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Effect of Organic Manures on Phosphorus Use Efficiency in Summer Rice in Acidic Soil of Northern Part of West Bengal

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ABSTRACT

A field experiment was conducted in *boro* (summer) seasons during December to May, 2021–22 and 2022–23 at Central Research Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India, in acidic soil (pH 5.10) of the terai region of West Bengal to assess the effect of replacing phosphorus (P) fertilizer application by farm yard manure (FYM) and vermicompost (VC) on P uptake and use efficiency by summer rice. The soil of the study area was sandy loam, medium in available P (16.48 kg ha^{-1}) content and deficient in available N (126.68 kg ha^{-1}). The experiment was laid out in a randomized complete block design with eleven treatment combinations including four P doses i.e., 25%, 50%, 75% and 100% of the recommended dose, the rest of which were supplemented by either FYM or VC. Significantly higher P uptake at different growth stages was noticed with the increasing fertilizer P application. Combined use of 25% P and 75% vermicompost was most effective for grain yield (5.70 t ha^{-1}), harvest index (HI) (42.80%) and agronomic P use efficiency (APUE) (15.25 kg kg^{-1}). Increasing fertilizer P dose to 75% and 100% with or without organic manures was not found effective in increasing yield and P use efficiency, while was also effective in uptake of P and apparent P recovery.

KEYWORDS: Summer rice, phosphorus uptake, phosphorus use efficiency, organic manure

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Rice (*Oryza sativa* L.) is the key global crop, with an annual production surpassing 780 mt globally, and is a primary food staple in Asian countries (Choi et al., 2007; Kim et al., 2023). According to the Ministry of Agriculture report of 2022–2023, India has 46 m ha land dedicated to rice farming, producing 130 mt year^{-1} with a productivity of 2.81 t ha^{-1}. In West Bengal, rice is cultivated in 5.58 m ha, yielding 16.6 mt year^{-1} with a productivity of 2.98 t ha^{-1}. The rice production in the conventional rice-wheat production system is facing an acute decline in factor productivity and yield stagnation due to nutritional deficiency and poor soil health (Singh et al., 2021; Dhanda et al., 2022). Phosphorus (P) is as crucial as water and is second to nitrogen (N) as the important limiting element for plant growth and nutrition. Phosphorus is one of the indispensable structural components in plant cells including nucleic acids, proteins, membrane-lipids, sugar-phosphates, adenylates etc. Phosphorus is necessary for various metabolic and physiological processes including energy metabolism, cell division, DNA synthesis and phospholipid biosynthesis (Isidra-Arellano et al., 2021; Iqbal et al., 2023). It is essential for energy transfer processes (Kumar et al., 2021). Rice also responds well to P fertilization in both upland and wetland conditions, but P has attained less focus than N. The phosphorus use efficiency (PUE) of rice is only around 25% (Dobermann and Frairhurst et al., 2000; Fixen et al., 2015), with rice alone absorbing 1.07 mt of phosphate (P_2O_5) at a rate of 24.3 kg ha^{-1}, indicating significant potential for improvement of P fertilization and management (Bhatta et al., 2021). There were some challenges such as resource scarcity and the environmental pollution caused by chemical P fertilizers are major concerns in modern agriculture (Yu et al., 2013; Yan et al., 2022). Phosphorus availability in most soils is limited due to slow diffusion and high fixation rate (Jokubauskaite et al., 2015; Ahash et al., 2025). Use of phosphatic fertilizers higher available P forms for plant uptake, but overuse of fertilizers can reduce PUE and increase the accumulation of surplus P in soil (Ayaga et al., 2006; Borda et al., 2014). Increasing the yield and use efficiency of P is imperative for rice productivity in all types of soils. Several strategies have been adopted to lower dependence on fertilizer P sources. Adoption of integrated nutrient management practices involving organic and inorganic fertilizers is the prime approach to make the production system more sustainable and profitable (Sarkar et al., 2017). Replacing mineral P fertilizer with organic manure could reduce the demand of P fertilizers (Bi et al., 2020). In double rice system long term organic manure substitution significantly increased PUE, P uptake and yield of rice (Hayatu et al., 2023). Besides the rice yield the integration of organic manures with fertilizers could also increase soil nutrient status and total productivity (Dhaliwal et al., 2023). However, limited information is available concerning how P application affects P uptake and use efficiency in rice in conventional practices in presence or absence of organic manures. Considering this the present study was undertaken to ascertain the effect of organic manures and graded doses of P on P uptake and use efficiency by rice in conventional practice in an acidic soil of northern part of West Bengal which is frequently reported as deficient in P.

2. MATERIALS AND METHODS

2.1. Experiment site and treatment details

The field experiment was conducted during boro (summer) seasons during December to May, 2021–22 and 2022–23 at Central Research Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India (26º19'86" N latitude and 89º23'53" E altitude of 51m AMSL),. The soil of the experimental field belongs to Typic Fluvaquents with 60.25, 19.63, 20.12% of sand, silt and clay respectively, having sandy loam texture. With an initial pH value of 5.10, the soil was classified as acidic, potentially affecting nutrient availability and microbial activity. The electrical conductivity (EC) was measured at 0.09 dS m^{-1}, indicating low salinity, suggesting minimal risk of salt accumulation. The organic carbon content was found to be 0.61%, categorized as medium, reflecting a moderate presence of decomposable organic matter. The available N, P_2O_5 and K_2O content were 126.68, 16.42 and 128.33 kg ha^{-1}, respectively. As a source of organic manures vermicompost and FYM were used. Vermicompost and FYM contain N, P_2O_5 and K_2O were 2.46, 1.15, 1.45% and 0.75, 0.30, 0.52% respectively. The experiment was conducted in randomized complete block design with 11 treatments and three replications growing a medium duration (120–130 days) rice cultivar, IET 24171 (Uttar Sona). The NPK recommendation (RDF) for summer rice in this region is 120:80:80 kg ha^{-1}. The treatment combinations were T_1-control (no P) (NK), T_2-NPK (RDF), T_3-100% vermicompost+NK, T_4-75% vermicompost+25% P+NK, T_5-50% vermicompost+50% P+NK, T_6-25% vermicompost+75% P+NK, T_7-100% FYM+NK, T_8-75% FYM+25% P+NK, T_9-50% FYM+50% P+NK, T_{10}-25% FYM+75% P+NK and T_{11}-50% vermicompost and 50% FYM+NK. Vermicompost and FYM were applied before transplanting or rice seedlings. Rice seedlings were manually transplanted in the main experimental plot as two seedlings per hill with 20×15 cm^2 hill spacing in 3×5 m^2 plots. Standard agronomic management practice was followed to grow the crop. Recommended doses of P_2O_5 and K_2O were applied in the soil at the final land preparation in the forms of single super phosphate (SSP) and muriate of potash (MoP). Nitrogen was applied as urea in three split doses each at transplanting, maximum tillering and booting stages. The rice grain yield was calculated from a harvest area of 4 m^2 quadrate from the central position in each plot and adjusted to 14% moisture content. Phosphorus content in the plant parts at different growth stages was measured by the wet digestion method using vanado-molybdate yellow color method as described by Jackson (1973) after digesting the samples in mixture HNO_3:$HCLO_4$ (9:4 m) at a temperature 105°C. The P uptake (in kg ha^{-1}) was computed by multiplying P content in dry matter and dry mater production in kg ha^{-1}.

2.2. Calculation of phosphorus use efficiencies

Phosphorus use efficacy of rice was quantified by calculating various indices, namely agronomic phosphorus use efficiency (APUE), physiological phosphorus use efficiency (PPUE), Apparent phosphorus recovery (APR), partial phosphorus productivity (PPP) (Syers et al., 2008) and grain P harvest index (Grain P HI) (Yoshida et al., 1976), using the equations:

APUE (kg kg^{-1})=(Yt–Yo)/Pa

PPUE (kg kg^{-1})=(Yt-Yo)/(Ut-Uo)

APR (%)=[(Ut-Uo)×100]/Pa

PPP (kg kg^{-1})=Yt/Pa

Grain P HI (%)=[Yt (grain)/Yt (grain+straw)]×100

Where, Yt=Grain yield in the treatment plot (kg ha^{-1}), Yo=Grain yield in the control plot (kg ha^{-1}), Ut=Uptake of P in the treatment plot (kg ha^{-1}), Uo=Uptake of P in the control plot (kg ha^{-1}), Pa=P applied in the test treatment (kg ha^{-1}) respectively and Yt (grain)=Grain yield (kg ha^{-1}), Yt (grain+straw)=Grain and straw yield (kg ha^{-1}) respectively.

2.3. Statistical analysis

One-way analysis of variance (ANOVA) in RCBD was performed using IBM SPSS as per Gomez and Gomez (1984) (version 26.0, SPSS Inc. Chicago, IL, USA) for pooled data from two years of field experiments. The significance of the difference between means was determined at 5% ($p<0.05$) level of probability using Duncan's multiple range test (DMRT).

3. RESULTS AND DISCUSSION

3.1. Phosphorus uptake at different growth stages of rice

The Puptake gradually increased with the crop age (Table 1). The P levels had significant influence on P uptake by rice at tillering, panicle initiation stage and flowering stages. The analysis of pooled data for these consecutive two years experiments showed that, P uptake significantly (at $p\leq0.05$) increased from 3.41 kg ha^{-1} in T_1 (no P. NK) (control) to 7.19 kg ha^{-1} in T_2 (NPK, RDF) in the tillering stage. The pooled data of two years showed that the highest P uptake was observed in T_2 (8.09 kg ha^{-1}) followed by T_6 (7.69 kg ha^{-1}), T_{10} (7.23 kg ha^{-1}) and lowest under control T_1 (4.80 kg ha^{-1}) at panicle initiation stage. Similarly in flowering stage also the maximum uptake of P (13.08 kg ha^{-1}) was recorded in T_2 followed by T_6 (10.83 kg ha^{-1}), and T_{10} (9.91 kg ha^{-1} while minimum was observed at the control plot i.e. T^1 (6.80 kg ha^{-1}). The phosphorus uptake at flowering stage

Table 1: Effect of phosphorus, FYM and vermicompost on uptake of P (kg ha^{-1}) at tillering, panicle initiation and flowering stages of summer rice

Treatments	Tillering			Panicle initiation			Flowering		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	3.39	3.42	3.41j*	4.48	5.12	4.80^{h}	6.67	6.93	6.80^{h}
T_2	7.12	7.26	7.19^{a}	7.92	8.25	8.09^{a}	12.69	13.46	13.08^{a}
T_3	4.20	3.98	4.09^{h}	5.16	5.88	5.52^{fg}	6.91	7.55	7.23^{g}
T_4	4.86	5.13	5.00^{f}	5.68	6.35	6.02^{ef}	7.77	7.96	7.87^{f}
T_5	5.28	5.69	5.49^{d}	6.45	6.82	6.64^{d}	8.92	9.64	9.28^{d}
T_6	6.28	6.53	6.40^{b}	7.53	7.85	7.69^{b}	10.27	11.38	10.83^{b}
T_7	3.44	3.49	3.47^{ij}	4.63	5.38	5.01^{g}	6.72	7.25	6.99^{gh}
T_8	4.58	4.62	4.60^{g}	5.49	5.96	5.73^{f}	7.34	8.02	7.68^{f}
T_9	4.99	5.36	5.18^{e}	6.12	6.46	6.29^{e}	8.09	8.37	8.23^{e}
T_{10}	6.19	6.31	6.25^{c}	7.12	7.33	7.23^{c}	9.54	10.28	9.91^{c}
T_{11}	3.56	3.61	3.59^{i}	4.66	5.64	5.15^{g}	6.79	7.39	7.09^{gh}
SEm±	0.021	0.020	0.014	0.023	0.030	0.019	0.039	0.046	0.030
LSD (p=0.05)	0.06	0.06	0.04	0.07	0.09	0.06	0.12	0.14	0.09

*Different letters in the same column are significantly different by duncan multiple range test (DMRT) at $p\leq 0.05$

was 81.91% and 61.68% higher than tillering and PI stages, respectively. The results depicted that the P uptake was significantly (at $p<0.05$) higher when the recommended rate of P fertilizer was applied than substituting inorganic P with organic manures. Similar result was reported by Banerjee et al. (2006) and Lu et al. (2021). Application of P through chemical fertilizers resulted in higher P uptake by rice plants compared to organic manure, due to the greater solubility and immediate availability of phosphorus in fertilizer. The P uptake in different stages also significantly ($p<0.05$) increased when P fertilizer was applied in increasing doses with the manure. A similar observation was also reported by Liu et al. (2024).

The different treatments combinations had significant (at $p<0.05$) influence on P uptake on rice grain and straw at harvest in both the years. The application of increasing doses of inorganic P increases the uptake of P. It was found that T_2 (9.74 kg ha^{-1}) [NPK (RDF)] was statistically superior in terms of P uptake in straw and statically at per with T_6 (9.72 kg ha^{-1}) [25% vemicompost+75% P+NK] among the rest of the treatments and lower in T_1 (4.80 kg ha^{-1}). On the other hand, P uptake by the grain significantly (at $p\leq0.05$) increased from 4.66 kg ha^{-1} in T_1 (no P. NK) (control) to 7.81 kg ha^{-1} in T_2 (NPK, RDF). In grain the P uptake was highest in T_2 (7.81 kg ha^{-1}) among all the treatments and lowest P uptake was in T_1 (4.66 kg ha^{-1}) (Figure 1). On an average the uptake of P was lower by 25.69% in grain than the straw at harvesting. The inorganic P fertilizers are hard to remove from soils, leading to soil P surplus. Higher rates of inorganic P input tend to increase the soil P pool, leading to a higher uptake of P (Sharpley and Wang, 2014).

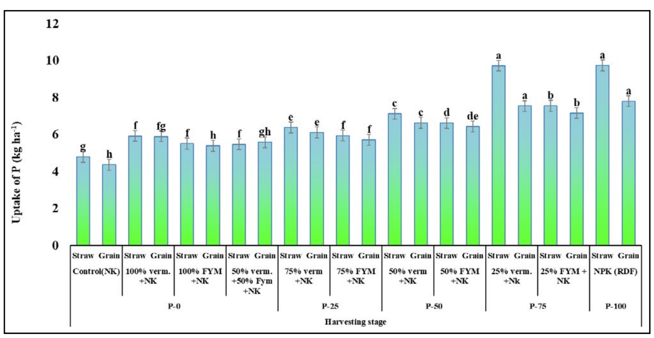

Figure 1: Effect of phosphorus, FYM and vermicompost on uptake of phosphorus (kg ha^{-1}) by rice grain and straw at harvesting stage

3.2. *Available phosphorus content in soil at different growth stages of rice*

The available P content in soil at different stages is shown in Figure 2. The figure indicates that the highest available P in soil was observed in T_2 (NPK, RDF) across all stages, while the lowest was recorded in T_1 (control) (no P, NK). A decreasing trend of available P in soil from tillering to flowering stages was also noted, likely due to plant uptake of P. The pooled available P over two years was comparatively higher by 79.90%, 60.50%, 25.71%, 15.63%, and 138.64%, 62.29%, 41.87%, 15.90% in T_2 (RDF treatment) than in treatments with 100%, 75%, 50%, and 25% P (RDF), vermicompost, and FYM at harvest, respectively. In all stages, soil available P was higher in treatments without combining P with organic manures (FYM and vermicompost). Similar results were reported by Lu et al. (2021) and Sun et al. (2022). The treatment where 100% P was replaced by organic manure (T_{11}), with 50% of P replaced by FYM and the remaining 50% by vermicompost, did not significantly increase soil available P. However, treatments combining vermicompost and/or FYM with inorganic P showed higher soil P and P uptake compared to the control. Organic manures improved the soil environment for nutrient and water movement by increasing soil organic carbon, adjusting soil pH, and reducing P adsorption when crop residues were incorporated, thus enhancing P availability in soil (Brar et al., 2015; Malobane et al., 2020).

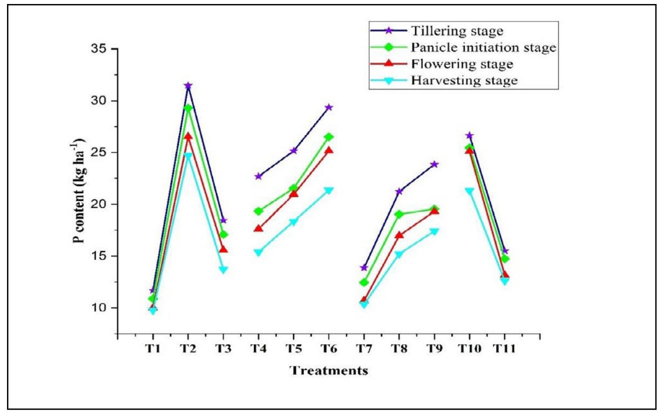

Figure 2: Effect of phosphorus, FYM and vermicompost on available phosphorus (kg ha^{-1}) content in soil at different stages of summer rice (pooled data of two years)

3.3. *Grain yield and phosphorus use efficiency*

The mean data on grain yield presented in Table 2 indicate that various organic and inorganic phosphorus (P) inputs significantly (at $p<0.05$) affected the grain yield. Among the different P sources, the combination of 75% vermicompost+25% P+NK, i.e., T_4, was effective in providing a well-balanced supply of essential nutrients aligned with the crop's requirements, leading to the significantly highest grain yield of 5.70 t ha^{-1} (at $p<0.05$). In contrast, the control plot (T_1) showed the lowest grain yield at 4.48 t ha^{-1}. The grain yield was about 27.23% higher in T_4 compared to the control (T_1) and 22.32% higher than T_2 (NPK, RDF). Grain yield significantly increased by 1.00, 1.22, 0.58 kg ha^{-1} with the addition of vermicompost at 100%, 75%, 50%, respectively, and by 0.4, 0.76, 0.37 kg ha^{-1} with FYM 100% and 75%, 50% RDF P from the control

Table 2: Effect of phosphorus, FYM and vermicompost on grain yield (t ha^{-1}), grain HI (%) and P use efficiency indices in summer rice (pooled over years)

Treatment	Grain yield (kg ha^{-1})	Grain HI (%)	APUE (kg kg^{-1})	PPUE (kg kg^{-1})	APR (%)	PPP (kg kg^{-1})
T_1	4.48^{h}	41.10^{c}	-	-	-	-
T_2	4.67^{g}	41.34^{c}	2.38^{j}	55.15^{h}	4.31^{a}	58.38^{f}
T_3	5.48^{b}	42.65^{a}	12.50^{b}	653.59^{b}	1.91^{g}	68.50^{b}
T_4	5.70^{a}	42.80^{a}	15.25^{a}	699.14^{a}	2.18^{f}	71.25^{a}
T_5	5.06^{d}	41.92^{abc}	7.25^{e}	256.07^{e}	2.83^{d}	63.25^{de}
T_6	4.74^{efg}	41.21^{c}	3.25^{h}	81.76^{g}	3.98^{b}	59.25^{f}
T_7	4.89^{e}	41.64^{bc}	5.13^{f}	400.00^{d}	1.28^{j}	61.13^{ef}
T_8	5.24^{c}	42.17^{abc}	9.50^{d}	565.06^{c}	1.68^{h}	65.50^{cd}
T_9	4.85^{ef}	41.54^{abc}	4.63^{g}	178.74^{f}	2.59^{e}	60.63^{ef}
T_{10}	4.71^{fg}	41.38^{c}	2.88^{i}	82.14^{g}	3.50^{c}	58.88^{f}
T_{11}	5.33^{c}	42.50^{ab}	10.6^{3c}	699.59^{a}	1.52^{i}	66.63^{bc}
SEm±	0.04	0.60	0.03	2.17	0.02	0.27
LSD (p= 0.05)	0.12	1.21	0.10	6.41	0.04	0.79

*Different letters in the same column are significantly different by Duncan Multiple Range Test (DMRT) at $p \leq$ 0.05

plot. Grain yield depended on the number of panicles bearing tillers $hill^{-1}$, grains $panicle^{-1}$, and grain weight. The results suggested that organic manures provided better nutritional quality and a favourable nutrient balance when supplemented with NPK, resulting in maximum yield. This might be because organic manure supplies nutrients to the crop more effectively and timely compared to other organic sources. This aligned with the findings of Singh et al. (2005). The positive effect of integrated nutrient management using both inorganic fertilizers and organic manures on higher crop yields was also reported earlier (Doley et al., 2021; Urmi et al., 2022). Significant improvements in plant height, tiller number, grain yield, and soil fertility were observed when vermicompost was combined with specific nutrient ratios (Shenoy et al., 2020). A similar trend of better performance was reported by Dash et al. (2010).

The harvest index (HI) indicated how photosynthates were partitioned from vegetative parts to reproductive parts of the plant. It was also defined as the ratio of economic yield to biological yield. This might be due to the fact that exposure of the reproductive stage of summer rice to higher temperatures could have restricted photosynthesis and the transfer of photosynthates from vegetative to reproductive parts. The results showed that HI was significantly influenced by the application of organic nutrients (Table 2). Like grain yield, the highest HI percentage was observed in T_4 treatment (42.80%), which was statistically similar to T_3 (42.65%). This could be because of better grain yield linked with increased biological yield due to improved nutrient availability. Conversely, plots without P+NK from RDF (T_1 treatment) had the lowest harvest index value at 41.10%, consistent with the findings of Verma et al. (2024).

The ability to recover P from applied phosphorus fertilizer resources was called agronomic phosphorus use efficiency (APUE). Phosphorus use efficiency was vital for nutrient cycling (Marzouk et al., 2024). This experiment showed that APUE was highest in T_4 treatment (75% vermicompost+25% P+NK) and lower in T_2 treatment (NPK, RDF). The APUE ranged from 15.25 to 2.38 kg kg^{-1}, and PPP ranged from 71.25 to 58.25 kg kg^{-1} (Table 2). The linear regression (Figure 3) indicated that APUE (R^2=0.99) and PPP (R^2=0.41) had a significant (at p<0.05) and positive relationship with grain yield. Combining

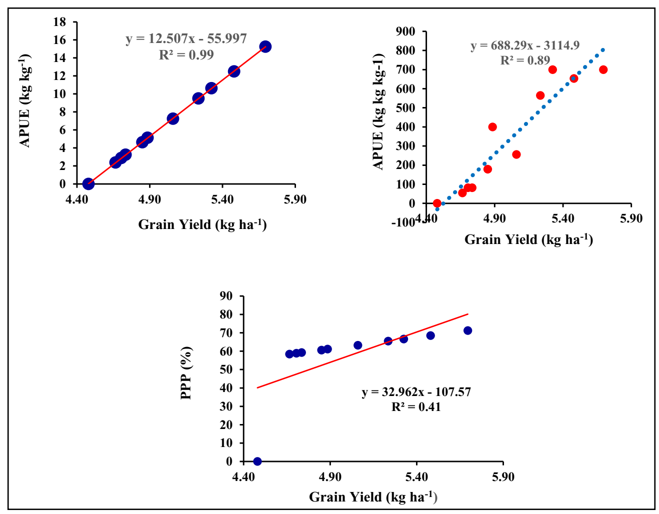

Figure 3: Linear association between agronomic phosphorus use efficiency (APUE), physiological phosphorus use efficiency (PPUE) and partial phosphorus productivity (PPP) with grain yield of rice

chemical fertilizers with organic manure could boost APUE by improving P availability and soil P activity. Higher P uptake, APUE, and PPP under T_4 treatment in our study could be due to increased P availability and enhanced soil microbial activity. The higher PPP values under 75% vermicompost+25% P+NK might be attributed to higher crop yields and more efficient P fertilizer utilization. Similar results were observed in PPUE, where the highest value was found in T_{11} (699.59 kg kg^{-1}) with 50% vermicompost+50% FYM+NK, statistically comparable to T_4 (699.14 kg kg^{-1}). PPUE showed a significant and positive (R^2=0.89) relationship with grain yield (Figure 3). Over the years, APR in treatments where vermicompost and FYM were applied alone without P had less impact, indicating P deficiency due to the reduction and mining of intrinsic soil P reserves to support plant growth. The APR was positive in inorganic P addition treatments, following the order: T_2>T_6>T_{10}>T_5, demonstrating a higher tendency of P build-up under these treatments. Since the total P input was the same across P-added treatments, the lower APR in our results could be due to higher P uptake, PUE, and crop yield, consistent with the findings of Liang et al. (2025).

4. CONCLUSION

TThe grain yield and different indices of phosphorus use efficiency (PUE) significantly increased with a higher rate of (75%) P replacement by vermicompost or FYM. Only inorganic P fertilizer application could not effectively increase rice yield; rather, it led to higher P accumulation in soil. Inorganic P fertilizer could be replaced up to 75% by organic manures for rice to achieve greater yield and higher P use efficiency. Vermicompost was found to be more effective than FYM. most characteristics, particularly in berry-related traits.

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