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RESEARCH ARTICLE

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Influence of Nutrient Management Options on the Phosphorus Fractions and Productivity of the Pulses Based Cropping Systems in Semi Arid Region of India

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ABSTRACT

Background: Phosphorus is vital plant nutrient and limiting factor for soil productivity, hence better management of agronomic practices may influence the P availability in soils. The different P fractions plays also role in management of soil productivity. The goal of our study was to evaluate the effect of synthetic fertilizer in combination with organic manures and microbes on phosphorus fractions and system productivity.

Methods: The study has planned in split plot design with two pulses based cropping systems and eight nutrient management options role and combination of inorganic fertilizers, organic manure and microbial inoculants. Different phosphorus fractions were determined using stepwise fractionation techniques and soil characteristics were ascertained using normal analytical procedures.

Result: The findings showed that the blackgram-mustard (B-M) cropping system outperformed the fallow-chickpea (F-C) cropping system in terms of soil porosity, water-holding capacity and phosphorus fraction. Compared to the initial status of the soil, both systems have better soil qualities. Similar to this, phosphorus fractions improved when 125%, 100% and 75% of the recommended inorganic fertilizer was applied in conjunction with FYM and microbial inoculants, as compared to when inorganic fertilizers were applied only. The system productivity was higher with B-M cropping system and also with 125%, 100% and 75% inorganic fertilizer with FYM and microbial inoculants. Overall, our study suggests that 25% of inorganic fertilizer can be reduced along with FYM and microbial inoculants in B-M cropping systems in semi-arid region.

Key words: Cropping system, Microbial inoculants, Nutrient management, Organic manures, Phosphorus fractions.

INTRODUCTION

Phosphorus is acknowledged as a crucial macronutrient for plants, significantly contributing to root development and, consequently, plant biomass (Mou *et al.,* 2020, Turner *et al.,* 2018, Haokip *et al.,* 2020). Phosphorus is readily fixed in various complex forms in both acidic and saline soils, resulting in low availability for plants. The majority phosphorus contained in soils are the inorganic forms such as calcium P, aluminium -P, iron- P, solid -P and occluded -P and Organic forms Weihrauch *et al.* (2018). The availability of the different forms mainly inorganic and organic forms of phosphorus depends also upon the climatic conditions of the region.

The semi-arid region is characterized by high temperatures, low precipitation and often minimal organic matter content. Consequently, the availability of both organic and total phosphorus remains low. The availability of phosphorus to plants mostly depends on pH, moisture and microbial activity. In saline soils where calcium predominates, phosphorus is fixed with calcium (Baccari *et al*., 2023). Consequently, in semi-arid locations, the augmentation of organic matter is essential for improved phosphorus availability in these soils.

Enhancing organic carbon levels in semi-arid regions is challenging, as elevated temperatures accelerate the breakdown of organic matter resulted poor in organic matter (Hartley *et al.,* 2021). In this context, the use of synthetic fertilizer is vital for the better production, however, fertilizer negatively impacts soil characteristics and contributes to environmental pollution. Therefore, it is

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essential to utilize organic manures in conjunction with chemical fertilizers to enhance crop growth and soil productivity (Padbhushan *et al.,* 2021).

Appropriate agronomic intervention has the ability to enhance soil fertility. It is essential to improve the organic carbon and phosphorus to enhance soil fertility. Comprehending the phosphorus fractions in soil is essential for the effective management of phosphorus fertilizers (He *et al*., 2023).

Two primary factors contributing to phosphorus availability in cultivated soil are the soil's inherent reserves and external supplementation via fertilizers, manure, or other sources. Phosphorus is a significant limitation for agricultural yield, particularly in black soils (Qiong *et al.,* 2022). Therefore, the monitoring and assessment of phosphorus availability are essential for evaluating soil fertility in intensive cropping systems, particularly in black soils (Dwivedi and Dwivedi 2015). Numerous studies have demonstrated that prolonged and consistent application of fertilizers or manures enhances the mobility of phosphorus in soil (Patel *et al.,* 2025). In soil, all forms of phosphorus are present, but typically aluminum-P and iron-P are more prevalent in acidic soils, while calcium-P predominates in neutral to alkaline soils (Dutta and Tamluy 2020; He *et al*., 2023). There is a deficiency of systematic scientific research about the combined application of inorganic and organic nutrient sources, coupled with microbial inoculants, on soil phosphorus fractions, notably in the pulses cropping system in the semi-arid region.

This study examines the productivity of pulse-based cropping systems in semi-arid regions, along with the physical and chemical properties of the soil. We hypothesize (1) the effects of organic and inorganic fertilizers on soil physicochemical properties and (2) the impact of these fertilizers on phosphorus fractions within pulse-based cropping systems. The study offers useful insights into the impact of the synergistic impacts of inorganic and organic sources, with beneficial microorganisms, on phosphorus fractions and the productivity of the B-M and F-C cropping systems.

MATERIALS AND METHODS

Study site and land history

A three years' field experiment was carried out at the Banda University of Agriculture and Technology in the Banda during 2020-21 to 2022-23, which is lies between Latitude 24°53′ and 25°55′N and Longitude 80°07′ and 81°34′E. The region has semi-arid climate with extremely warm during summer and cold in winters. The average annual rainfall received during wet season was 752 mm and in dry season 63.2 mm during growth period of crop. The three years average annual evopo-transpiration was 7.2 mm. The initial experimental soil has Silty Clay loam texture with pH is 8.10, the low in organic carbon (0.31%) and medium in available phosphorus (6.07 mg kg^{-1}) and high in available potassium (110.2 mg kg^{-1}).

Experimental detail

A replicated experiment was designed in a split plot design with two cropping systems (CS) as main factors (F-C and B-M) and eight nutrient management (NM) options *viz.* Control(based on the survey of the fertilizer application of local farmers) (C), recommended dose of the crops by state government (RD) (NPK),100% RD + FYM (NPK+FYM),100% RD +Zn @ of 10 kg ha^{-1} (NPK+Zn), 125% RD+FYM+ Microbial inoculants (125%NPK+FYM+M), 100% RD+ FYM+ Microbial inoculants (100% NPK+FYM+M), 75% RD + FYM+ microbial inoculants (75% NPK+FYM+M) and 50% RD +FYM + Microbial inoculants (50% NPK+FYM+M). The experimental field covered an area of 1,291 m^2, while the size of each experimental plot was 21m^2. The nutrient management treatments were implemented to the dry season crop. Microbial inoculants (*Rhizobium* spp., Phosphorus solubilizing bacteria and A*zotobacte*r spp.) were applied as a 200 ml of microbial inoculates mixed with 100 kg of FYM per acre two day before of the experiment and incubated over night and applied to the per plot before the seeding. The state government recommended dose of fertilizer (N: P_2O_5: K_2O) for the blackgram 20: 40:0 kg ha^{-1}, chickpea 20:60:20 kg $ha^{-1}$and for mustard crop 80:60:40 kg ha^{-1}. The FYM was used as organic source and applied 5 t ha^{-1} $year^{-1}$ applied 10 days before sowing of dry season crop.

Soil sampling and parameter analysis

A composite soil sample from the two depths (0-15 cm and 15-30 cm) was collected before the initiation of experiment (2020) and after the completion of the experiment (2023). The soil samples were processed and subjected to various chemical analysis by adopting standard protocols. Physico-chemical properties were analysed by using different methods like for soil pH and electrical conductivity were determined in 1:2 soil/water ratio. Available potassium was extracted with ammonium acetate and flame photometer.

Soil phosphorus fractionation analysis

The P fractions were determined by the use of sequential different extractant approach proposed by Hedley *et al.,* (1982) and Tiessen and Moir (1993): The 1.0 gram of soil was extracted with 0.5 M $NaHCO_3$ for the determination of available P. Saloid–P was extracted by 1N NH_4Cl, Aluminium P (Al-P) extracted by 0.5N NH_4 F buffered at pH 8.2, Iron (Fe-P) extracted by 0.1N NaOH, Reductant soluble P (RS-P) extracted by sodium citrate and sodium dithionite, Occluded–P extracted by 0.1N NaOH, Calcium P (Ca-P) extracted by 0.5N H_2SO_4 later on the P estimated by the ascorbic acid method by using spectrophotometer. Further, The organic phosphorus was measured by treating with diluted acid after oxidation of organic matter in muffle furnace and the total phosphorus determined by the 60% $HClO_4$ after the pre treatment with HNO_3.

System yield

The yield of black gram, chickpea and mustard was estimated by manually harvesting a 2 m^2 area of the net plot and threshing it. The minimum support price (MSP) of black gram and mustard used to convert the yield into chickpea equivalent by adopting following formula.

$$\text{Chickpea equivalent yield} = \frac{\text{Yield of crop} \times \text{minimum support price of crop}}{\text{Minimum support price of chickpea}}$$

Statistical analysis

The data was analyzed by the SPSS version software. Fisher's LSD (least significant difference) test was used to compare the mean values of the analyzed parameters at the P<0.05 level of significance.

RESULTS AND DISCUSSION

Soil properties

The interaction between the CS and the NM options was found to be non-significant in studied soil properties for both the soil depths. The main factors and sub-factor were also not influenced the pH and electrical conductivity at both depths of soil. The bulk density and particle density were not influenced by the cropping systems. In case of WHC, The B-M cropping system resulted in significant higher WHC content (49.12% and 47.19%) than F-C cropping system (48.09% and 47.19%), respectively at both depths of soil. Similarly, B-M cropping system had potassium content which is significantly 2.5% higher than F-C cropping system. The crop cultivation during both seasons received nutrients as compared to the single crop in a year, further, the cultivation of pulses crops supported to improvement in soil fertility (Stagnari *et al.,* 2017), hence irrespective of the treatments improvement in soil properties were visible in both treatments in comparison to initial status. Cropping systems, B-M cropping system had better porosity at depth (15-30 cm) while improved WHC at both depths as compared the F-C cropping system. It might me because of soil cover for longer period due to two crops, thereby higher roots activity improved the porosity and WHC than single crop grown in F-C cropping system. Similar finding was also narrated by (Meena *et al.,* 2016 and Babu *et al.,* 2020). The B-M cropping system had significantly higher potassium content than the F-C cropping system in both depths. Application of potassium fertilizers in both the seasons and the application microbial inoculants positively maintained that potassium level of soil solution (Hassan 2016 and Nawaz *et al.,* 2023).

In case of NM options, the treatments where 125%-75% inorganic fertilizers along with FYM and microbial inoculants were applied estimated similar porosity content and significantly higher than sole application of the inorganic fertilizers treatments (Control, NPK and NPK+Zn). Moreover, 50% reduction in inorganic fertilizer had statistically similar porosity content than NPK+FYM, NPK+Zn and75% NPK+FYM+M and was found statistically superior over control and RD. In case of WHC, At both the soil depths, treatment 125%NPK+FYM+M (51.04%) and

Table 1: Effect of cropping systems and nutrient management strategies on physic chemical and physical properties.

Treatment	pH	Electrical conductivity (dSm^{-1})	Available potassium (mg kg^{-1})	Bulk density (gcm^{-3})	Porosity (%)	Water holding capacity (%)	pH	Electrical conductivity (dSm^{-1})	Available potassium (mg kg^{-1})	Bulk density (gcm^{-3})	Porosity (%)	Water holding capacity (%)
	0-15 cm						15-30 cm					
Main factor												
F-C	7.48	0.25	124.7	1.31	49.6	48.1	7.44	0.23	110.3	1.34	47.1	46.0
B-M	7.45	0.24	127.8	1.31	49.5	49.1	7.43	0.23	112.7	1.34	46.6	47.2
Sub factor												
Control	7.46	0.21	122.7	1.31	47.8	46.7	7.42	0.22	108.8	1.34	45.7	44.4
NPK	7.43	0.23	123.4	1.31	48.4	46.8	7.44	0.21	109.2	1.34	46.1	45.4
NPK+FYM	7.50	0.25	125.4	1.30	48.7	48.0	7.44	0.25	110.1	1.34	45.9	46.0
NPK+Zn	7.49	0.23	124.2	1.29	48.9	47.0	7.45	0.24	110.4	1.33	46.1	45.1
125 % NPK+FYM+M	7.38	0.20	129.7	1.30	51.2	51.	7.42	0.25	114.4	1.33	47.9	48.8
100 % NPK+FYM+M	7.45	0.23	128.8	1.31	50.6	50.1	7.43	0.23	113.6	1.36	47.8	48.1
75 % NPK+FYM+M	7.50	0.26	130.2	1.32	50.8	51.1	7.45	0.22	115.1	1.35	47.8	48.8
50 % NPK+FYM+M	7.49	0.23	125.6	1.33	49.9	48.2	7.44	0.21	110.6	1.32	47.5	46.3
Main factor CD (P≤0.05)	NS	NS	0.93	NS	NS	0.80	NS	NS	2.82	NS	0.36	0.92
Sub factor CD (P≤0.05)	NS	NS	1.303	NS	0.89	0.60	NS	NS	2.239	NS	0.69	1.06
Interaction A × B (P≤0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

F-C: Fallow-Chickpea; B-M: Blackgram-Mustard; F: Farm yard Manure; M: Microbial inoculants.

75%NPK+FYM+M (51.08%) was statistically similar and recorded significantly higher values of WHC, while at sub-surface depth treatment 125% NPK+FYM+M, 75% NPK+FYM+M and 50% NPK+F+M were statistically similar and superior over other treatments .The results ascribed that the use of organic manures and microbial inoculants (MI) improved the soil aggregation and other physical properties and also enhancement in soil organic carbon status which resulted in improvement of soil porosity and WHC. The results were in line of the confirmation of (Ahmad *et al.,* 2017 and Meena *et al.,* 2020).

Further, the potassium content of the soil was significantly higher in with 125%NPK+FYM+M and 75% NPK+FYM+M over the control and 50% NPK +FYM +M while remaining other treatments was similar K content in both the depths (Table 1). Increased available K because of organic manure use may be attributed to the decreased K-fixation and more release of K due to interaction of organic matter with clays, besides the direct K addition to the soil (Sharma and Sepehia 2014 and Sawarkar *et al*., 2013).

Phosphorus fractions

In case of surface soils, the interaction between CS and NM was found to be non significant. Further Al-P was not detectable in our soils hence data is not given in manuscript. The inorganic fraction of phosphorous, organic phosphorous, available P and total P are as expected higher in surface soil (0-15 cm) than sub-surface (15-30 cm) irrespective of the treatments (Table 2 and Fig 2). It is might be due to surface soil was more affected by the agronomic practices, addition of phosphatic fertilizer, addition of organic manures, microbial inoculants and roots activities than the subsurface soils. Similarly, (Sawarkar *et al.,* 2013 and Dubey *et al.,* 2016) reported that the higher phosphorus fraction in surface layer might be due to addition of phosphatic fertilizer, organic residue and microbial activity.

CS, it is evident from the data, the crop grown in both wet and dry season *i.e*. B-M cropping system had significantly higher phosphorus fractions compared to F-C cropping system except Fe-P and Ca-P. The B-M cropping system had 2.85 %,8.13 %, 6.07 %, 3.99 %, 2.51 %, 2.29 % and 2.55 % higher phosphorus fractions available P, saloid-P, Reductant Soluble-P, occluded-P, Ca-P, Inorganic-P, mineral-P, organic-P and total-P than F-C cropping system, respectively (Fig 1). The B-M mustard cropping system had higher all P fractions as well as total P except Fe-P and Ca-P than mono cropping. This trend might be due to cultivation of two crops in year received phosphate fertilizers both the seasons and better root activity. Further, initially the phosphorus content of soil is very low but due to practice of continuous application of phosphatic fertilizers along with FYM and microbial inoculants improves the content of different fraction of the phosphorous of the soil. Similar results (Motavalli and Miles, 2002 and Zhang *et al.*, 2020) also reported that synthetic inorganic fertilizer and organic manure could increase the inorganic and organic P fractions of the soils. Further, (Khadka *et al*., 2024) also

Table 2: Effect of cropping system and nutrient management strategies on phosphorus fractions of the sub – surface soil (15-30 cm).

Treatment	Phosphorus fractions (mg kg^{-1})									
	Available - P	Saloid - P	Fe - P	Reductant soluble P	Occluded - P	Ca - P	Inorganic P	Mineral P	Organic P	Total P
Main factor										
F-C	8.58	7.89	4.70	2.64	7.03	29.37	52.46	83.83	29.55	113.39
B-M	8.90	8.23	4.07	2.73	7.13	29.70	53.67	86.59	30.53	117.12
Sub factor										
Control	7.67	7.04	3.62	2.13	5.49	27.15	47.62	86.19	25.02	111.21
NPK	8.03	7.16	3.84	2.40	6.11	28.68	50.12	85.32	27.06	112.38
NPK+FYM	8.19	7.20	3.99	2.61	6.14	28.59	50.60	84.48	27.91	112.40
NPK+Zn	8.59	7.59	4.06	2.76	7.38	30.09	53.09	84.38	29.68	114.06
125 % NPK+FYM+M	9.75	9.28	4.22	2.99	8.52	30.87	57.11	85.40	33.87	119.27
100 % NPK+FYM+M	9.55	9.16	4.15	2.98	7.55	30.77	56.61	84.41	33.96	118.38
75 % NPK+FYM+M	9.67	9.15	4.18	2.95	8.08	31.19	57.14	86.23	33.04	119.28
50 % NPK+FYM+M	8.55	7.95	4.07	2.71	7.42	28.99	52.29	85.27	29.82	115.09
Main factorCD ($P \leq 0.05$)	0.08	0.08	0.006	0.005	0.11	0.45	0.61	3.93	1.07	1.68
Sub factorCD ($P \leq 0.05$)	NS	NS	NS	0.12	NS	NS	NS	NS	NS	2.22
Interaction A × B ($P \leq 0.05$)	0.54	0.56	0.15	0.19	0.65	1.27	1.47	NS	1.96	2.45
Factor ACD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

F-C: Fallow-chickpea; B-M: Blackgram-mustard; F: Farm yard manure; M: Microbial inoculants; P: Phosphorus; Fe: Iron; Ca: Calcium.

reported that cropping system influenced the different fractions of the phosphorus.

In case of NM options, the similar trend was observed with available P and loosely bound P *i.e.* saloid- P, inorganic, organic and total-P for both the depths and Ca-P for 0-15 cm application of inorganic fertilizers 75%, 100% and 125% + FYM + microbial inoculants estimated similar phosphorus fractions and significantly superior than the sole application of inorganic fertilizers in control and RD (Fig 2 and Table 2). Further 50 % NPK+F+M was also similar the RDF alone or RDF with FYM or Zn application. The results were in close conformity with the findings of other scientist, who stated that incorporation of FYM with RDF enhance available P content of soil (Bagde *et al.,* 2023) increased saloid-P and Ca-P content (Dubey *et al.,* 2016 and Sawarkar *et al.,* 2013), increases in iron-P and occluded-P (Sawarkar *et al.,* 2013 and Qiong *et al.,* 2022). The reductant soluble-P recorded lower values of P fraction in comparison to Ca-P and increased with the inclusion of organics in combination with RDF (Dotaniya *et al.,* 2014). In case of organic-P the

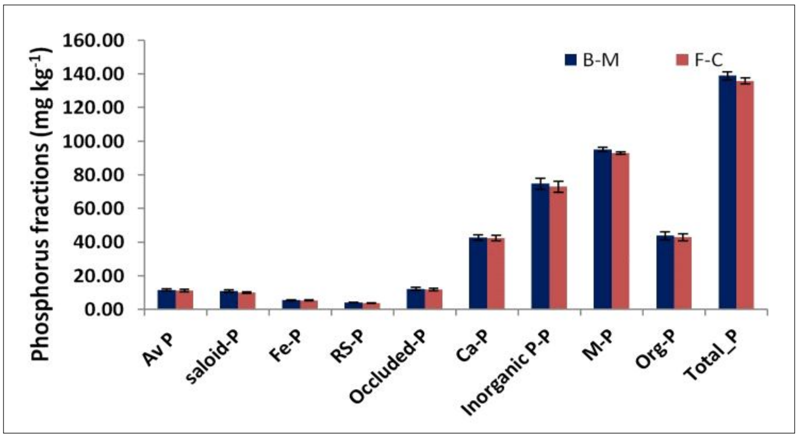
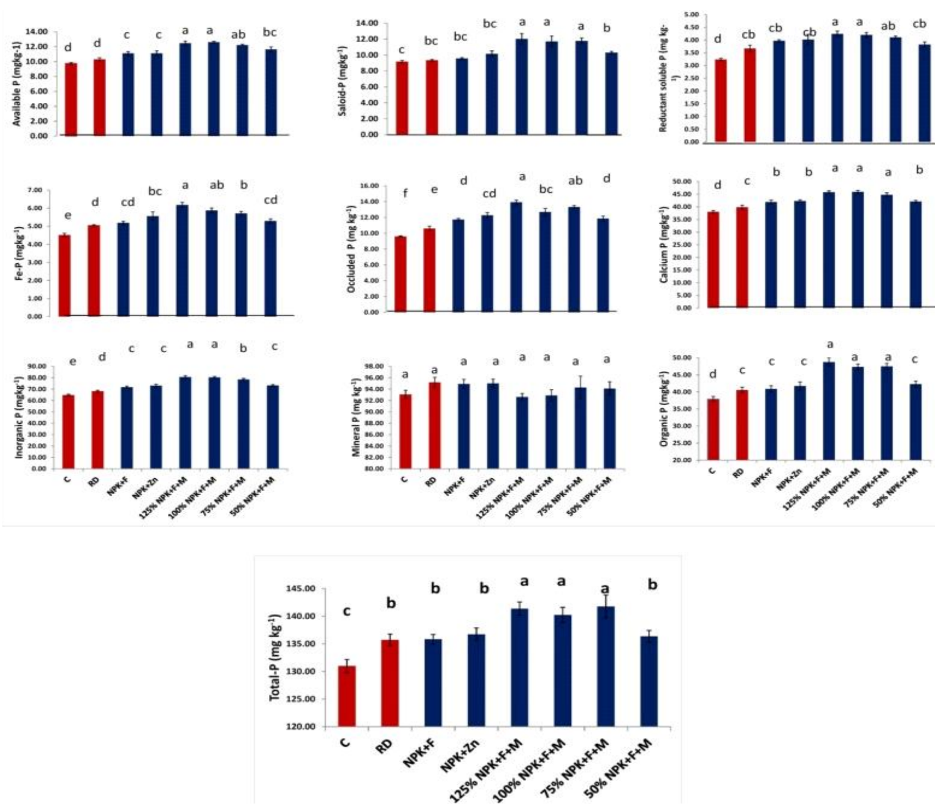


Fig 1: Effect of cropping systems on phosphorus fractions of the surface soil (0-15 cm).



C: control; RD: State fertilizer recommended dose; F: FYM; M: Microbial inoculants

Fig 2: Effect of nutrient management strategies on phosphorus fractions of the surface soil (0-15 cm).

Table 3: Effect of nutrient management options on the chickpea equivalent yield (q ha^{-1}).

Treatments	Chickpea equivalent yield (q ha^{-1})		Mean Yield
	F-C	B-M	(q ha^{-1})
Control	20.8	34.6	27.7
NPK	21.8	36.8	29.3
NPK+FYM	25.0	42.4	33.7
NPK+Zn	25.0	42.8	33.9
125 % NPK+FYM+M	27.5	46.1	36.8
100 % NPK+FYM+M	27.6	47.1	37.4
75 % NPK+FYM+M	27.6	44.8	36.2
50 % NPK+FYM+M	24.4	40.5	32.5
Mean Yield (kg ha^{-1})	25.0	41.9	33.4
CD at 5% Main factor	5.73		
CD at 5% Sub factor	3.65		
CD at 5% Interaction	NS		

F-C: Fallow-chickpea; B-M: Blackgram-mustard; F: Farm yard manure; M: Microbial inoculants.

use of FYM enhances the organic carbon status in soil which is positive relationships with organic-P, thereby increases its fraction in soil (Kumar *et al.,* 2013 and Manimaran 2015).

System productivity (chickpea equivalent yield)

As expected, B-M cropping system produced higher chickpea equivalent yield as compared to F-C cropping system. It was 67.6% higher than F-C cropping system. In case of sub treatments 125% NPK+FYM+M-75% NPK+FYM+M treatments had significantly higher chickpea equivalent yield than the C, RD and 50% NPK+F+M treatments (Table 3). It might be due to adequate supply of the nutrient from the inorganic and organic sources. The FYM and microbial inoculants could be improved beneficial microbes in the soil, which improved soil chemical properties and resulted better mean equivalent yield in (125% NPK+FYM+M-75% NPK+FYM+M) plots. Similar result also reported by the (Tomar and Singh, 2025 and Arya *et al.,* 2007) the application of FYM and microbial inoculants with inorganic fertilizer improved the productivity of pulses crop.

CONCLUSION

Our study unequivocally showed that cultivating two crops annually in a semiarid location positively affected soil porosity, water-holding capacity and accessible potassium content. Moreover, the crop in both seasons exhibited enhanced system productivity and soil characteristics. This study clearly demonstrated that the continual application of phosphatic fertilizer enhanced the phosphorus status of soils. The research indicates that the black gram-mustard cropping system, utilizing a combination of inorganic fertilizers, organic manures and microbial inoculants in nutrient-deficient soils, along with a 25% reduction in inorganic fertilizer from the second year onward, enhances productivity and soil fertility in India's semi-arid regions. Our findings demonstrated that most phosphorus was fixed as calcium-P; hence, the management strategies effectively addressed the process.

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Authors contribution

Conceptualization, Amit Mishra; Methodology, investigation and writing-original draft preparation, Vishal Singh. and Amit Mishra.; writing-review and editing: Anand Kumar Chaubey and Jagannath Pathak; Laboratory Analysis: Arbind Kumar Gupta, Ashutosh Rai; All authors read and approved the final manuscript.

Data availability

Data available with corresponding author and first author and may be made available on request.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

No animal were used for the study.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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