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Effect of phosphorus management practices on growth, production and economics of wheat (*Triticum aestivum*) in an acid Alfisol

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ABSTRACT

The study was carried out during winter (*rabi*) season of 2021–22 and 2022–23 at Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh to explore and understand the impact of different phosphorus management practices on wheat yield and quality in acid Alfisol of Himachal Pradesh. The experiment was laid out in a randomised block design (RBD) with nine treatments (T_1, Control; T_2,100% NPK; T_3, 100% NPK + lime; T_4, 100% NPK + 10 t/ha FYM; T_5, 0.5 t/ha *Ghan jeevamrit* + *Jeevamrit* sprays at 21 days interval; T_6, 100% NK + 3 t/ha PROM; T_7, 100% NK + 75% P + 0.75 t/ha PROM; T_8, 100% NK + 50% P + 1.5 t/ha PROM and T_9, 100% NK + 25% P + 2.25 t/ha PROM) replicated thrice. The wheat variety selected for the study was HPW 368 variety. Crop growth parameters, such as plant height, tiller count, root volume, and root mass density were assessed along with yield attributes like productive tillers, grains/spike, and 1000 grain weight. The results indicated that the application of 1.5 t/ha PROM combined with 100% NK and 50% P through single super phosphate (T_8) resulted in the highest plant growth, root development, grain yield (4.25 t/ha) and straw yield (6.45 t/ha). This treatment also produced the highest net returns (62,017 ₹/ha). Whereas, the highest B:C ratio was recorded under T_2 treatment i.e. 100% NPK (1.83) followed by T_8 (1.72), demonstrating superior economic viability. Thus, application of 100% NK + 50% P + 1.5 t/ha PROM to wheat crop was found best for realising higher growth, production and profitability under phosphorus-limited acid Alfisol conditions.

Keywords: Economics, Growth, Phosphate rich organic manure, Production, Wheat

Wheat (*Triticum aestivum* L.) is one of the most widely grown staple food crops globally, after rice (Ankit *et al.* 2024). It is a primary food source for a significant portion of the global population, providing essential nutrients and energy (Kumar *et al.* 2024). Grain quality of wheat is influenced by organic compounds, minerals, vitamins, antioxidants, and anti-nutritional compounds (Moisa *et al.* 2024). It is a nutrient-intensive crop, depleting significant amounts of soil nutrients, with phosphorus being the second most critical nutrient after nitrogen (Singh 2019). Phosphorus is vital for plant growth, involved in DNA and RNA structure, energy molecules (ATP, ADP), photosynthesis, and respiration (Khan *et al.* 2023). It also promotes root development, seedling establishment, and water use efficiency, enhancing wheat grain yield and quality (Udawat 2023).

In acid soils, phosphorus availability is restricted due to its tendency to form insoluble complexes with iron and aluminium, making it unavailable for plants (Johan *et al.* 2021). This limitation impacts the potential yield of crops, including wheat (Ditta *et al.* 2018). Furthermore, the reduced use of phosphatic fertilisers, especially in import-dependent countries like India, heightens this challenge. Rising fertiliser costs, coupled with over-reliance on chemical fertilisers, threaten agricultural sustainability and the environment (Rahaman *et al.* 2024).

Thus, there is a pressing need to focus on the efficient utilisation of alternative, cost-effective, and fud organic sources of phosphorus. The incorporation of organic phosphorus sources, especially phosphate-rich organic manure (PROM), in conjunction with inorganic fertilisers, represents a sound management practice. This approach aids in accumulating soil organic carbon, increasing phosphorus availability to crops, sustaining yields and enhancing soil quality to augment overall crop production (Noor *et al.* 2021). Thus, the aim of this experiment was to study the effect of phosphorus management practices on wheat productivity and economics in an acid Alfisol of Himachal Pradesh.

MATERIALS AND METHODS

The study was carried out during winter (*rabi*) season of 2021–22 and 2022–23 at Chaudhary Sarwan Kumar

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Himachal Pradesh Krishi Vishvavidyalaya, Palampur, (32.11° N and 76.53° E; at an elevation of 1250 m amsl), Himachal Pradesh. The climate of the experimental area was characterised as wet temperate with mild summers and cool winters. Rainfall in the area ranges from 2500–3000 mm annually on an average.

In both years, the trial was set up using a randomised block design (RBD) with three replications. There were twenty-seven plots and the unit plot size was 5 m × 2 m. There were nine treatments, i.e. T_1, Control; T_2,100% NPK; T_3, 100% NPK + lime; T_4, 100% NPK + 10 t/ha FYM; T_5, 0.5 t/ha *Ghan jeevamrit* + *Jeevamrit* sprays at 21 days interval; T_6, 100% NK + 3 t/ha PROM; T_7, 100% NK + 75% P + 0.75 t/ha PROM; T_8,100% NK + 50% P + 1.5 t/ha PROM and T_9, 100% NK + 25% P + 2.25 t/ha PROM. The recommended NPK fertiliser (120:60:30) was supplied through urea, single super phosphate (SSP) and muriate of potash, respectively. The wheat variety selected for the study was HPW 368 variety. At the time of sowing, the treatments were supplied with full dose of P and K and half of N. The remaining half dose of N was top dressed in two equal splits at crown root initiation stage and booting stage. At 60, 90 and 120 days after sowing (DAS), plant height and number of tillers/m^2 were counted. Days to 50% flowering and maturity were also counted. At harvest, number of productive tillers, number of grains/panicle and weight of thousand grains were recorded. Root parameters like root volume (RV) through displacement method (Misra and Ahmed 1987) and root mass density (RMD) were calculated. Sun dry weight of both grain and straw was recorded plot-wise for each treatment and the harvest index (HI) was calculated by using the formula:

$$\text{HI} = \frac{\text{Grain yield (t/ha)}}{\text{Biological yield (t/ha)}}$$

The data were interpreted using the Analysis of Variance (ANOVA) approach for randomised block design, as defined by Gomez and Gomez (1984) and the means of the treatments were tested for least significant differences at 0.05 using OPSTAT software. Relationship of grain yield and number of grains/spike with soil available P were worked out by computing simple correlation of coefficients using Microsoft excel 2016 software. Based on input costs, the cost of cultivation, gross return, net income, and B:C were calculated at the end of the experiment.

RESULTS AND DISCUSSION

Plant growth parameters: Data on wheat growth characteristics showed that, with the exception of the T_5 treatment, all treatments increased plant height and tiller's count significantly above the control (Fig. 1). The pooled data from the two-year trial showed that the T_8 treatment had the highest plant height at 60, 90, and 120 DAS viz. 35.1, 64.0 and 98.6 cm with an increase of 36.1, 30.6 and 30.5%, respectively over T_1 i.e. control. Significantly, maximum number of tillers/m^2 were also recorded in T_8 treatment i.e. 184, 264 and 291 and lowest were recorded in T_1 (131, 168 and 180), that was statistically at par with natural farming treatment T_5 (135, 170 and 182). Highest plant height (35.8, 60.1 and 91.0 cm) and number of tillers/m^2 (170, 240 and 267) were recorded in T_4 treatment i.e. 100% NPK + 10 t/ha FYM over T_2 (100% NPK) and T_3 (100% NPK + lime). This could be ascribed to the integrated application of phosphorus from both organic (PROM and FYM) and inorganic (SSP) sources, which had a major effect on the growth and development of cell components, efficient cell division and rapid translocation of synthesised carbohydrates to growing parts (Patel *et al.* 2018). These factors ultimately led to an increase in the height and number of tillers on the plant. Wahid *et al.* (2015) and Jalil *et al.* (2017) also found that synthetic fertiliser in addition to organic manure provides more nutrients resulting in better growth and development of crop than sole application of rock phosphate. The present results were also aligned with the findings obtained by Anwar *et al.* (2017), Billah *et al.* (2020) and Udawat (2023) who found that integrated use

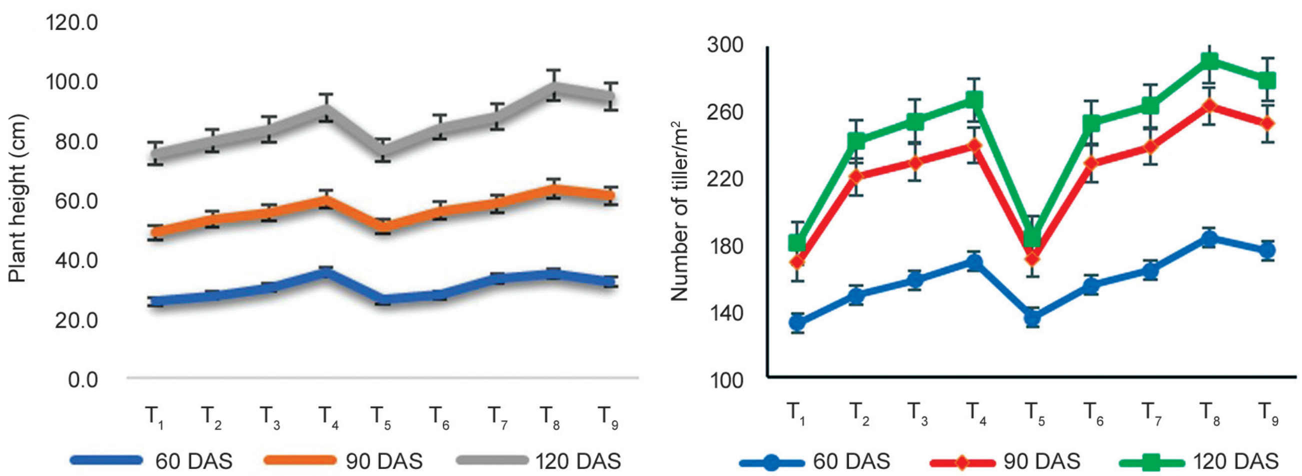

Fig. 1 Effect of phosphorus management practices on plant height and number of tillers at different growth stages (2 years pooled data).
Treatment details are given under Materials and Methods. DAS, Days after sowing.

Table 1 Effect of phosphorus management practices on development phases and yield attributing characters of wheat (2 years pooled data)

Treatments	Days to 50% flowering	Days to physiological maturity	Number of productive tillers	Number of grains/ spike	1000-grain weight
T_1	117.9	159.8	178	32.5	44.1
T_2	117.4	158.3	231	45.4	44.7
T_3	116.6	158.3	245	48.9	44.8
T_4	115.2	157.7	261	52.8	45.5
T_5	117.9	159.2	182	32.9	44.2
T_6	116.6	158.0	235	48.1	44.9
T_7	115.2	159.3	250	51.0	45.2
T_8	115.0	155.9	270	55.3	45.8
T_9	115.1	157.1	261	52.5	45.6
LSD (p=0.05)	2.1	1.9	9.5	2.1	0.2

Treatment details are given under Materials and Methods.

of inorganic fertilisers with rock phosphate significantly increased the plant height and tillers in wheat crop as compared to the solo application of chemical fertilisers.

Pooled data presented in Table 1 revealed that days to 50% flowering and days to physiological maturity reduced significantly with the combined application of inorganic and organic P sources (T_8, T_9, T_4, T_7) as compared to sole application of inorganic or organic fertilisers. This might be explained as phosphorus influence on root mass and its indirect role in formation of cytokinin hormone, which enhances initiation of flowering in the plants (Mohamad 2011).

The pooled data on root volume (RV) and root mass density (RMD) of wheat, influenced by various phosphorus management practices (Fig. 2), indicated that the T_8 treatment recorded a statistically higher RV of 1332 cm^3/m^3. Also, RMD was recorded maximum in this treatment (1323 g/m^3) which was statistically at par with T_9 treatment (1302 g/m^3). Application of 100% NPK + 10 t/ha FYM (T_4) resulted in significant increase in RV and RMD by 14.0 and 44.5, 10.0 and 25.8, 3.6 and 14.8%, respectively over 100% NPK and 100% NPK + lime, respectively. This might be due to direct addition of organic matter in the soil that made soil porous and well pulverised, reduced bulk density and mechanical resistance for root penetration. Moreover, addition of organic manure also increased P availability by formation of phospho-humus complexes that prevents its fixation in soil and hence, enhanced root volume and root mass density (Klopp *et al.* 2023). The lowest RV and RMD was recorded in control followed by T_5 treatment. This increase in RV and RMD under T_8 treatment could be attributed to the integrated application of chemical fertilisers and PROM which enhances the availability of phosphorus, resulting in better root formation, proliferation and elongation as phosphorus is crucial for root development (Sabah *et al.* 2016), thereby increasing RV and RMD. The positive effect of phosphorus on root growth of wheat has also been highlighted by Ahmed *et al.* (2019).

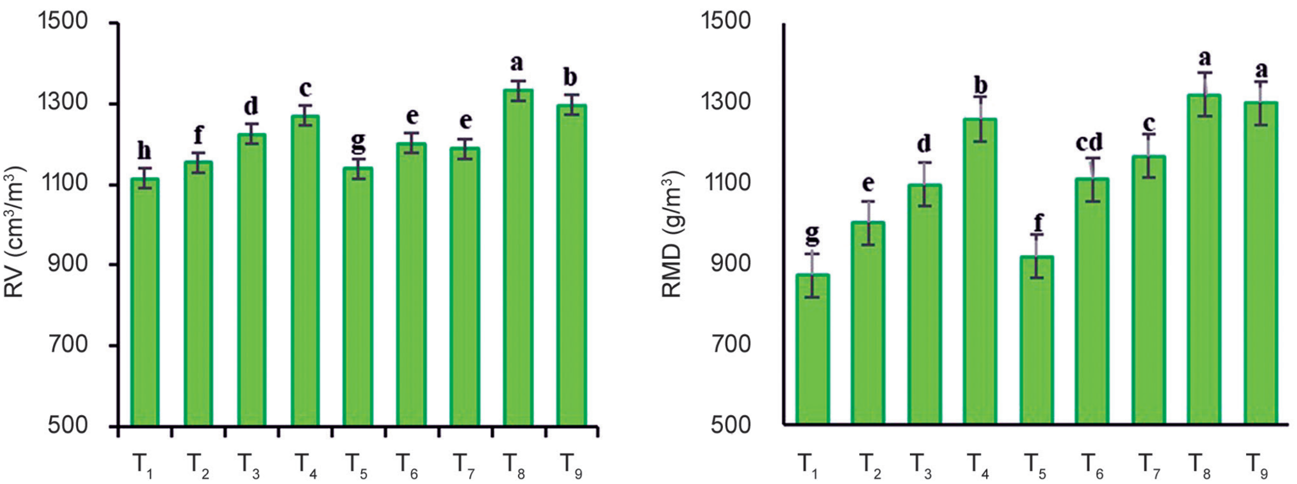

Fig. 2 Effect of phosphorus management practices on root volume (RV) and root mass density (RMD) of wheat (2 years pooled data). Treatment details are given under Materials and Methods.

Yield attributes: The pooled data in Table 1 clearly illustrated that various phosphorus management practices had a considerable impact on the number of productive tillers, grains/spike and 1000 grain weight in the wheat crop. The higher number of productive tillers/m^2 was recorded in T_8 treatment (270) that was statistically at par with T_9 treatment (261). The number of effective tillers increased by 46.6% over control, 13.0% over 100% NPK, and 6.5% over 100% NPK + lime in the T_4 treatment. The maximum number of grains/spike were recorded under T_8 treatment (55.3) as compared to other treatments. Application of 100% NPK + 10 t/ha FYM (T_4) significantly increased number of grains/spike by 62.4% over control, 16.3% over 100% NPK and 7.9% over 100% NPK + lime. The minimum number of effective tillers and grains/spike were recorded in control and were statistically at par with T_5 treatment. The maximum 1000 grain weight was recorded under T_8 treatment (45.8 g) followed by T_9 treatment (45.6 g) and T_4 (45.5 g). In T_1 and T_5 treatment, lowest 1000 grain weight was recorded i.e. 44.1 and 44.2 g, respectively. Adequate supply of phosphorus from inorganic source (SSP) at initial crop growth stages as well as the slow release of phosphorus from PROM might have ensured adequate supply of phosphorus to plant resulting in better photosynthetic activity and carbohydrate use efficiency of the crop that stimulated root growth as well as the uptake of other nutrients resulting in higher number of productive tillers, grains/spike and test weight (Kumar *et al.* 2019, Ahmad *et al.* 2022).

Wheat yield: Pooled data in Table 2 showed significant increase in grain and straw yields of wheat in all the treatments except treatment T_5. With a significant increase of 116.8, 51.8, and 34.9% over T_1, T_2, and T_3 treatments, respectively, treatment T_8 (4.25 t/ha) achieved the highest pooled grain yield among the other treatments. Application of 100% NPK + 10 t/ha FYM (T_4) also resulted in 31.1 and 16.5% increase in grain yield over T_2 and T_3 treatments, respectively. Application of 100% NPK + lime (T_3) also increased grain yield (3.15 t/ha) over sole application of 100% NPK (2.80 t/ha). The lowest grain yield was recorded in T_1 (1.96 t/ha) that was statistically at par with T_5 treatment (2.14 t/ha). Similarly, maximum straw yield (6.45 t/ha) with the increase of 77.7% was recorded in treatment T_8, over the control. Application of 100% NPK + 10 t/ha FYM increased straw yield over T_1, T_2 and T_3 treatment by 56.0, 18.2, and 8.0%, respectively. Higher straw yield (5.24 t/ha) due to the application of 100% NPK + lime (T_3) over sole application of 100% NPK (4.79 t/ha) could be attributed to increase in soil *p*H by reducing H^+ and Al^{+3} toxicity, more cation exchange capacity, increased availability of P, Ca, Mg and uptake of the nutrients (Gourav *et al.* 2019, Mohammed *et al.* 2021). The minimum straw yield was recorded in T_1 i.e. control (3.63 t/ha) and was statistically at par with T_5 treatment comprising 0.5 t/ha *Ghanjeevamrit* + *Jeevamrit* spray (3.80 t/ha). The integrated phosphorus treatments increased the microbial population, especially, phosphate solubilising bacteria in the rhizosphere, which resulted into more solubilisation of the non-labile P to labile pool. This eventually led to a more robust root system, improving soil nutrients uptake and better dry matter accumulation along with translocation of photosynthates from source to the sink thereby increased the yield (Udawat 2023). A strong correlation was also observed between number of grains/spike and soil available P with grain yield (Fig. 3). In integrated treatments, the role of 100% N and K in crop production cannot be over-looked. Nitrogen plays a significant role in synthesis of enzymes, proteins, hormones, vitamins and alkaloids, whereas, potassium helps in cellular extension, enzyme activation, photosynthesis, transportation and uptake of other essential nutrients, hence, enhancing wheat production significantly (Pandey *et al.* 2020). Similar findings were reported by Anwar *et al.* (2017).

Harvest index (HI): The highest HI was observed in T_8 treatment (39.7%) that was statistically at par with all the different levels of PROM integrated with chemical fertilisers (T_7, T_9) and T_4, followed by T_6 and T_3 treatments (Table 2).

Table 2 Effect of phosphorus management practices on yield (t/ha) and harvest index (%) of wheat (2 years pooled data)

Treatments	Grain yield (t/ha)			Straw yield (t/ha)			HI (%)		
	2021–22	2022–23	Pooled	2021–22	2022–23	Pooled	2021–22	2022–23	Pooled
T_1	1.82	2.10	1.96	3.31	3.95	3.63	35.5	35.0	35.3
T_2	2.66	2.94	2.80	4.54	5.04	4.79	37.0	36.8	36.9
T_3	2.97	3.33	3.15	4.98	5.50	5.24	37.3	37.7	37.5
T_4	3.31	4.03	3.67	5.44	5.87	5.66	37.8	40.7	39.3
T_5	1.97	2.31	2.14	3.52	4.08	3.80	35.9	36.1	36.0
T_6	2.99	3.27	3.13	4.96	5.45	5.20	37.6	37.5	37.6
T_7	3.28	3.65	3.46	5.40	5.81	5.60	37.8	38.6	38.2
T_8	3.87	4.63	4.25	6.21	6.69	6.45	38.4	40.9	39.7
T_9	3.59	4.31	3.95	5.85	6.31	6.08	38.0	40.6	39.3
LSD (p=0.05)	0.28	0.29	0.26	0.41	0.46	0.42	1.1	2.8	2.0

HI, Harvest index. Treatment details are given under Materials and Methods.

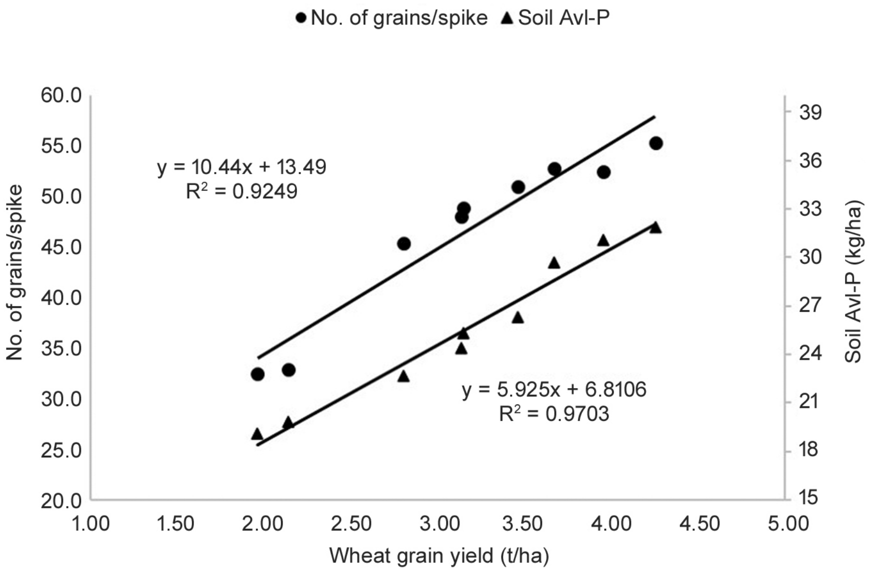

Fig. 3 Correlation between number of grains/spike and soil available P.

The lowest HI was recorded in control (35.3%), which was statistically at par with T_5 (36.0%) and T_2 treatment (36.9%). Integrated application of chemical fertilisers and PROM or FYM or lime resulted in higher HI. A possible explanation for the potential rise in yield attributing factors and yield is the efficient translocation of photo-assimilates from source to sink, thereby, resulting in higher HI (Anwar *et al.* 2017). The lowest HI recorded in control, natural farming and 100% NPK treatment might be ascribed to the lower ratio of grain yield to straw yield in these treatments.

Economics: A close examination of the data (Table 3) revealed that the highest net returns were recorded under T_8 treatment (62,017 ₹/ha) followed by T_9 treatment (56,271 ₹/ha). Lowest net returns were recorded under control (21,503 ₹/ha). But the highest B:C ratio was recorded under T_2 treatment (1.83) followed by T_8 (1.72) and T_7 treatment (1.72). Lowest B:C ratio was recorded under T_6 treatment (0.47) due to higher cost of PROM, which enhanced the cost of cultivation. Majeed *et al.* (2018) also reported that integrated application of enriched rock phosphate along with chemical fertilisers resulted in higher B:C ratio over individual application of rock phosphate.

Table 3 Effect of phosphorus management practices on cost of cultivation, gross returns, net returns and B:C (2 years pooled data)

Treatments	Cost of cultivation	Gross revenue	Net returns	B:C
		(₹/ha)		
T_1	24,973	46,476	21,503	0.86
T_2	23,175	65,630	42,456	1.83
T_3	44,175	73,451	29,277	0.66
T_4	33,175	84,709	51,535	1.55
T_5	23,983	50,377	26,395	1.10
T_6	49,592	73,071	23,479	0.47
T_7	29,575	80,431	50,856	1.72
T_8	36,018	98,035	62,017	1.72
T_9	34,962	91,233	56,271	1.61

Treatment details are given under Materials and Methods.

Thus, based on the two-year study, it can be concluded that the application of 1.5 t/ha PROM in combination with 100% NK and 50% P through SSP (T_8) proved to be the most effective phosphorus management strategy for wheat cultivation in acid Alfisol conditions. This treatment significantly enhanced key yield attributes, such as plant height, tiller count, number of productive tillers, grains/spike, and 1000 grain weight, which directly contributed to a higher grain yield and straw yield. The integrated approach not only improved crop development but also ensured better phosphorus availability to the plants, resulting in optimal nutrient uptake, enhanced photosynthetic activity, and efficient translocation of photo-assimilates. The improved plant health and yield was also reflected in the highest gross returns and net returns under the integrated practices compared to other treatments. Furthermore, the combined application of organic and inorganic phosphorus sources enhanced soil fertility, supported sustainable agricultural practices, and improved the economic viability of wheat production under phosphorus-limited conditions. Therefore, this phosphorus management practice can be regarded as the most effective approach for enhancing wheat productivity and profitability in acid Alfisol.

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