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INTEGRATED APPLICATION OF ROCK PHOSPHATE AND ORGANIC FERTILIZERS ENHANCES SOYBEAN YIELD, SOIL FERTILITY AND NUTRIENT UPTAKE IN CALCAREOUS SOIL OF PESHAWAR, PAKISTAN

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Abstract
In alkaline and calcareous soils, P deficiency is often a significant constraint on crop production, and application of low-cost rock phosphate may not yield significant crop response. To test the effect of rock phosphate (RP) with farmyard manure (FYM), poultry manure (PM) and compost on yield and post harvest soil fertility and plant uptake of nutrients, a field experiment was conducted at Agricultural Research Institute, Tarnab, Peshawar, during kharif season 2020 with soybean (Glycine max L.). The experimental design was a randomized complete block with 12 treatments of fertilizer and 3 replications. Treatment means were reorganized from the original means in the thesis; publication-ready figures were created by python. The results indicated that the joint application of RP and organic fertilizer had a significant effect on the productivity and soil fertility characteristics of soybean. The maximum total dry matter yield (9530 kg ha-1), grain yield (3554 kg ha-1), pods plant-1 (190), 1000-grain weight (155 g), plant N uptake (150.14 kg ha-1) and plant P uptake (16.96 kg ha-1) were recorded under RP+FYM+PM+compost. This treatment resulted in a 89.6% gain in total dry matter, 99.3% increase in grain yield, 132.6% higher in N uptake and 175.8% higher in P uptake than RP alone. The post harvest soil organic matter and AB-DTPA-extractable P also rose from 1.54% to 4.95 mg kg-1, respectively, in the integrated treatment compared to the control. The results indicate that the use of co-application with various organic amendments can increase the agronomic value of local soil RP by improving the nutrient release, organic matter accumulation and plant nutrient uptake in calcareous soils.

INTRODUCTION

Soybean (Glycine max L.) is an important crop that is a legume species having high protein and oil content, is a source of food and feed and has the capacity to increase soil nitrogen through biological N fixation. Soybean is also poorly utilized in Pakistan compared to other field crops and its productivity is limited by poor crop establishment and limited availability of essential nutrients and low soil organic matter. Of these nutrients, phosphorus is especially crucial for early root development, nodulation, energy transfer and reproductive development. In alkaline and calcareous soils of KP, applied P can, however, become immediately unavailable as a result of precipitation and fixation with calcium compounds.

The locally available form of phosphate, rock phosphate, is relatively cheap and is also the form with low direct agronomic efficiency in high pH soils. Therefore, the use of RP along with organic amendments is important as FYM, PM and compost contains organic acids during decomposition, it increases the biological activity of the soil, it increases the exchange capacity of soil as well as it increases the dissolution of sparingly soluble P compounds. The use of organic amendments along with inorganic P sources have also been highlighted for their positive interactions in calcareous soils by decreasing P fixation and increasing P availability to crops (Ahmad et al., 2022; Khan et al., 2022; Adnan et al., 2022).

The current manuscript further leverages the collective expertise of the author group accumulated over the past few years in the region, related to water quality assessment, soil fertility, biochar use for nutrient management, pest management and crop productivity. According to these studies, there is a need for site-specific, low cost and environmentally friendly management strategies in the adjoining areas and Khyber Pakhtunkhwa (A. A. Khan et al., 2025; S. Khan and B. Khan, 2026; Farooq et al., 2026a; Farooq et al., 2026b; Jalal et al., 2026; A. Khan et al., 2026; Anees et al., 2026; Rehman et al., 2026; Farooq et al., 2026c; Qamar et al., 2026). The various papers presented here are based on different crops and environmental themes, but all of them are in support of the idea of soil and environmental management through integration rather than via single input.

Objectives

- To evaluate the effect of RP alone and in combination with FYM, PM and compost on soybean yield and yield components;
- To determine the effect of integrated RP-organic fertilizer treatments on post-harvest soil pH, soil organic matter, total N and extractable P;
- To quantify the response of plant N and P concentration and uptake to RP-organic fertilizer combinations.

Materials and Methods

Field experiment was carried out at the Agricultural Research Institute (Tarnab), Peshawar in kharif 2020. The cultivar used was NARC-II of soybean. Initial soil properties are given in Table 1 and the soil of the experimental field was silty loam, alkaline and calcareous and in low organic matter, total N and extractable P levels.

The experiment was used in a randomized complete block design (RCBD) having three replications. The size of each plot was 3 m x 5 m. Soybean was seeded at the recommended rate of 100 kg ha-1. RP and organic source of phosphorus were applied at the same level as 60 kg of P2O5. Urea (25 kg ha-1) was used as the nitrogen source in 2 splits and sulfate of potash was used for potassium at 60 kg ha-1 at planting. FYM contained 0.8% N, 0.21% P and 0.68% K, while PM contained 3.2% N, 1.83% P and 0.83% K. The treatment structure is shown in Table 2.

Total dry matter yield, pods plant-1, grains pod-1, grain yield, 1000 grain weight, post harvest soil pH, soil organic matter, total soil N, AB-DTPA extractable P, plant N and P concentration, and plant N and P uptake were recorded. The uptake of N and P by plants was reported as kg ha-1. Soil and plant samples were subjected to routine analysis, such as pH in soil-water suspension, AB-DTPA extraction for available P, Kjeldahl digestion for total N and the Walkley-Black procedure for soil organic matter.

Data obtained from the original experiment were analysed statistically by analysis of variance for RCBD and means compared by LSD at $P<0.05$. In this article, treatments were reorganized in Python 3.11 using pandas. Mean values for treatment were transformed to percentage increases over RP.

Table 1 Initial physicochemical properties of the experimental soil.

Property	Unit	Value
Sand	%	29.3
Silt	%	67.8
Clay	%	2.9
Textural class	-	Silty loam
Lime	%	12.73
pH (1:5)	-	7.9
EC (1:5)	dS m-1	0.28
Organic matter	%	0.6
Total nitrogen	%	0.08
AB-DTPA extractable P	mg kg-1	3.1

Table 2 Treatment structure used in the soybean field experiment.

Code	Treatment	Description
T1	Control	No fertilizer
T2	RP	Rock phosphate at 60 kg P2O5 ha-1
T3	FYM	Farmyard manure at 10 t ha-1
T4	PM	Poultry manure at 10 t ha-1
T5	Compost	Compost at 10 t ha-1
T6	RP+FYM	Rock phosphate + FYM at 10 t ha-1
T7	RP+PM	Rock phosphate + PM at 10 t ha-1
T8	RP+Compost	Rock phosphate + compost at 10 t ha-1
T9	RP+PM+FYM	Rock phosphate + PM + FYM at 5 + 5 t ha-1
T10	RP+PM+Compost	Rock phosphate + PM + compost at 5 + 5 t ha-1
T11	RP+FYM+Compost	Rock phosphate + FYM + compost at 5 + 5 t ha-1
T12	RP+FYM+PM+Compost	Rock phosphate + FYM + PM + compost at 3.3 + 3.3 + 3.3 t ha-1

Results

Results of RP in combination with organic fertilizers significantly stimulated soybean biomass. The total dry matter yield obtained ranged from 4831 kg ha-1 for the control to 9530 kg ha-1 for RP+FYM+PM+compost treatment (Table 3; Figure 1). With reference to RP, RP+FYM+PM+compost recorded a 89.6% and RP+FYM+compost recorded a 81.8% increase in TSM over RP. The combined application of manure and compost was a better nutrient release and better plant growth compared to one P source at a time, as indicated by this response.

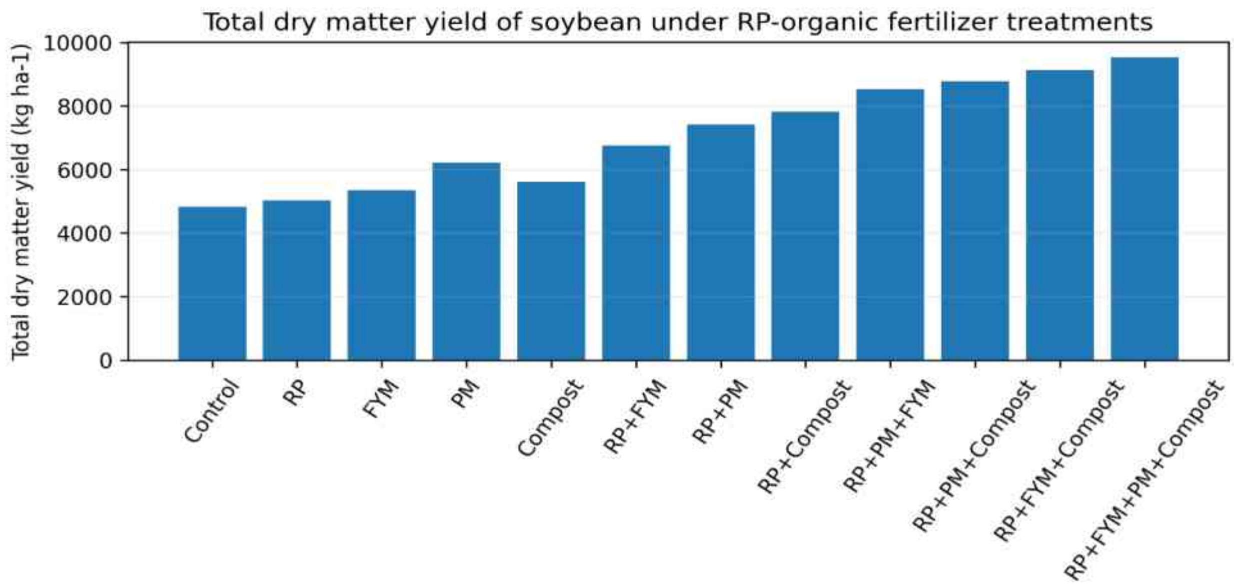

Figure 1 Total dry matter yield of soybean under RP-organic fertilizer treatments

The same overall pattern was observed for yield components. Pods plant-1 rose from 142 (control) to 145 (RP) to 190 (RP+FYM+PM+compost). Integrated treatments, incorporating RP along with several organic amendments had the highest grains pod-1. The Thousand grain weight also increased from 126 g in control and 132 g in RP alone to 155 g in RP+FYM+PM+compost treatment.

The combination of RP and organic fertilizers had a highly beneficial effect on grain yield. The highest grain yield (3554 kg ha-1) was achieved with RP+FYM+PM+compost, followed by RP+FYM+compost (2770 kg ha-1), RP+PM+compost (2664 kg ha-1) and RP+compost (2636 kg ha-1) (Table 3; Figure 2). The actual treatment result was obtained by recalculation using Python, which showed grain yields that were improved by 99.3% compared to RP and 151.9% compared to unfertilized control (Figure 5).

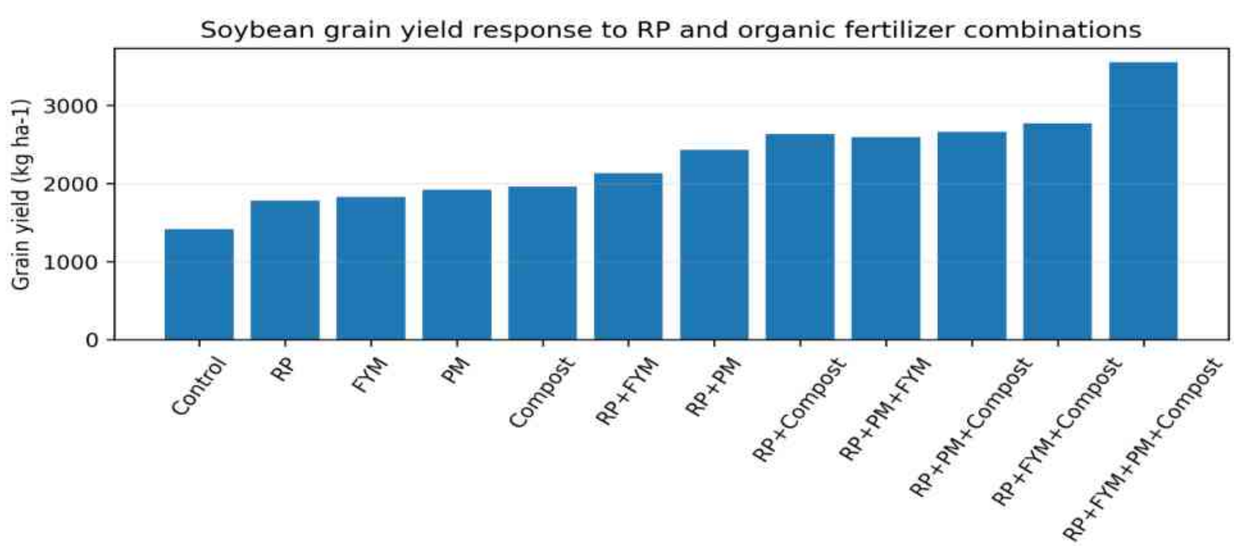

Figure 2 Soybean grain yield response to RP and organic fertilizer combinations

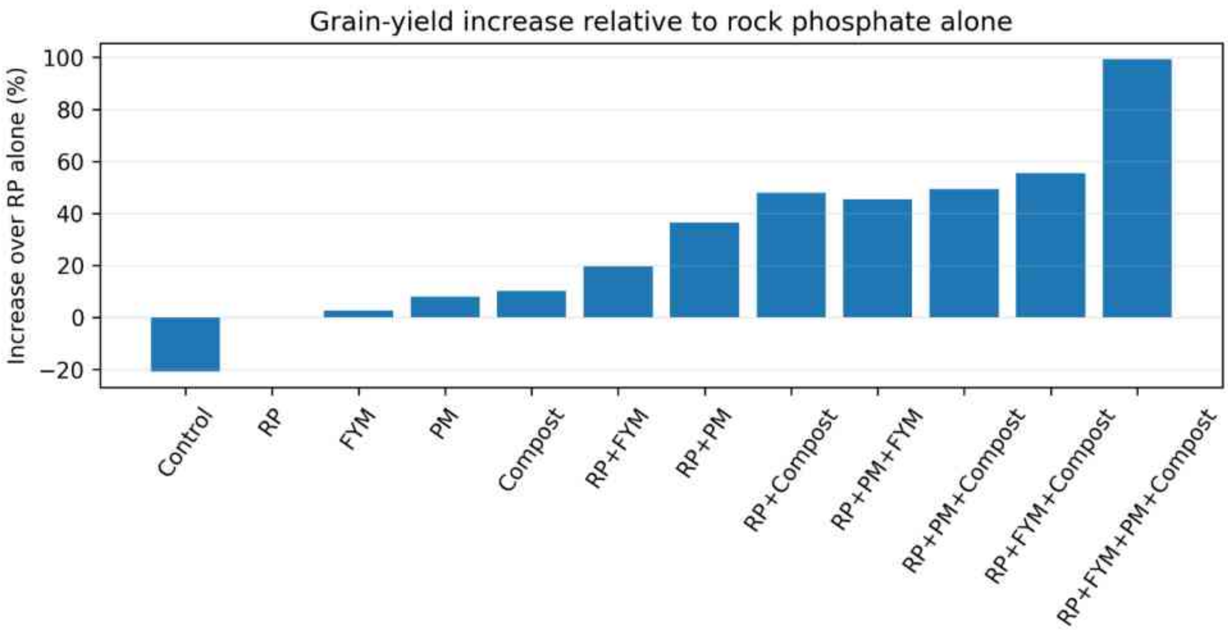

Figure 3 Grain-yield increase relative to rock phosphate alone

The pH of the soil post-harvest decreased from 7.70 in the control to 7.28 under RP+FYM+PM+compost indicating a more favorable post-harvest soil environment for rhizosphere due to the decomposition of organic amendments and its associated organic acids. The increase in soil organic matter from 0.59% in the control to 1.54% under the full integrated treatment. The integrated RP-organic application showed an increase in the level of soil P under RP+FYM+PM+compost (4.95 mg kg-1) compared to control (2.28 mg kg-1) and hence improved the status of soil P (Table 4; Figure 3).

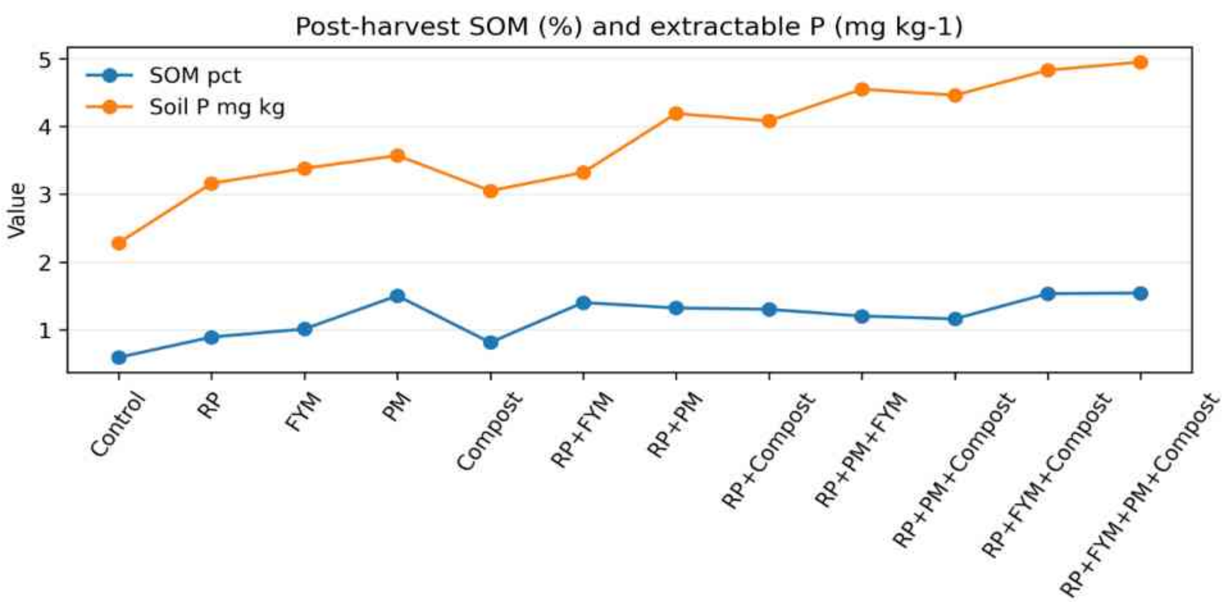

Figure 4 Post-harvest soil organic matter and extractable phosphorus response to treatments

The integrated nutrient management had a significant effect on plant N and P uptake. Values of N uptake (150.14 kg ha-1) and P uptake (16.96 kg ha-1) were the highest under RP+FYM+PM+compost (Table 5; Figure 4). This was a 132.6% and 175.8% higher than the uptake of N and P with RP alone, respectively. The increased uptake observed is consistent with the increased biomass production and increased post harvest nutrient availability of the same treatment.

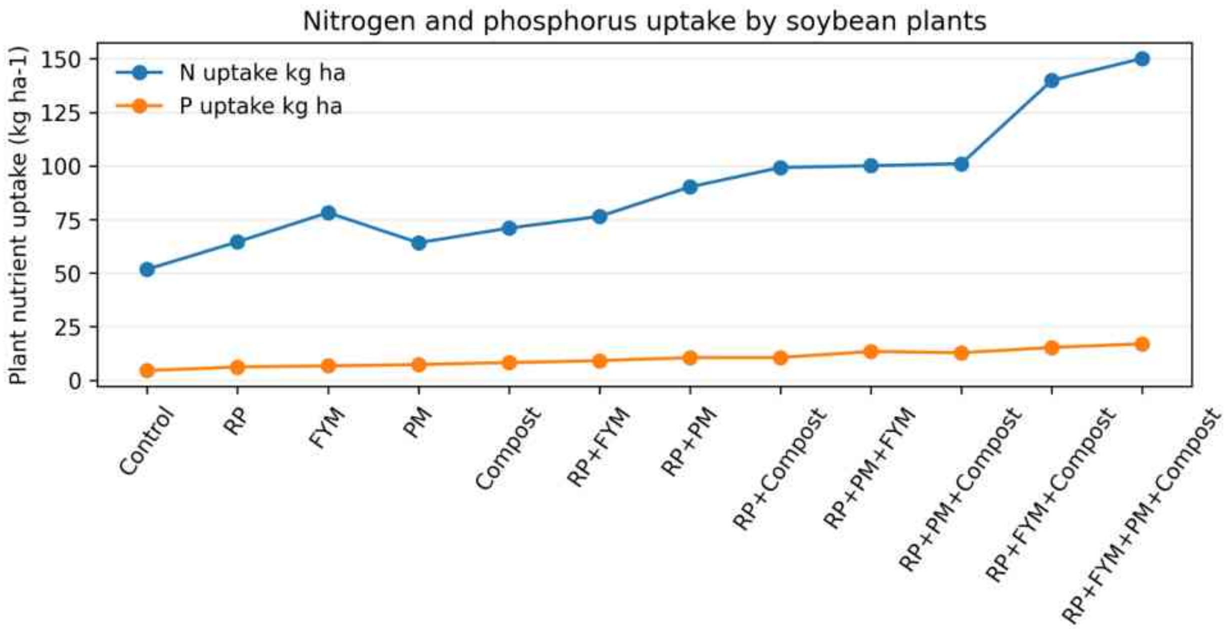

Figure 5 Nitrogen and phosphorus uptake by soybean plants under RP-organic fertilizer treatments

Table 3 Soybean yield and yield components as affected by RP and organic fertilizers.

Treatment	TDM (kg ha-1)	Pods plant-1	Grains pod-1	Grain yield (kg ha-1)	1000-grain weight (g)
Control	4831	142	2	1411	126
RP	5026	145	2	1783	132
FYM	5344	146	3	1830	134
PM	6218	163	3	1923	135
Compost	5618	155	2	1963	136
RP+FYM	6757	163	3	2133	142
RP+PM	7417	169	3	2434	144
RP+Compost	7816	176	3	2636	147
RP+PM+FYM	8526	182	4	2594	146
RP+PM+Compost	8770	185	3	2664	146
RP+FYM+Compost	9136	189	3	2770	154
RP+FYM+PM+Compost	9530	190	4	3554	155

Table 4 Post-harvest soil properties after soybean harvest.

Treatment	pH	SOM (%)	Total soil N (%)	AB-DTPA P (mg kg-1)
Control	7.70	0.59	0.10	2.28
RP	7.67	0.89	0.11	3.16
FYM	7.60	1.01	0.17	3.38
PM	7.55	1.50	0.18	3.57
Compost	7.68	0.81	0.18	3.05
RP+FYM	7.47	1.40	0.19	3.32
RP+PM	7.42	1.32	0.18	4.19
RP+Compost	7.56	1.30	0.17	4.08
RP+PM+FYM	7.36	1.20	0.17	4.55
RP+PM+Compost	7.41	1.16	0.15	4.46
RP+FYM+Compost	7.36	1.53	0.15	4.83
RP+FYM+PM+Compost	7.28	1.54	0.18	4.95

Table 5 Plant nutrient concentration and uptake by soybean.

Treatment	Plant N (%)	Plant P (%)	N uptake (kg ha-1)	P uptake (kg ha-1)
Control	1.02	0.07	51.75	4.56
RP	1.10	0.20	64.56	6.15
FYM	1.13	0.20	78.21	6.71
PM	1.15	0.13	64.14	7.32
Compost	1.14	0.12	70.99	8.22
RP+FYM	1.13	0.12	76.43	9.14
RP+PM	1.16	0.12	90.21	10.54
RP+Compost	1.14	0.13	99.23	10.60
RP+PM+FYM	1.17	0.13	100.10	13.41
RP+PM+Compost	1.15	0.13	100.99	12.78
RP+FYM+Compost	1.23	0.13	139.84	15.31
RP+FYM+PM+Compost	1.27	0.14	150.14	16.96

Table 6 Derived percentage increase over rock phosphate alone.

Treatment	TDM increase (%)	Grain-yield increase (%)	N uptake increase (%)	P uptake increase (%)
Control	-3.9	-20.9	-19.8	-25.9
RP	0.0	0.0	0.0	0.0
FYM	6.3	2.6	21.1	9.1
PM	23.7	7.9	-0.7	19.0
Compost	11.8	10.1	10.0	33.7
RP+FYM	34.4	19.6	18.4	48.6
RP+PM	47.6	36.5	39.7	71.4
RP+Compost	55.5	47.8	53.7	72.4
RP+PM+FYM	69.6	45.5	55.0	118.0
RP+PM+Compost	74.5	49.4	56.4	107.8
RP+FYM+Compost	81.8	55.4	116.6	148.9

Treatment	TDM increase (%)	Grain-yield increase (%)	N uptake increase (%)	P uptake increase (%)
RP+FYM+PM+Compost	89.6	99.3	132.6	175.8

Discussion

Complementary effects of the organic amendments can be used to explain the enhanced performance of RP+FYM+PM+compost. FYM adds slowly mineralizable organic matter and enhances the physical condition of the soil. PM is a bit higher in N and P and can promote earlier nutrient availability. Compost can provide organic matter that will persist in the soil and can also provide microbial activity and organic acids. These amendments can be used in combination with RP to enhance RP solubilization and decrease P fixation in calcareous soils under the influence of decomposition derived organic acids and microbial processes.

Agronomically the decrease of post-harvest pH under integrated treatments is important since high post harvest pH is one of the major factors which contributes to low availability of P in calcareous soil. A small drop in the pH of the soil surrounding decomposing organic materials may enhance dissolution of RP and mobilization of P in soil solution. The AB-DTPA-extractable P has increased for RP+FYM+PM+compost which reinforces the argument against use of RP alone in high pH and lime soils. Ahmad et al. (2022), Khan et al. (2022) and Rahim et al. (2024) reported similar mechanisms to the ones reported for organic amendments and P fertilizers in calcareous soils.

The response of grain yield was correlated with the growth of the biomass, pods plant-1 and thousand-grain weight. This suggests that the integrated treatment not only stimulated vegetative growth but also assisted in reproductive development and assimilate partitioning. The increased N uptake in RP-organic mixtures might be due to better root development, biological activity and nutrient retention. This is especially important for P uptake, as P is directly linked to energy transfer, root growth and seed production.

The practical results showed that RP alone produced only limited yield advantage over the control and when combined with other organic sources, RP resulted in a significant boost in productivity. This indicates that farmers using similar calcareous soils might benefit more with local RP if used with organic fertilizers. It is recommended to assess the feasibility of multiple sources of organics in the field with a cost benefit analysis, transport costs, manure availability and nutrient-balance calculations.

There are some limitations in the study. The paper is based on the same season/place, and the treatment means were derived from a thesis dataset and not new multi-season trials. Future research should compare the most effective treatments over seasons, soybean varieties and soils and incorporate factors of phosphorus use efficiency, microbial dynamics, organic acid dynamics, and economic analysis.

Conclusion

In the present study under the calcareous soil condition of Peshawar, the best result for improving the yield of soybean, soil fertility and nutrient uptake was achieved by the application of rock phosphate along with farmyard manure, poultry manure and compost. The total dry matter yield, grain yield, pods plant-1, 1000-grain weight, post harvest soil organic matter, extractable soil P, plant N uptake and plant P uptake were highest for the full integrated treatment. The results indicate that RP is better applied in combination with organic amendments and not in isolation particularly on alkaline, calcareous soils where P availability is low. Field-scale testing and economic evaluation are suggested prior to the development of farmer-level recommendations, followed by multi-season testing.

Recommendations

The use of RP in calcareous soils with organic amendments, mainly FYM, PM and compost can enhance P availability, yield and nutrient uptake in soya beans. RP (without FYM) + compost or PM + compost may be effective alternatives when all amendments are not available. More widespread testing is suggested to determine how effective this P-use is and the effect on microbial activity before use on a larger scale, and the economic viability of this use.

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