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Impact of Different Levels and Sources of P on Grain Quality and Crop Productivity of Pearl Millet in Semi–arid Region of Northwest India

Preeti [a++], Sunita Sheoran [b#], Dhram Prakash [c†*], Rameshwar Singh [c†], Rajni Kant Sharma [a‡], Ravinder Singh Chauhan [a^], Priyanka [a##], Ravina Yadav [a++] and Neetu Choudhary [d##]

[a] Chaudhary Charan Singh Haryana Agricultural University, Hisar (125004) India.
[b] CCS HAU College of Agriculture, Bawal, Rewari (123501) India.
[c] CCS HAU Regional Research Station, Bawal, Rewari (123501) India.
[d] Rajmata Vijayaraje Scindia Krishi Vidhyalaya (RVSKVV), Gwalior, MP (474002) India.

Authors' contributions

This work was carried out in collaboration among all authors. Author Preeti performed data processing and prepared the draft copy of the manuscript; Authors SS and DP carried out correction, editing, and final preparation of the manuscript; Authors RS, RKS, RSC, Priyanka, RY, and NC handled data arrangement. All authors read and approved the final manuscript.

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[++] PhD Scholar; [#] Assistant Professor; [†] Assistant Scientist; [‡] Associate Professor;
[^] Senior District Extension Specialist (Plant Pathology); [##] Msc Scholar;
**Corresponding author: E-mail: dhramprakashteotia@gmail.com;*

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ABSTRACT

A field study was conducted during the *Kharif* season of 2021 at the Research Farm of the Department of Soil Science, CCS HAU, Hisar, to assess the influence of various phosphorus levels and sources on yield and nutrient uptake by pearl millet crop. The study included eleven treatment combinations, arranged in a randomized block design (RBD) with three replications. Adoption of different nutrient management practices significantly improved the crop yield and nutrients uptake (N and K). The highest (33.66 and 80.70 q ha^{-1}) grain and straw yield of pearl millet was observed with the application of 7.5 t of FYM ha^{-1} along with SSP over rest of the treatments. Highest N content (1.94 and 1.42 % in grain and straw, respectively) and protein content (12.13 %) of pearl millet was observed with the application of full recommended dose of P through SSP. Whereas, K content was found highest (0.44 and 1.85 %) with the supply of 7.5 t of FYM ha^{-1} in conjunction with SSP. Similarly, highest N uptake (163.26 kg ha^{-1}) by pearl millet was observed with the application of full recommended dose of P through SSP, whereas, K uptake was found highest (164.10 kg ha^{-1}) with the supply of 7.5 t of FYM ha^{-1} in conjunction with SSP over other treatments. The results from the study indicated that instead of using P fertilizers alone, the integrated use of FYM and P fertilizers may be more effective to improve nutrient uptake and to sustain crop productivity.

Keywords: Crop yield; phosphorus; nutrient uptake; protein content and farmyard manure.

1. INTRODUCTION

Pearl millet is one of the most important staple food crop adopted by poor and small land holders in Asia and Africa continent (Gurjar et al., 2022, Saini et al., 2024). It accounts for 50% of global millet's production and occupies an area of 6.93 mha with an average production of 9.62 m tones and productivity of 1436 kg ha^{-1} (Anonymous, 2023). It is the sixth most important cereal crop in the world next to maize, rice, wheat, barley and sorghum (Satyavathi et al*.,* 2021). The pearl millet grain contains high protein content, balanced amino acid profile, high levels of iron, zinc and insoluble dietary fiber (Sheoran et al*.,* 2024). It has special health benefiting properties for people suffering from diseases like diabetes, obesity, allergy and acidity *etc.* as it has high proportions of slowly digestible starch (SDS) and resistant starch (RS) that contribute to low glycemic index (GI). Pearl millet-based cropping system is most popular in semi-arid tropics of India, because of its limited water requirement, low requirements of inputs and labour and high profitability compared to other intensive cropping sequences (Sheoran et al*.,* 2024). But, now a day's agriculture is facing several issues like low fertilizer use efficiency, stagnation in crop productivity, imbalance between nutrient removal and supply in the soils. So, the balanced nutrition is needed which could be achieved through adoption of best nutrient management practices (Bedoussac et al*.,* 2015).

Phosphorus (P) is considered the second most essential macronutrient after nitrogen, and most crops show a positive response to its application. Deficiency of this nutrient is widespread across the globe. Phosphorus plays a vital role in cell division, root development, grain formation, the growth of reproductive structures, and it is a key component of nucleic acids (Blackshaw et al*.,* 2004). It also helps mitigate the adverse effects of excessive nitrogen in plants. In addition, phosphorus supports the activity of nitrogen-fixing bacteria, promotes pod development, and accelerates pod maturity, thereby enhancing nitrogen accumulation (Tisdale et al*.,* 1984). Despite its importance, phosphorus is among the least mobile and least available nutrients in the soil, and its limited availability often constrains plant growth. Worldwide, an estimated 5.7 billion hectares of agricultural land suffer from phosphorus deficiency (Dhillon et al., 2017). Therefore, sufficient quantity of soluble form of phosphorus fertilizers are applied to achieve maximum plant productivity, improves agronomic efficiency, and uptake of essential nutrients (Prakash et al., 2018; Urlić et al*.,* 2023, Marzouk et al*.,* 2024). Single super phosphate (SSP) and di-ammonium phosphate (DAP) are commonly used as inorganic P fertilizers by the farmers. SSP contains 16 % P_2O_5, 11-12% sulfur, and 20% calcium and it does not have a great influence on soil pH. Whereas, DAP contains 18-21% N and 46-53% P_2O_5 and temporarily lowers the soil pH initially. Both SSP and DAP are water soluble fertilizers, contains P in readily available form for plants and is widely used in India. So, inorganic P fertilizers are used in many agroecosystems, but only 20–30 % of the P applied is taken up by plants during the initial

period (Richardson and Simpson, 2011), and remaining leads to P losses through runoff from soils, contributing to P accumulation in water bodies, that causes eutrophication and toxic algal blooms in aquatic environment (Zak et al*.,* 2018, Han et al., 2022). Moreover, mineral fertilizers *viz*. phosphate rock is non-renewable P resource (Dawson and Hilton, 2011, Ning et al*.,* 2020). So, for avoiding these limitations and improving the use efficiency of P fertilizers, conjoint use of manures and chemical fertilizers depending upon the availability, nature and properties of the soil and crops, can be used. This would not only maximize the crop production and improve the quality of agricultural produces but would also help in maintaining the fertility. The productivity and quality of the soil would be maintained via improving soil organic matter (SOM), microbial biodiversity and populations (Meena and Biswas, 2013, Parihar et al., 2013).

Considering the above facts, this experiment was conducted at Hisar with the aim to evaluate the impact of different levels and sources of phosphorus application on grain quality and crop productivity under Pearl Millet-Mustard cropping system in semi-arid regions of North-west India.

2. MATERIALS AND METHODS

2.1 Study Location and Treatment Details

The field experiment was started in *Rabi*, 2020 at Research Farm, Department of Soil Science. The experimental site is situated at coordinates $29^0$10 latitude and $75^0$46 longitudes in the northwest region of India. The climate in this region is semi-arid, characterized by an average annual temperature of 24.8^{0}C and average yearly rainfall 443 mm. The soil had a sandy loam texture having initial pH of 7.98, electrical conductivity (EC) 0.31 dSm^{-1}, soil organic carbon content of 0.45 %, available N of 134.0 mg kg^{-1}, available P of 12.27 mg kg^{-1} and available K of 420.0 mg kg^{-1}. The experiment encompassed a total of eleven treatments, which included the recommended dose of P applied *via* fertilizers such as DAP, RP, and SSP, or half of the recommended P fertilizers in combination with 7.5 t FYM ha^{-1}. It was replicated three times in a randomized block design on permanent plots, as shown in Table 1. The FYM was incorporated on a dry weight basis prior to sowing the pearl millet crop. Urea served as the nitrogen source administered in two equal portions across all treatments except the control.

2.2 Sample Collection, Preparation and Analysis

After field preparation, pearl millet variety HHB 299 was sown in August, 2021 and harvested manually in November, 2021 at about 2-3 cm above the ground level. After harvesting of the crop, each plot was threshed separately. Grain yield and bundle weight from each plot was recorded and computed as q ha^{-1}. Straw yield for each plot was worked out by subtracting the grain yield from total biological yield of individual plot.

Representative grain and straw samples from individual plots were collected and were initially dried in air and then in an oven at 60±2^{0}C. For estimation of N, 0.5 g of plant material was digested in concentrated (H_2SO_4:$HClO_4$::4:1) digestion mixture. After digestion, the N was determined by colorimetric (Nessler's reagent) method and the intensity of developed orange color was measured at 440 nm using visible spectrophotometer. For the estimation of P and K, 0.5 g of the plant sample was digested in 4:1 nitric acid and perchloric acid (HNO_3: $HClO_4$) mixture. Total P in digested sample was determined by Vanado-molybdate yellow color method (Jackson, 1973) and the intensity of yellow color was measured at 440 nm using visible spectrophotometer. Potassium in the extract was determined by flame-photometer.

Protein content in grain was estimated by multiplying nitrogen content in grain (percentage) by a factor 6.25 (Gassi et al*.,*1973).

> Protein content (%) = Nitrogen content in grain (%) x 6.25

The nutrient uptake by the pearl millet crop was computed from the data of N and K concentration and grain and straw yield, using the following formula:

> Nutrient uptake (kg ha^{-1}) = Nutrient content in grain or straw (%) x grain or straw yield (q ha^{-1})

2.3 Statistical Analysis

The experimental outcomes were scrutinized through an online statistical analysis platform (OPSTAT: Sheoran et al., 1998). The CD value was determined through a significance level of 5% ($\alpha = 0.05$).

Table 1. Treatment details carried out during the experiment

Treatment no.	Pearl millet (HHB 299)	Mustard (RH 725)
T_1	Control	Control
T_2	P_{60SSP}	P_{20SSP}
T_3	P_{60DAP}	P_{20DAP}
T_4	P_{60RP}	P_{20RP}
T_5	P_{60RP}	P_{20SSP}
T_6	P_{60RP}	P_{20DAP}
T_7	$FYM_{7.5t}+P_{30SSP}$	$FYM_{7.5t}+P_{10SSP}$
T_8	$FYM_{7.5t}+P_{30DAP}$	$FYM_{7.5t}+P_{10DAP}$
T_9	$FYM_{7.5t}+P_{30RP}$	$FYM_{7.5t}+P_{10RP}$
T_{10}	$FYM_{7.5t}+P_{30RP}$	$FYM_{7.5t}+P_{10SSP}$
T_{11}	$FYM_{7.5t}+P_{30RP}$	$FYM_{7.5t}+P_{10DAP}$

SSP- single super phosphate, DAP- di-ammonium phosphate, RP- rock phosphate and FYM – farm-yard manure

3. RESULTS AND DISCUSSION

3.1 Grain and Straw Yield

The grain and straw yield of pearl millet ranged from 23.79 to 33.66 q ha^{-1} and 50.81 to 80.70 q ha^{-1}, respectively, under various treatments (Table 2). The application of various nutrients management sources increased the grain and straw yield over control. The results are in line with the outcomes of several studies by - Tang et al*.* (2011); Noonari et al*.* (2016); Mussarat et al. (2021); Navghare et al. (2023); Kumari et al. (2024); Meshram et al. (2024); Yan et al. (2024); Sheoran et al*.* (2025). The highest and lowest grain and straw yield was obtained with the application of 7.5 t FYM ha^{-1} along with half recommended dose of P through SSP (T_7) and in the control plots (T_1), respectively. Application of full recommended dose of P through various P fertilizers significantly and RP non-significantly increased the grain yield over control. However, application of full recommended dose of P through various P fertilizers significantly increased the straw yield over the control. Addition of full recommended dose of P through SSP showed higher grain and straw yield followed by DAP and RP. However, application of various P fertilizers doses showed non-significant effect with each other. The higher productivity with SSP over other phosphatic fertilizers sources might be attributed to the additional amount of sulphur in SSP, that has also been reported by several authors (Khan et al*.,* 2010; Saha et al., 2013; Ahmad et al*.,* 2019; Vora et al*.,* 2018; Amanullah et al*.,* 2019). Application of 7.5 t FYM ha^{-1} in combination with half of recommended dose of P through various chemical fertilizers significantly increased the grain and straw yield over control (Brar et al*.,* 2015; Waheed et al*.,* 2015). Incorporation of FYM along with P through SSP showed higher grain and straw yield followed by FYM along with RP and DAP. Application of full recommended dose of P through SSP, DAP and RP in both crops increased the grain yield by 25.76%, 20.84% and 11.55%, respectively, and straw yield by 45.83%, 38.57% and 28.51%, respectively, over control treatment. Application of half recommended dose of P through SSP, DAP, RP along with 7.5 t of FYM ha^{-1} in both the crops increased the grain yield by 12.5%, 8.20% and 23.88%, and straw yield by 8.9%, 7.66% and 21.43%, over application of full recommended dose of P through SSP, DAP and RP in both crops, respectively. However, application of $FYM_{7.5t}+P_{30RP}$ under treatments T_{10} and T_{11} increased the grain yield by 12.01% and 12.95 % over T_5 and T_6, respectively.

3.2 Nutrient Content (N and K)

Application of P fertilizers significantly increased the N content in pearl millet grain and straw over control plots (Table 2). Similar results were also reported by Jadav et al*.* (2016); Patel (2016); Singh (2018); Patel et al*.* (2019); Chauhan et al. (2020); Mahmood et al. (2020); Kumari et al. (2024); Yan et al. (2024); Sheoran et al*.* (2025). The N content in pearl millet grain varied from 1.56% to 1.94% and straw from 0.76% to 1.42% under various treatments (Table 2). The highest and lowest N content in grain and straw was observed with thse application of full recommended dose of P through SSP (T_2) and control plots (T_1), respectively. The full recommended dose of P or FYM along with half recommended dose of P applied through various doses of P fertilizers significantly increased the N content. Addition of P through SSP showed higher N content followed by DAP and RP (Table 2). Similar results were reported by Gaind & Nain (2007); Awaad et al*.* (2009), Saha et al. (2013); Alkhader et al*.* (2015), Waheed et al. (2015).

Potassium content in pearl millet grain and straw varied from 0.27% to 0.44% and 1.34% to 1.85% under various treatments (Table 2). The highest and the lowest K content was found with the application of FYM along with half recommended dose of P through SSP (T_7) and control plots (T_1), respectively. Application of P through various P fertilizers increased the K content over control. The effect of application of full recommended doses of P through fertilizers was significant except for T_4 (P_{60RP}) in grain and non-significant in straw, except for T_2 (P_{60SSP}) and T_5 (P_{60RP}). Addition of P through SSP showed higher K content followed by DAP and RP (Alkhader et al*.,* 2015, Waheed et al., 2015).

3.3 Protein Content

Protein content in pearl millet grain varied from 9.75% to 12.33% under various treatments (Table 2) and application of different nutrient management sources increased the protein content in grain over control. This was also reported by Mali et al*.* (2017); Ranpariya et al*.* (2017); Bhuva and Detroja (2018); Bhawariya et al*.* (2022); Sunda et al*.* (2023); Sheoran et al*.* (2024). The highest and lowest protein content was observed with the application of full recommended dose of P through DAP and control plots, respectively. Increased protein content in plots receiving P fertilizers could be linked to enhanced nitrogen uptake by the grain, supported by the residual effect of phosphorus. Application of P through various P fertilizers significantly increased the protein content in grain over control. The full recommended dose of P applied through DAP showed higher protein content as compared to SSP and RP. Application of 7.5 t FYM ha^{-1} in combination with half of recommended dose of P through various chemical fertilizers significantly increased the protein content over control. This result was also reported by Mali et al*.* (2017); Bhawariya et al*.* (2022); Sunda et al*.* (2023). Incorporation of FYM along with P through SSP showed higher protein content as compared to FYM along with P through DAP or RP. Application of FYM along with RP non-significantly increased the protein content as compared to full recommended dose of P through RP. However, FYM along with SSP and DAP showed significant lower protein content in pearl millet grain as compared to full recommended dose of P through SSP and DAP.

3.4 Nutrient Uptake

The N uptake by pearl millet grain and straw varied from 37.11 to 61.26 kg ha^{-1} and 38.61 to 105.22 kg ha^{-1}, respectively, under various treatments (Table 3). The highest N uptake by grain was found with the application of 7.5 t FYM ha^{-1} along with half of recommended dose of P through SSP (T_7). However, full recommended dose of P through SSP (T_2) showed highest N uptake in straw. Application of full recommended dose of P and FYM along with half recommended dose of P significantly increased the N uptake over control. Addition of full recommended dose of P through SSP or application of FYM along with half recommended dose of P through SSP showed higher N uptake followed by DAP and RP. Similar results were also reported by Alkhader et al*.,* (2015); Waheed et al., (2015); Khan et al*.*, (2018); Wabela et al*.,* (2024).

Data presented in Table 3 revealed that K uptake by pearl millet grain and straw varied from 6.42 to 14.81 kg ha^{-1} and 68.08 to 149.29 kg ha^{-1}, respectively. Under various treatments and applications of different nutrient management sources increased the K uptake by grain and straw over control. This was also reported by Wabela et al*.,* (2024); Yan et al. (2024). The highest and lowest K uptake was observed with the application of 7.5 t FYM ha^{-1} alongwith half of recommended dose of P through SSP and control plots, respectively. Application of P through various P fertilizers significantly increased the K uptake by pearl millet grain and straw over control. Similar results were findings by Chauhan et al., (2020); Mahmood et al., (2020). With full recommended dose of P and FYM along with half recommended dose of P through SSP showed higher K uptake followed by DAP and RP.

3.5 Total Nutrient Uptake by Pearl Millet

Total N and K uptake by pearl millet varied from 75.72 to 163.26 kg ha^{-1} and 74.50 to 164.10 kg ha^{-1} under various treatments (Table 3). The highest and lowest total N and K uptake was observed with the application of full recommended dose of P through SSP (T_2) and FYM along with half recommended dose of P through SSP and control plots (T_1), respectively. Application of full recommended dose of P through various P fertilizers significantly increased N uptake (T_2: 163.26, T_3: 149.54 and T_4: 101.00 kg ha^{-1} for SSP, DAP and RP, respectively) and K uptake (T_2: 131.87, T_3: 117.08 and T_4: 103.42 kg ha^{-1} for SSP, DAP and RP, respectively), over the control. Addition of full recommended dose of P through SSP showed

higher total N and K uptake. These results were also reported by Khan et al. (2019). Effects of application of various P fertilizers showing significant effect with each other were also reported by Alkhader et al., (2015); Waheed & Arshad (2015). It may be attributed to the more mineralization and solubilization of available nutrients through direct and indirect mechanism of nutrients in soil and transport of nutrients to plant. Incorporation of 7.5 t FYM ha^{-1} in combination with half of recommended dose of P through various chemical fertilizers (T_7: 151.64, T_8: 137.24 and T_9: 133.14 kg ha^{-1} for FYM along with SSP, DAP and RP, respectively and T_7: 164.10, T_8: 146.31 and T_9: 132.31 kg ha^{-1} for FYM along with SSP, DAP and RP, respectively), significantly increased the total N and P uptake, respectively over the control. Incorporation of FYM along with P through SSP showed significantly higher total N and K uptake as compared to application of FYM along with P through DAP and RP. Application of FYM along with half of recommended dose of P through SSP and DAP showed significantly lower total N uptake as compared to full recommended dose of P through SSP and DAP. Application of FYM along with RP significantly increased the total N uptake as compared to full recommended dose of P through RP. Whereas, application of FYM along with half of recommended dose of P through SSP, DAP and RP significantly increased the total K uptake as compared to full recommended dose of P through SSP, DAP and RP.

Table 2. Effect of different levels and sources of phosphorus on grain and straw yield, nutrient content (N and K) in grain and straw and protein content in pearl millet

Treatment no.	Pearl millet	Mustard	Crop yield (q ha^{-1})		Grain		Straw		Protein content (%)
			Grain	Straw	N (%)	K (%)	N (%)	K (%)	
T_1	Control	Control	23.79	50.81	1.56	0.27	0.76	1.34	9.75
T_2	P_{60SSP}	P_{20SSP}	29.92	74.10	1.94	0.37	1.42	1.63	12.13
T_3	P_{60DAP}	P_{20DAP}	28.75	70.41	1.92	0.35	1.34	1.52	12.00
T_4	P_{60RP}	P_{20RP}	26.54	65.30	1.69	0.28	0.86	1.47	10.56
T_5	P_{60RP}	P_{20SSP}	27.88	69.52	1.83	0.33	1.23	1.58	11.44
T_6	P_{60RP}	P_{20DAP}	27.25	67.25	1.80	0.32	1.13	1.50	11.25
T_7	$FYM_{7.5t}+P_{30SSP}$	$FYM_{7.5t}+P_{10SSP}$	33.66	80.70	1.82	0.44	1.12	1.85	11.38
T_8	$FYM_{7.5t}+P_{30DAP}$	$FYM_{7.5t}+P_{10DAP}$	31.11	75.81	1.78	0.39	1.08	1.77	11.13
T_9	$FYM_{7.5t}+P_{30RP}$	$FYM_{7.5t}+P_{10RP}$	32.88	79.30	1.71	0.31	0.97	1.54	10.69
T_{10}	$FYM_{7.5t}+P_{30RP}$	$FYM_{7.5t}+P_{10SSP}$	31.23	76.92	1.76	0.38	1.08	1.80	11.00
T_{11}	$FYM_{7.5t}+P_{30RP}$	$FYM_{7.5t}+P_{10DAP}$	30.78	74.65	1.74	0.36	1.06	1.73	10.88
CD (0.05)			3.94	6.59	0.11	0.02	0.07	0.20	0.68

Table 3. Effect of different levels and sources of phosphorus on nutrient uptake (N and K) in grain and straw

Treatment nº.	Pearl millet	Mustard	N uptake (kg ha^{-1})			K uptake (kg ha^{-1})		
			Grain	Straw	Total	Grain	Straw	Total
T_1	Control	Control	37.11	38.61	75.72	6.42	68.08	74.50
T_2	P_{60SSP}	P_{20SSP}	58.04	105.22	163.26	11.07	120.78	131.87
T_3	P_{60DAP}	P_{20DAP}	55.20	94.34	149.54	10.06	107.02	117.08
T_4	P_{60RP}	P_{20RP}	44.85	56.15	101.00	7.43	95.99	103.42
T_5	P_{60RP}	P_{20SSP}	51.02	85.50	136.52	9.20	109.84	119.04
T_6	P_{60RP}	P_{20DAP}	49.05	75.99	125.04	8.72	100.87	109.59
T_7	$FYM_{7.5t}+P_{30SSP}$	$FYM_{7.5t}+P_{10SSP}$	61.26	90.38	151.64	14.81	149.29	164.10
T_8	$FYM_{7.5t}+P_{30DAP}$	$FYM_{7.5t}+P_{10DAP}$	55.37	81.87	137.24	12.13	134.18	146.31
T_9	$FYM_{7.5t}+P_{30RP}$	$FYM_{7.5t}+P_{10RP}$	56.22	76.92	133.14	10.19	122.12	132.31
T_{10}	$FYM_{7.5t}+P_{30RP}$	$FYM_{7.5t}+P_{10SSP}$	54.96	83.07	138.03	11.86	138.45	150.31
T_{11}	$FYM_{7.5t}+P_{30RP}$	$FYM_{7.5t}+P_{10DAP}$	53.55	79.12	132.67	11.08	129.14	140.22
CD (0.05)			5.92	1.84	11.08	1.15	6.54	5.20

4. CONCLUSION

The results revealed that the application of P fertilizer either alone or in combination with farmyard manure (FYM), enhances productivity and nutrient uptake of pearl millet. Among the various P sources, application of SSP either alone or in combination with 7.5 t FYM ha^{-1} is beneficial for most of the studied variables. Therefore, it is concluded that instead of using P fertilizers alone, the integrated use of FYM and P fertilizers would be more effective to improve soil health and to sustain crop productivity.

ETHICAL APPROVAL

"All the authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki."

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.

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COMPETING INTERESTS

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Ahmad, M., Khan, I., Muhammad, D., Mussarat, M., & Shafi, M. I. (2019). Effect of phosphorus sources and their levels on spring maize. *Pakistan Journal of Scientific and Industrial Research Series B: Biological Sciences, 62*(1), 8–14. https://doi.org/10.52763/PJSIR.BIOL.SCI.62.1.2019.8.14

AlKhader, A. M. F., & Abu Rayyan, A. M. (2015). The impact of phosphorus fertilizers on nutrients content and uptake in lettuce (*Lactuca sativa* L.) and on selected chemical properties of a calcareous soil. *Jordan Journal of Agricultural Sciences, 11*(4), 1021–1034. https://doi.org/10.12816/0011034

Amanullah, D., Khan, N., Khan, M. I., Khalid, S., Iqbal, A., & Tawaha, A. R. (2019). Wheat biomass and harvest index increases with integrated use of phosphorus, zinc and beneficial microbes under semi-arid climates. *Journal of Microbiology, Biotechnology and Food Science, 9*(2), 242–247. https://doi.org/10.15414/jmbfs.2019.9.2.242-247

Anonymous. (2023). *Agricultural statistics at a glance 2023*. Department of Agriculture & Farmers Welfare, Economics & Statistics Division, Ministry of Agriculture & Farmers Welfare, Government of India. https://desagri.gov.in/wp-content/uploads/2024/09/Agricultural-Statistics-at-a-Glance-2023.pdf

Awaad, M. S., Rashad, A. A., & Bayoumi, M. A. (2009). Effect of farmyard manure combined with some phosphate sources on the productivity of canola plants grown on a sandy soil. *Research Journal of Agriculture and Biological Sciences, 5*, 1176–1181. http://www.aensiweb.com/rjabs.html

Bedoussac, L., Journet, E. P., Hauggaard-Nielsen, H., Naudin, C., Corre-Hellou, G., Jensen, E. S., Prieur, L., & Justes, E. (2015). Ecological principles underlying the increase of productivity achieved by cereal–grain legume intercrops in organic farming: A review. *Agronomy for Sustainable Development, 35*, 911–935. https://doi.org/10.1007/s13593-014-0277-7

Bhawariya, A., Pareek, N. K., Sunda, S. L., Singh, B., Rathore, M. K. R., Dhayal, S., & Kanwar, A. (2022). Quality parameters of cluster bean (*Cyamopsis tetragonoloba* L. Taub.) as influenced by organics and fertilizers. *The Pharma Innovation Journal, 11*(4), 1454–1457. https://doi.org/10.35248/0970-1907.24.40.1042-1045

Bhuva, H. M., & Detroja, A. C. (2018). Influence of nutrient management with organic manures on productivity, profitability and quality of pearl millet (*Pennisetum glaucum*)–chickpea (*Cicer arietinum*)

sequence. *Indian Journal of Agronomy*. https://doi.org/10.59797/ija.v63i3.5651

Blackshaw, R. E., Brandt, R. N., Janzen, H. H., & Entz, T. (2004). Weed species response to phosphorus fertilization. *Weed Science, 52*(3), 406–412. https://doi.org/10.1614/WS-03-122R

Brar, B. S., Singh, J., Singh, G., & Kaur, G. (2015). Effects of long-term application of inorganic and organic fertilizers on soil organic carbon and physical properties in maize–wheat rotation. *Agronomy, 5*, 220–238. https://doi.org/10.3390/agronomy5020220

Chauhan, Z. Y., Patel, D. K., & Bhabhor, K. (2020). Effect of nitrogen, phosphorus and sulphur on yield, nutrient uptake and soil fertility after harvest of mustard (*Brassica juncea* L.). *International Journal of Current Microbiology and Applied Sciences, 9*(6), 3506–3512. https://doi.org/10.20546/ijcmas.2020.906.412

Dawson, C. J., & Hilton, J. (2011). Fertiliser availability in a resource-limited world: Production and recycling of nitrogen and phosphorus. *Food Policy, 36*, S14–S22. https://doi.org/10.1016/j.foodpol.2010.11.012

Dhillon, J., Torres, G., Driver, E., Figueiredo, B., & Raun, W. R. (2017). World phosphorus use efficiency in cereal crops. *Agronomy Journal, 109*, 1670–1677. https://doi.org/10.2134/agronj2016.08.0483

Gaind, S., & Nain, L. (2007). Chemical and biological properties of wheat soil in response to paddy straw incorporation and its biodegradation by fungal inoculants. *Biodegradation, 18*(4), 495–503. https://doi.org/10.1007/s10532-006-9082-6

Gassi, S., Tikoo, J. L., & Banerjee, S. K. (1973). Changes in protein and methionine content in the maturing seeds of legumes. *Seed Research, 1*, 104–106. https://seedresearch.org/

Gurjar, B. S., Singh, K., Yogi, A. K., & Khangarot, A. K. (2022). Effect of foliar nutrition on pearl millet performance: A review. *The Pharma Innovation, 11*(2), 1682–1687. https://doi.org/10.22271/Pharma.2022.v11.i2x.2003

Han, Y., White, P. J., & Cheng, L. (2022). Mechanisms for improving phosphorus utilization efficiency in plants: A review. *Annals of Botany*. https://doi.org/10.1093/aob/mcab145

Jackson, M. L. (1973). *Soil chemical analysis*. Prentice Hall. https://www.scirp.org/reference/referencespapers?referenceid=2511222

Jadav, N. J., Parmar, J. K., Gangwal, T. V., & Patel, M. V. (2016). Effect of phosphorus, sulphur and phosphate solubilizing bacteria on yield, nutrient uptake and soil fertility after harvest of mustard. *Asian Journal of Soil Science, 11*(2), 307–317. https://doi.org/10.15740/HAS/AJSS/11.2/307-317

Khan, A., Lu, G., Ayaz, M., Zhang, H., Wang, R., Lv, F., Sun, B., & Zhang, S. (2018). Phosphorus efficiency, soil phosphorus dynamics and critical phosphorus level under long-term fertilization for single and double cropping systems. *Agriculture, Ecosystems and Environment*. https://doi.org/10.1016/j.agee.2018.01.006

Khan, M. B., Lone, M. I., Ullah, R., Kaleem, S., & Ahmed, M. (2010). Effect of different phosphatic fertilizers on growth attributes of wheat (*Triticum aestivum* L.). *Journal of American Science, 6*(12), 1256–1262. http://www.americanscience.org

Khan, M., Shah, S. S., Khan, A., Sarwar, M., & Ahmed, S. (2019). Efficacy of manually prepared single super phosphate fertilizer on rain-fed wheat crop under sub-humid climate. *Pakistan Journal of Agricultural Research, 32*(3), 527–534. https://doi.org/10.17582/journal.pjar/2019/32.3.527.534

Kumari, M., Prakash, D., Sheoran, S., Yadav, P. K., Ankit, Y., H. K., Apurva, Gupta, R. K., El-Hendawy, S., & Mattar, M. A. (2024). Long-term manuring and fertilization influence on soil properties and wheat productivity in semi-arid regions. *Agronomy, 14*(10), 2383. https://doi.org/10.3390/agronomy14102383

Mahmood, M., Tian, Y., Ma, Q., Ahmed, W., Mehmood, S., Hui, X., & Wang, Z. (2020). Changes in phosphorus fractions and its availability status in relation to long-term P fertilization in loess plateau of China. *Agronomy*. https://doi.org/10.3390/agronomy10111818

Mali, M. K., Meena, R. H., & Jat, G. (2017). Effect of composted rock phosphate with organic materials on yield, nutrient uptake and soil fertility after harvest of maize (*Zea mays* L.). *International Journal of Current Microbiology and Applied Sciences*. https://doi.org/10.20546/ijcmas.2017.606.106

Marzouk, S. H., Tindwa, H. J., Amuri, N. A., Chande, H. H., & Semoka, J. M. (2024). Enhancing phosphorus use efficiency and soil quality indicators in lowland paddy ecosystem through *Azolla*, rice straw, and NPKS fertilizers. *Frontiers in Agronomy*. https://doi.org/10.3389/fagro.2024.1376110

Meena, M. D., & Biswas, D. R. (2013). Residual effect of rock phosphate and waste mica enriched compost on yield and nutrient uptake by soybean. *Legume Research, 36*(5), 406–413. https://arccjournals.com/journal/legume-research

Meshram, P., Patil, A., Jadhav, A., Gosavi, A., & Bagade, P. (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

Mussarat, M., Ali, H., Muhammad, D., Mian, I., Khan, S., Adnan, M., Fahad, S., Wahid, F., Dawar, K., Ali, S., Zia, A., Ahmad, M., Khan, S., Shah, W. A., Romman, M., Parvez, R., Siddiqui, M. H., Khan, A., Wang, D., & Jiang, X. (2021). Comparing the phosphorus use efficiency of pre-treated (organically) rock phosphate with soluble P fertilizers in maize under calcareous soils. *PeerJ, 9*, e11452. https://doi.org/10.7717/peerj.11452

Navghare, N. R., Age, A. B., Jadhao, S. D., Rakhonde, O. S., & Pandao, M. R. (2023). The impact of different phosphorus levels on soil fertility, yield, phosphorus dynamics, and use efficiency after cotton harvest. *The Pharma Innovation Journal, 12*(6), 4168–4171. https://www.thepharmajournal.com/archives/2023/vol12issue6/PartF/12-6-100-990.pdf

Ning, C. C., Ma, Q., Yuan, H. Y., Zhou, C. R., Xia, Z. Q., & Yu, W. T. (2020). Mineral fertilizers with recycled manure boost crop yield and P balance in a long-term field trial. *Nutrient Cycling in Agroecosystems, 116*, 271–283. https://doi.org/10.1007/s10705-019-10043-y

Noonari, S., Kalhoro, S. A., Ali, A., Mahar, A., Raza, S., Ahmed, M., Shah, S. F. A., & Baloch, S. U. (2016). Effect of different levels of phosphorus and method of application on the growth and yield of wheat. *Natural Science, 8*(7), 305–314. https://doi.org/10.4236/ns.2016.87035

Parihar, C. M., Bhakar, R. N., Rana, K. S., Jat, M. L., Singh, A. K., Jat, S. L., Parihar, M. D., & Sharma, S. (2013). Energy scenario, carbon efficiency, nitrogen and phosphorus dynamics of pearl millet–mustard system under diverse nutrient and tillage management practices. *African Journal of Agricultural Research, 8*(10), 903–915. https://doi.org/10.5897/AJAR12.810

Patel, D. M., Patel, H. K., Desai, C. K., Chauhan, S. A., & Prajapati, R. B. (2016). Effect of different levels of nitrogen, phosphorus and potassium on N, P and K content and uptake of isabgol (*Plantago ovata* Forsk.). *Journal of Pure and Applied Microbiology, 10*(3), 2443–2447. https://doi.org/10.22207/JPAM.10.3.91

Patel, H. B., Shah, K. A., & Patel, K. H. (2019). Response of greengram to different level of phosphorus and organic liquid fertilizer on yield, quality, nutrient content and uptake. *International Journal of Current Microbiology and Applied Sciences, 8*(4), 1234–1242. https://doi.org/10.20546/ijcmas.2019.804.142

Prakash, D., Benbi, D. K., & Saroa, G. S. (2018). Land-use effects on phosphorus fractions in Indo-Gangetic alluvial soils. *Agroforestry Systems, 92*, 437–448. https://doi.org/10.1007/s10457-016-0061-6

Ranpariya, V. S., Polara, K. B., Hirpara, D. V., & Bodar, K. H. (2017). Effect of potassium, zinc and FYM on content and uptake of nutrients in seed of summer greengram (*Vigna radiata* L.) and post-harvest soil fertility under medium black calcareous soil. *International Journal of Chemical Studies, 5*(5), 1055–1058. https://www.thepharmajournal.com/archives/2022/vol11issue8S/PartW/S-11-8-164-371.pdf

Richardson, A. E., & Simpson, R. J. (2011). Soil microorganisms mediating phosphorus availability: Update on microbial phosphorus. *Plant Physiology, 156*, 989–996. https://doi.org/10.1104/pp.111.175448

Saha, B. N., Saha, S., Poddar, P., & Chand, T. (2013). Phosphate fractions as influenced by long-term phosphorus fertilization. *Indian Journal of Agricultural Research, 47*(1), 59–65.

https://arccjournals.com/journal/indian-journal-of-agricultural-research/ARCC007

Saini, C. S., Sharma, O. P., Dhaker, D. L., Choudhary, Y. S., Bhamboo, K., & Choudhary, S. (2024). Effect of nutrient management through organic and inorganic fertilizers on productivity of pearl millet. *International Journal of Research in Agronomy, 7*(10), 336–340. https://doi.org/10.33545/2618060X.2024.v7.i10Se.1792

Satyavathi, C. T., Ambawat, S., Khandelwal, V., & Srivastava, R. K. (2021). Pearl millet: A climate-resilient nutricereal for mitigating hidden hunger and provide nutritional security. *Frontiers in Plant Science, 12*, 659938. https://doi.org/10.3389/fpls.2021.659938

Sheoran, O. P., Tonk, D. S., Kaushik, L. S., Hasija, R. C., & Pannu, R. S. (1998). Statistical software package for agricultural research workers. In D. S. Hooda & R. C. Hasija (Eds.), *Recent advances in information theory, statistics and computer applications* (pp. 139–143). CCS HAU, Hisar.

Sheoran, S., Prakash, D., Raj, D., Mor, V. S., Yadav, P. K., Gupta, R. K., Alamri, S., & Siddiqui, M. H. (2024). Long-term organic and N fertilization influence the quality and productivity of pearl millet under pearl millet–wheat sequence in north India. *Scientific Reports*. https://doi.org/10.1038/s41598-024-70009-1

Sheoran, S., Prakash, D., Raj, D., Yadav, P. K., Singh, R., Gupta, R. K., Alamri, S., Siddiqui, M. H., & Khan, S. (2025). Organic manure and fertilizer N management strategies improve soil health at different growth stages of pearl millet under pearl millet–wheat sequence. *BMC Plant Biology*. https://doi.org/10.1186/s12870-025-06128-2

Singh, R., Singh, D., Pratap, T., Singh, A. K., Singh, H., & Dubey, S. K. (2018). Effect of different levels of phosphorus, sulphur and biofertilizers inoculation on nutrient content and uptake of chickpea (*Cicer arietinum* L.). *International Journal of Chemical Studies, 6*(6), 2574–2579. https://doi.org/10.22271/chemi.2018.v6.i6ag.2574

Sunda, S. L., Singh, D. P., Jain, H. K., Bamboriya, J. S., Bhawariya, A., Meena, A. K., & Dhayal, S. (2023). Effect of INM on nutrient content and quality parameters of maize in typic haplustepts. *The Pharma Innovation Journal, 12*(3), 1787–1790. https://www.thepharmajournal.com/archives/2023/vol12issue3/PartZ/12-2-10-990.pdf

Tang, K., Aham, S., & Chemara, S. (2011). Impact of long-term application of NPK fertilizers on soil properties in wheat-based cropping system. *Biology and Fertility of Soils, 89*, 698–710. https://doi.org/10.1007/s00374-011-0590-z

Tisdale, S. L., Nelson, W. L., Beaton, J. D., & Havlin, J. L. (1995). *Soil fertility and fertilizer*. Prentice Hall of India. https://www.scirp.org/reference/referencespapers?referenceid=1651875

Urlić, B., Dumičić, G., Radić, T., Goreta Ban, S., & Romić, M. (2023). Phosphorus use efficiency of leafy *Brassica* sp. grown in three contrasting soils: Growth, enzyme activity and phosphorus fractionation. *Plants*. https://doi.org/10.3390/plants12061295

Vora, V. D., Hirpara, D. S., Vekaria, P. D., Sutaria, G. S., & Vala, F. G. (2018). Effect of phosphorus management on yield, nutrient uptake by sesame and post-harvest soil fertility under rainfed condition. *Journal of Pharmacognosy and Phytochemistry, 7*(5), 65–69. https://www.phytojournal.com/archives/2018/vol7issue5/index.html

Wabela, R., Abera, G., Lemma, B., & Gobena, A. (2024). Effects of integrated fertilizer application on selected soil properties and yield attributes of common bean (*Phaseolus vulgaris* L.) on different soil types. *Heliyon, 10*(19), e38163. https://doi.org/10.1016/j.heliyon.2024.e38163

Waheed, M., & Arshad, M. (2015). Improving effectiveness of rock phosphate through mixing with farmyard manure, humic acid and effective microbes to enhance yield and phosphorus uptake by wheat. *Pure and Applied Biology, 4*(4), 480–490. https://doi.org/10.19045/bspab.2015.44005

Yan, X., Chen, X., Tou, Y., Luo, Z., Ma, C., Huang, W., Cui, C., Chen, X., Wu, L., & Zhang, F. (2024). Exploring phosphorus fertiliser management in wheat production. *European Journal of Agronomy, 153*, 127063. https://doi.org/10.1016/j.eja.2023.127063

Zak, D. H., Kronvang, B., Carstensen, M. V., Hoffmann, C. C., Kjeldgaard, A., Larsen, S.

E., Audet, J., Egemose, S., Jørgensen, C. A., Feuerbach, P., Gertz, F., & Jensen, H. S. (2018). Nitrogen and phosphorus removal from agricultural runoff in integrated buffer zones. *Environmental Science & Technology, 52*(11), 6508–6517. https://doi.org/10.1021/acs.est.8b01036

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