INTRODUCTION

Phosphorus (P) is a vital macronutrient essential for crop growth, development and nutrient use efficiency (NUE). It plays a key role in processes like energy transfer, root proliferation, cell division, and overall plant productivity (Havlin et al., 2007). Despite its crucial role, phosphorus utilization in agricultural soils is highly inefficient, with only about 15-20% of applied phosphorus being absorbed by plants (Malhotra et al., 2018).

Enhancing phosphorus use efficiency (PUE) especially in regions like India where widespread soil phosphorus deficiencies and the high cost of chemical fertilizers are challenges to sustainable agriculture.

These soils tend to bind phosphorus, forming insoluble compounds that limit its availability to plants (Sims and Sharpley, 2005). The present challenges for phosphorus management, as the combination of pH and calcium interactions often immobilizes P, further reducing its bioavailability. Thus, enhancing the solubility and availability of phosphorus in soils through innovative phosphorus management strategies is essential for improving nutrient use efficiency and overall soil health.

The use of different phosphorus sources—such as chemical fertilizers, rock phosphate (RP), and organic amendments like farmyard manure (FYM) and vermicompost (VC)—in combination with phosphorus-solubilizing bio-inoculants, offers a promising approach to improving PUE in soils. In particular, phosphate-solubilizing bacteria (PSB) like *Pseudomonas* and *Bacillus* have been shown to enhance the availability of phosphorus by breaking down insoluble forms of P in the soil (Siva Sankar et al., 1984). Organic manures such as FYM and VC contribute to soil structure and microbial activity, promoting the mineralization of organic phosphorus and its uptake by plants. Vermicompost, in particular, provides a more readily available form of phosphorus compared to FYM, which releases nutrients more slowly due to its complex organic matter content (Kaleem et al., 2010).

One of the most cost-effective and environmentally friendly alternatives to synthetic fertilizers is the use of Phosphate-Rich Organic Manure (PROM), created by combining rock phosphate with organic matter and bio-inoculants. PROM has gained popularity due to its slow-release properties, which ensure long-term phosphorus availability and promote soil health. This practice is especially beneficial for low-calcareous soils where chemical fertilizers may be less effective due to phosphorus fixation. The use of PROM in integrated nutrient management systems can enhance soil properties, improve microbial activity, and provide a more sustainable approach to nutrient management (Naseer and Muhammad, 2014).

Soybean (*Glycine max*), a major leguminous crop, is particularly sensitive to soil phosphorus levels. Its high protein and oil content make phosphorus availability crucial for achieving optimal yields. Despite its importance, limited research has been conducted on the fate of phosphorus when applied via organic amendments such as PROM in low-calcareous soils. Understanding the effects of different phosphorus sources and levels on nutrient use efficiency and soil properties is essential for developing sustainable phosphorus management practices, particularly in the context of soil systems where phosphorus availability is often limited by soil chemistry.

2. MATERIALS AND METHODS

A field experiment was conducted at the Post Graduate Instructional Farm, Division of Soil Science, College of Agriculture, Pune (MS) during *kharif* season of 2023. A representative soil sample from the 0–30 cm layer, was collected from the field. The soil sample used for the experiment was slightly alkaline with a pH of 7.8 with a low electrical conductivity (EC) (0.3 dS m^{-1}), moderate in organic carbon (0.61%) and calcium carbonate (6.42%), low in available nitrogen (263.42 kg ha^{-1}) and available phosphorus (20.17 kg ha^{-1}) but high available potassium levels (697.76 kg ha^{-1}) and sufficient micronutrients.

The soybean, variety KDS-726 (*Phule Sangam*) was grown as test crop. The PROM was prepared at Vermicompost Yard, Division of Soil Science, College of Agriculture, Pune.

The recommended dose of fertilizer (50:75:45 kg ha^{-1} of N, P_2O_5 and K_2O) was applied except to absolute control. The recommended dose of phosphorus was supplied through various sources such as PROM, vermicompost as an organic sources and DAP and SSP as an inorganic source. The nitrogen and potassium were supplied through urea and muriate of potash, respectively. PROM, FYM and vermicompost were applied at sowing. The proximate analysis of PROM, Farmyard manure (FYM), vermicompost was done before start of experiment (Table 1).

Plant samples were collected at harvest of soybean crop. The PROM, FYM, VC, plant and soil samples were analyzed by using standard analytical methods. The plant samples were analyzed for nutrient concentrations. The soil samples were analyzed for chemical properties. The nutrient use efficiency was computed by using standard formula. A randomized block design (RBD) with analysis of variance (ANOVA) was employed to assess treatment effects on all studied characteristics (Panse and Sukhatme, 1985).

Table 1. Proximate analysis of PROM, FYM and vermicompost

Sr. No	Parameters	PROM	FYM	Vermicompost
1	pH (1:10)	7.18	7.49	6.91
2	EC (dS m^{-1})	1.74	1.66	2.12
3	Moisture (%)	24.02	23.50	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 (mg kg^{-1})	12.70	186	388
9	Total Mn (mg kg^{-1})	0.67	35.7	65.7
10	Total Zn (mg kg^{-1})	2.69	14.8	18.3
11	Total Cu (mg kg^{-1})	0.46	4.39	15.2
12	C:N ratio	24:1	39:1	20:1
13	C:P ratio	1.44:1	57.07:1	38.97:1

3. RESULTS AND DISCUSSION

3.1 Influence of Sources and Level of Phosphorus on Nutrient Use Efficiency and Agronomic Efficiency (Table 2)

The higher nutrient use efficiency was registered in treatment 100% P_2O_5 through SSP + FYM at 12.5 t ha^{-1} (16.25 kg kg^{-1}). It was closely followed by the treatment integration of 100% P_2O_5 through DAP + FYM at 12.5 t ha^{-1} (15.67 kg kg^{-1}) and 100% P_2O_5 through vermicompost (15.52 kg kg^{-1}). The application of 100% P_2O_5 through PROM recorded higher nutrient use efficiency (13.31 kg kg^{-1}) over the treatment RDF (11.52 kg kg^{-1}). The data confirmed the role of organic manures in increasing nutrient use efficiency as addition of organic manure provides a slow, steady release of nutrients, while inorganic fertilizers offer readily available forms. Together, providing the more balanced nutrient supply throughout the growing season, reducing nutrient losses and maximizing plant uptake which showed higher nutrient use efficiency.

On the other hand, FYM and vermicompost offer these benefits, PROM emerges as a promising alternative because of its readily available phosphorus content, similar to inorganic fertilizers, which can be crucial early in the growing season for root development and nutrient uptake. Additionally, PROM potentially retains some of the long-term benefits of organic sources, making it a well-rounded option for improving NUE compared to relying solely on inorganic fertilizers or traditional FYM.

In respect of agronomic nutrient use efficiency due to nitrogen addition, higher agronomic nutrient use efficiency was observed in 100% P_2O_5 through SSP + FYM @12.5 t ha^{-1} (40 kg grain kg $nutrient^{-1}$) closely followed by treatment T_6 (38 kg grain kg $nutrient^{-1}$) and treatment T_8 (37 kg grain kg $nutrient^{-1}$). The agronomic efficiency of nitrogen was observed higher in treatment through 100% P_2O_5 through PROM (30 kg grain kg $nutrient^{-1}$) over treatment RDF (24 kg grain kg $nutrient^{-1}$).

Increased application of phosphorus enhances nitrogen use efficiency, while the presence of microorganism facilitates the conversion of organic nutrients into inorganic forms which are readily available for plant uptake (Makwana et al., 2020).

The similar trends were observed in case of agronomic nutrient use efficiency of P and K applied to soybean crop. In both the cases the agronomic nutrient use efficiency was higher in 100% P_2O_5 through PROM over RDF. In general, application of 100% P_2O_5 through SSP registered higher agronomic nutrient use efficiency of nitrogen (40), phosphorus (26) and potassium (44) to soybean crop. The application of 100% P_2O_5 through PROM observed to be superior for increasing phosphorus use efficiency (20kg grain kg $nutrient^{-1}$) when compared with application RDF (16 kg grain kg $nutrient^{-1}$) to soybean crop. From this observation, it could be inferred that application of organic manure add effective role in increasing nutrient use efficiency and agronomic efficiency.

Table 2. Influence of sources and levels of phosphorus on nutrient use efficiency and agronomic efficiency of applied N, P and K for soybean

Treat. No.	Treatments	Nutrient use efficiency (kg kg^{-1})	Agronomic efficiency (kg grain kg $nutrient^{-1}$)		
			N	P	K
T_1	Absolute control	-	-	-	-
T_2	RDF (50:75:45 kg ha^{-1} N: P_2O_5: K_2O)	11.52	24	16	26
T_3	50% P_2O_5 through PROM	10.47	20	13	22
T_4	75% P_2O_5 through PROM	11.22	23	15	25
T_5	100% P_2O_5 through PROM	13.31	30	20	33
T_6	100% P_2O_5 through DAP + FYM @12.5 t ha^{-1}	15.67	38	25	42
T_7	100% P_2O_5 through SSP + FYM @12.5 t ha^{-1}	16.25	40	26	44
T_8	100% P_2O_5 through Vermicompost	15.52	37	25	41

3.2 Influence of Sources and Level of Phosphorus on Soil Chemical Properties after Harvest of Soybean

Soil pH: The data on soil pH indicated that it was remained unaffected significantly due to different sources and levels of phosphorus to soybean crop. The pH value ranged between 7.80 to 7.87. There were no significantly changes in application of organic and inorganic different treatments may be due to higher buffering capacity of the soil (Dwivedi et al*.,* 2007).

Electrical conductivity of soil: Among different treatments, electrical conductivity of soil was significantly increased in treatment where 100% P_2O_5 through vermicompost was applied (0.40 dS m^{-1}). However, it was at par with the treatment 100% P_2O_5 through PROM (0.39 dS m^{-1}). This increase was significantly superior over rest of the treatments. The increase in electrical conductivity of soil due to application of these organic manures might be due to solubilization of salts in soil.

Organic carbon: The application of 100% P_2O_5 through vermicompost (0.66 %) registered significant higher organic carbon over rest of the treatment except the treatment of 100% P_2O_5 through PROM (0.64 %). It was also noticed that the application of organic sources *viz.* PROM, FYM and vermicompost significantly increased organic carbon in soil when compared with recommended dose of fertilizer (50:75:45 kg ha^{-1} N: P_2O_5: K_2O) (0.58 %). This indicated that integration of organic and inorganic fertilizers found beneficial for improving or maintaining organic carbon content in soil. It was interested to note that the application of FYM, vermicompost and PROM found equally effective for maintaining organic carbon content in soil.

The increase in soil organic carbon can be attributed due to the direct addition of organic matter and the subsequent stimulation of microbial activity and biomass production (Babulkar et al., 2000). These findings are supported by Yaduvanshi (2001).

Calcium carbonate: The application of 100% P_2O_5 through PROM showed significantly lower calcium carbonate (6.29%) in soil. This treatment was at par with the treatment 100% P_2O_5 through vermicompost (6.30%). In general, it was also observed that the application of organic manure like PROM, FYM and vermicompost found beneficial to reduce calcium carbonate content in soil significantly over the application of chemical fertilizers only (6.42%). This confirms the beneficial role of organic manure for decreasing calcium carbonate content in soil. This may be because of liberation of different organic acids which are responsible for solubilizing calcium carbonate in soil.

Table 3. Influence of sources and levels of phosphorus on soil chemical properties after harvest of soybean

Treat. No.	Treatments	pH (1:2.5)	Electrical Conductivity (dS m^{-1})	Organic Carbon (%)	$CaCO_3$ (%)
T_1	Absolute control	7.83	0.31	0.57	6.41
T_2	RDF (50:75:45 kg ha^{-1} N: P_2O_5: K_2O)	7.87	0.31	0.58	6.42
T_3	50% P_2O_5 through PROM	7.80	0.33	0.61	6.38
T_4	75% P_2O_5 through PROM	7.83	0.36	0.62	6.35
T_5	100% P_2O_5 through PROM	7.80	0.39	0.64	6.29
T_6	100% P_2O_5 through DAP + FYM @12.5 t ha^{-1}	7.83	0.33	0.62	6.37
T_7	100% P_2O_5 through SSP + FYM @12.5 t ha^{-1}	7.87	0.32	0.63	6.35
T_8	100% P_2O_5 through Vermicompost	7.80	0.40	0.66	6.30
	SE(m) ±	0.05	0.01	0.01	0.01
	CD (0.05)	NS	0.03	0.03	0.04
	Initial	7.80	0.30	0.61	6.42

3.3 Influence of Sources and Level of Phosphorus on Soil Available Macro and Micronutrients after Harvest of Soybean (Table 4)

Available nitrogen: The data on soil available nitrogen content revealed a statistically significant effect due to the application of phosphorus (P) at different levels and from different sources. Notably, the treatment 100% P_2O_5 through SSP + FYM at 12.5 kg ha^{-1} (297.33 kg ha^{-1}) exhibited the higher available nitrogen content compared to all other treatments, with the exception of the treatment receiving 100% P_2O_5 through vermicompost (295.67 kg ha^{-1}) and 100% P_2O_5 through DAP + FYM at 12.5 t ha^{-1} (293.67 kg ha^{-1}). It was also noticed that the treatment 100% P_2O_5 through PROM (287.33 kg ha^{-1}), 75% P_2O_5 through PROM (284.00 kg ha^{-1}) and 50% P_2O_5 through PROM (273.67 kg ha^{-1}) were superior over recommended dose of fertilizer - 50:75:45 kg ha^{-1} N: P_2O_5: K_2O (265.33 kg ha^{-1}) as far as availability of nitrogen is concerned. This increase in content of available nitrogen in soil due to application of PROM, FYM and vermicompost might be attributed to increase in microbial activities in soil which are responsible for release of nutrients in soil.

Available phosphorus: The data registered on available phosphorus showed a significant change due to the different levels and sources of phosphorus to soybean crop. The application of 100% P_2O_5 through DAP + FYM at 12.5 t ha^{-1} resulted in a significantly higher level of available phosphorus, reaching 41.33 kg ha^{-1}, but was at par with the application of 100% P_2O_5 through SSP + FYM at 12.5 t ha^{-1}, reaching 39.33 kg ha^{-1}. It was also noted that the application of 100% P_2O_5 through PROM (37.33 kg ha^{-1}) and 75% P_2O_5 through PROM (30.67 kg ha^{-1}) were significantly superior over the recommended dose of fertilizer (50:75:45 kg ha^{-1} N: P_2O_5: K_2O) (27.67 kg ha^{-1}). The application of 100% P_2O_5 through PROM could improve available phosphorus status (37.33 kg ha^{-1}) in soil when compared with RDF (27.67 kg ha^{-1}).

Available potassium: The application of 100% P_2O_5 through DAP + FYM @12.5 t ha^{-1} had registered significantly higher available potassium (745.33 kg ha^{-1}) but was at par with treatment 100% P_2O_5 through SSP+FYM at 12.5 t ha^{-1} (744.67 kg ha^{-1}). Further, it was also noticed that the application of PROM at all levels significantly increased availability of potassium in soil compared with RDF (709.00 kg ha^{-1}). It was also recorded that all the treatment with combination of organic manure and inorganic fertilizers and all levels of PROM were significantly superior over recommended dose of fertilizer (50:75:45 kg ha^{-1} N: P_2O_5: K_2O) (709.00 kg ha^{-1}) to soybean crop.

Table 4. Influence of sources and levels of phosphorus on soil available macro and micronutrients after harvest of soybean

Treat. No.	Treatments	N	P	K	Fe	Mn	Zn	Cu
		(kg ha^{-1})			(mg kg^{-1})			
T_1	Absolute control	245.00	14.67	680.00	4.9	8.4	3.5	8.7
T_2	RDF (50:75:45 kg ha^{-1} N: P_2O_5: K_2O)	265.33	27.67	709.00	5.0	8.3	3.5	9.1
T_3	50% P_2O_5 through PROM	273.67	26.67	716.00	5.0	8.7	3.9	9.0
T_4	75% P_2O_5 through PROM	284.00	30.67	718.67	5.2	9.0	4.1	9.1
T_5	100% P_2O_5 through PROM	287.33	37.33	737.67	5.4	9.2	4.4	9.8
T_6	100% P_2O_5 through DAP + FYM @12.5 t ha^{-1}	293.67	41.33	745.33	5.5	9.3	4.1	10.0
T_7	100% P_2O_5 through SSP + FYM @12.5 t ha^{-1}	297.33	39.33	744.67	5.4	9.3	4.1	10.0
T_8	100% P_2O_5 through Vermicompost	295.67	34.00	732.33	5.7	9.9	4.6	10.4
	SE(m) ±	2.65	0.93	2.04	0.04	0.12	0.04	0.14
	CD (0.05)	8.11	2.86	6.25	0.12	0.39	0.14	0.44
	Initial	263.42	20.17	697.76	5.1	8.8	4.1	9.1

Available iron: The data investigated showed significantly superior results in terms of the availability of iron in soil after the harvest of the soybean crop at different levels and sources of phosphorus. Among the various treatments, the treatment application of 100% P_2O_5 through vermicompost recorded significantly superior results in terms of iron availability (5.7 mg kg^{-1}) and was at par with treatment 100% P_2O_5 through DAP + FYM @12.5 t ha^{-1} (5.5 mg kg^{-1}). The application of 100% P_2O_5 through vermicompost showed significantly higher iron (5.7 mg kg^{-1}) over the application of 100% P_2O_5 through PROM (5.4 mg kg^{-1}). However, 100% P_2O_5 through PROM and 75% P_2O_5 through PROM showed significantly higher availability of iron in soil (5.4 mg kg^{-1} and 5.2 mg kg^{-1}, respectively) when compared with the recommended dose of fertilizer (50:75:45 kg ha^{-1} N: P_2O_5: K_2O) (5.0 mg kg^{-1}).

Available manganese: The application of 100% P_2O_5 through vermicompost resulted in significantly higher availability of manganese in soil, reaching 9.9 mg kg^{-1} over all the treatments applied through different levels and sources of phosphorus. The data also mentioned the superiority of treatment T_5-100% P_2O_5 through PROM, T_4-75% P_2O_5 through PROM and T_3-50% P_2O_5 through PROM (9.2 mg kg^{-1}, 9.0 mg kg^{-1} and 8.7 mg kg^{-1}, respectively) over T_2 (RDF) (8.3 mg kg^{-1}).

Available zinc: The significant variations in the availability of zinc contents among different organic and inorganic fertilizer treatments, particularly at varying levels and sources of phosphorus, highlight the complex interplay of soil nutrients. The treatment T_8-100% P_2O_5 through vermicompost registered significantly higher performance in terms of the availability of zinc in the soil (4.6 mg kg^{-1}). Similarly, the treatment with 100% P_2O_5 through PROM (4.4 mg kg^{-1}) showed at par results with T_8. It was interesting to note that 100% P_2O_5 through PROM, 75% P_2O_5 through PROM, and 50% P_2O_5 through PROM showed significantly higher results (4.4 mg kg^{-1}, 4.1 mg kg^{-1}, and 3.9 mg kg^{-1}, respectively) over the recommended doses of fertilizers 50:75:45 kg ha^{-1} N: P_2O_5: K_2O (3.5 mg kg^{-1}). These results highlight the importance of PROM in increasing zinc availability in soil.

Available copper: The data on the availability of copper in soil showcased substantial change across diverse fertilizer treatments, reflecting the intricate dynamics influenced by varying phosphorus levels and sources. The application of T_8-100% P_2O_5 through vermicompost substantially resulted in significantly higher availability of copper in soil (10.4 mg kg^{-1}). The application of 100% P_2O_5 through SSP+FYM @12.5 t ha^{-1} (10.0 mg kg^{-1}) and 100% P_2O_5 through DAP+FYM @12.5 t ha^{-1} (10.0 mg kg^{-1}) showed similar results with T_8. The application of 100% P_2O_5 through PROM found significantly better (9.8 mg kg^{-1}) results in terms of copper content in soil over the treatment-recommended dose of fertilizer (9.1 mg kg^{-1}).

The increase in soil nutrient availability after the application of various organic and inorganic fertilizers, including FYM, vermicompost, and PROM, can be attributed to multiple factors. Organic manures enhance microbial activity, which in turn promotes nutrient mineralization, releasing essential elements such as nitrogen, phosphorus, and potassium over a prolonged period. The microbial decomposition of organic matter also produces organic acids that increase the solubility of native phosphates and micronutrients like iron, manganese, zinc, and copper. Organic manures like PROM and vermicompost add organic colloids to the soil, increasing cation exchange capacity and improving nutrient retention. The gradual decomposition of these organic materials releases CO_2, which forms carbonic acids that break down primary soil minerals, releasing additional nutrients. The symbiotic activity of nitrogen-fixing bacteria like Rhizobium further enhances nitrogen availability in soybean cropping systems. These processes collectively improve the bio-physicochemical characteristics of soil, ensuring a sustained and efficient release of nutrients throughout the crop's growing period (Bharadwaj and Omanwar, 1994; Singh et al., 2012; Khan et al., 1984; Majumdar et al., 2005; Chesti et al., 2015; Mehta and Patel, 1967; Katyal and Sharma, 1991; Tisdale et al., 1993).

4. CONCLUSION

The study revealed that the application of organic fertilizers, such as PROM, FYM, and vermicompost, significantly enhanced nutrient use efficiency and soil health compared to the recommended dose of fertilizer. Among the organic sources, PROM was particularly effective in improving phosphorus use efficiency and increasing the availability of essential micronutrients like iron, manganese, zinc, and copper. The combination of organic and inorganic fertilizers also demonstrated synergistic effects in improving nutrient uptake and soil fertility. Overall, the findings suggest that integrating organic fertilizers into agricultural practices can be a sustainable and beneficial approach for enhancing crop productivity and promoting soil health.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Babhulkar, P. S., Wandile, R. M., Badole, W. P., & Balpande, S. S. (2000). Residual effect of long-term application of FYM and fertilization on soil properties (Vertisols) and yield of soybean. *Journal of the Indian Society of Soil Science, 48*, 89–92.

Bharadwaj, V., & Omanwar, P. K. (1994). Long-term effects of continuous rotational cropping and fertilization on crop yields and soil properties II. Effects on EC, pH, organic matter and available nutrients of soil. *Journal of the Indian Society of Soil Science, 42*, 387–392.

Chesti, M. H., Kohli, A., Mujtaba, A., Sofi, J. A., Qadri, T. N., Peer, Q. J. A., Dar, M. A., & Bisati, I. A. (2015). Effect of integrated application of inorganic and organic sources on soil properties, yield, and nutrient uptake by rice in the intermediate zone of Jammu and Kashmir. *Journal of the Indian Society of Soil Science, 63*(1), 88–92.

Dwivedi, A. K., Singh, M., Kauraw, D. L., Wanjari, R. H., & Chauhan, S. S. (2007). Research bulletin on impact of fertilizer and manure use for three decades on crop productivity and sustainability and soil quality under Soybean-Wheat system on a Vertisol in Central India. *Indian Institute of Soil Science*, 224–235.

Havlin, J. L., Beaton, J. D., Tisdale, S. L., & Nelson, W. L. (2007). *Soil fertility and fertilizers: An introduction to nutrient management* (7th ed., pp. 162–163, 171, & 199).

Kaleem, A. M., Manzoor, M., & Tahir, M. M. (2010). Efficiency of rhizobium inoculation and P fertilization in enhancing nodulation, seed yield, and phosphorus use efficiency by field-grown soybean under the hilly region of Rawalakot Azad Jammu and Kashmir, Pakistan. *Journal of Plant Nutrition, 33*(7), 1080–1102.

Katyal, J. C., & Sharma, B. D. (1991). DTPA extractable and total Zn, Cu, Mn, and Fe in Indian soils and their association with some soil properties. *Geoderma, 49*, 165–179.

Khan, G., Gupta, S. K., & Banerjee, S. K. (1984). Studies on solubilization of phosphorus in presence of different city wastes. *Journal of the Indian Society of Soil Science, 29*, 123–124.

Majumdar, B., Venkatesh, M. S., Kumar, K., & Patiram. (2005). Effect of potassium and farmyard manure on yield, nutrient uptake, and quality of ginger in a Typic hapludalf of Meghalaya. *Indian Journal of Agricultural Science, 75*, 809–811.

Makwana, S. N., Patel, G. G., Patel, H. K., Shiyal, V. N., & Patel, B. K. (2020). Effect of inorganic and organic nutrients on growth and yield of summer green gram (*Vigna radiata* L.). *International Journal of Current Microbiology and Applied Sciences, 1*(11), 730–738.

Malhotra, H., Vandana, Sharma, S., & Pandey, R. (2018). *Phosphorus nutrition, plant growth in response to deficiency and excess*. Mineral Nutrition Laboratory, Division of Plant Physiology, ICAR-Indian Agricultural Research Institute, New Delhi, India.

Mehta, B. V., & Patel, N. K. (1967). Forms of manganese and their distribution in soil profiles of Kaira district of Gujarat. *Journal of the Indian Society of Soil Science, 15*, 41–47.

Naseer, M., & Muhammad, D. (2014). Direct and residual effect of Hazara rock phosphate (HRP) on wheat and succeeding maize in alkaline calcareous soils. *Pakistan Journal of Botany, 46*(5), 1755–1761.

Panse, V. A., & Sukhatme, P. V. (1985). *Statistical methods for agricultural workers* (Revised ed.). ICAR, New Delhi.

Sims, J. T., & Sharpley, A. N. (2005). Phosphorus in agriculture: Problems and solutions. *Journal of Environmental Quality, 34*(2), 758–764.

Singh, M., Wanjari, R. H., Dwivedi, A., & Dalal, R. (2012). Yield response to applied nutrients and estimates of N2 fixation in a 33-year-old soybean–wheat experiment on a Vertisol. *Experimental Agriculture, 48*, 311–325.

Siva Sankar, A., Reddy, P. R., & Subba Rao, I. V. (1984). Nodulation and nitrogen fixation in groundnut as affected by seed size and phosphorus. *Legume Research, 7*(1), 5.

Tisdale, S. L., Nelson, W. L., Beaton, J. D., & Havlin, J. L. (1993). *Soil fertility and fertilizers* (pp. 634). MacMillan Publishers.

Yaduvanshi, N. P. S. (2001). Effect of five years of rice–wheat cropping and NPK fertilizer use with and without organic and green manures on soil properties and crop yield in a reclaimed sodic soil. *Journal of the Indian Society of Soil Science, 49*, 774–719.

Peer-review history:
The peer review history for this paper can be accessed here:
https://prh.ikprress.org/review-history/12471