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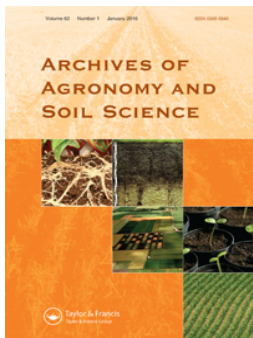
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## Long-term manuring and fertilization influence soil inorganic phosphorus transformation vis-a-vis rice yield in a rice–wheat cropping system

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A study on the rice–wheat cropping system was conducted at Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India, to assess the effects of long-term manuring and fertilization on transformation of the inorganic phosphorus (P) fraction in soil after 22 years of the crop cycle. Soil samples were collected after *Kharif* from seven treated plots having different types of organic amendments like farm yard manure, paddy straw and green manuring with 50% substitution of nitrogen levels in rice crop only. The result showed that the yield trend of rice was maintained due to the buildup of P from various organic inputs. Although cultivation for 22 years without adding any fertilizer caused a significant decrease in almost all the forms of P viz. avail-P, saloid P, iron phosphorus fraction (Fe-P), aluminum phosphorus fraction (Al-P), calcium phosphorus fraction (Ca-P) and total P in control. Partial substitution of inorganic fertilizer N (50%) with organics, however, caused a significant increase in almost all the P fractions in soil over the control. The relative abundance of all the fractions of inorganic P irrespective of treatments was as follows: Fe-P > reductant soluble P fraction > occluded P > Al-P > Ca-P > saloid P. Saloid and Fe-P were the dominating fractions responsible for 92% variation of available P and total P levels, respectively.

**Keywords:** fertilization; inorganic phosphorus; long-term; manuring; rice–wheat cropping system

### Introduction

The rice–wheat rotation occupies about 28.8 million ha land mainly spread over Asia's five countries, namely, India, Pakistan, Nepal, Bangladesh and China (Prasad 2005; Moola et al. 2011). It is the most important predominant cropping system of the Indo-Gangetic Plains in India which played a significant role in the food security of the region since from the era of Green Revolution started during the early 1970s (Chauhan et al. 2012; Koshal 2014). Over the last two decades, production in this system kept pace with increasing population. But, in recent findings, there has been clear evidence of declining

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trends of rice and wheat yield (Chauhan et al. 2012). One of the main constraints to rice and wheat production is low organic matter content and low indigenous nutrient supply (Biswas & Sharma 2008). Among the major nutrients, phosphorus (P) is one of the major limiting factors for plant growth in many soils under long-term cropping specifically under rice–wheat rotation (Tarafdar et al. 2006). So, its maintenance in an adequate amount through inorganic and organic P fertilization is critical for the long-term sustainability of the cropping system as P is an essential element for vital life processes such as photosynthesis, energy transformation, etc. (Solomon et al. 2014). P in soil is mostly present in two forms viz. organic P fraction which derived from plant residue and soil flora and fauna tissue and inorganic fraction which is mainly associated with calcium, aluminum and iron. It is one of the major nutrient elements, which limits the crop growth and it has been the subject of continuous research because of its complex nature as soil P dynamics are characterized by physicochemical (sorption–desorption) and biological processes (immobilization–mineralization) (Azeez & Averbek 2010; Abolfazli et al. 2012; Opala et al. 2012). Different soluble sources of P such as manures and fertilizers when added to the soil readily changed into unavailable forms and in time react further to become highly insoluble soil P fractions and give an idea about the P supplying capacity to plants (Saleque et al. 2004). The P fertilizer exceeding crop removal is retained mainly as adsorbed P on the surface of soil particles and associated with amorphous Al and Fe oxides (Beck & Sanchez 1994; Meena & Biswas 2014). This increased soil P can modify fertilizer management practices and increases P movement to surface water causing eutrophication (Sharpley et al. 1994). The status of P in long-term fertilized soil must be determined to assess the fertilizer P needs and ensure environmental quality. Long-term field experiments (LTFE) are valuable for determining yield trends, estimating nutrient dynamics and balances, understanding changes in yield, predicting soil carrying capacity, and assessing system sustainability (Regmi et al. 2002). Long-term cultivation with different fertilizer treatments and cropping systems may have tremendous influence on the availability of P as well as transformation into different fractions. External addition of the P fertilizer to soil in intensive cropping systems often exceeds P demands by crops which lead to P accumulation in soils as chemically stable and insoluble forms that may become available to plants in subsequent years. The relative solubility of inorganic soil P fractions governs the replenishment of the liable pool when it is depleted by removal of P by plants (Sarkar et al. 2013). So, knowledge of different inorganic fractions of soil P together with their distribution in soil is of much relevance in accessing the long-term availability of P to the crops and in formulating sound fertilizer recommendation. This will help not only to increase the bioavailability of soil P but also to reduce the water pollution through run off P. To improve the efficiency of P application, to sustain crop productivity, restore soil health and also to meet a part of chemical fertilizer requirement, it is imperative to maximize the recycling of P from crop residues and organic and mineral fertilizers (Hegde & Dwivedi 1993). Integrated use of organic manures and phosphatic fertilizers result in not only improved efficiency of the later (Vats et al. 2001) but also significantly increase the availability of P. So, more information regarding the forms of P in soils under influences of long-term manuring and fertilization is required to assess bioavailability of P and the environmental consequences of the high levels of P that can occur in such soils. By keeping the abovementioned views in mind, the present study was undertaken to determine how the abundance and quantity of soil inorganic P fraction were affected by long-term application of fertilizers and manures and its role in mobility and subsequent availability to crop which effects the yield of rice in an irrigated LTFE with the rice–wheat cropping system in the hot humid subtropics of eastern India.

## Materials and methods

### Location of the experimental site

In the present investigation, soil samples were collected from a long-term field experiment with a rice–wheat cropping system on an inceptisol located in the hot, humid subtropics (23°N and 89°E with an elevation of 9.5 m) at the University Teaching Farm, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India, which was established in 1986 along the new alluvial soil zone of the state. The experimental site receives an average annual rainfall of approximately 1480 mm and experiences the mean annual minimum and maximum temperature of 36.2°C (May) and 12.5°C (January), respectively. The average maximum relative humidity reaches 90% during July and the minimum 50% in March. The soil is hyperthermic and silty clay to clay in texture. The soils are classified as Aeric Haplaquept (inceptisols). The studied soil is neutral (pH 7.2) in reaction with sand, silt, and clay values of 500, 295, and 205 g kg<sup>-1</sup>, respectively. The initial total and oxidizable organic C of the soil (0–0.2 m) were 14.2 and 8.8 g kg<sup>-1</sup>, respectively. The initial bulk density and cation exchange capacity values of the experimental sites were 1.2 Mg m<sup>-3</sup> and 22.0 C mol (P+) kg<sup>-1</sup>, respectively.

### Treatment details

Two crops, viz., rice (*O. sativa* L., cv IET 4094) and wheat (*T. aestivum* L., cv UP 262) were grown (rice – 20 × 10 cm, wheat – 20 cm solid row spacing) annually with necessary ploughing, on average, to a depth of 0.20 m using a power tiller. The experiment was laid out in a randomized block design with the following treatments presented in Table 1. Farmyard manure (FYM), paddy straw (PS), and green manuring (GM) were used as organics. For GM, *Sesbania sesban* (L.) was used. The GM (1.5 t ha<sup>-1</sup>), well decomposed FYM (6.9 t ha<sup>-1</sup>) and PS (5.0 t ha<sup>-1</sup>) were manually spread uniformly on the surface of the specified plots (size: 8 × 8 m), respectively, at the time of puddling of rice crop. The NPK fertilizers at the rate of 80–40–40 (kg ha<sup>-1</sup>) for rice and 100–60–40 (kg ha<sup>-1</sup>) for wheat as recommended by the State Agricultural Department for those crops on the basis of average soil fertility indices of the region were applied in the form of urea,

Table 1. Treatment details.

Treatment	Kharif	Rabi
T <sub>1</sub>	No fertilizers, no organic manure (control)	No fertilizers no organic manure (control)
T <sub>2</sub>	50% recommended NPK dose through fertilizers	50% recommended NPK dose through fertilizer.
T <sub>3</sub>	100% recommended NPK dose through fertilizers	100% recommended NPK dose through fertilizers
T <sub>4</sub>	50% recommended NPK dose through fertilizers+ 50% N through farm yard manure	100% recommended NPK dose through fertilizers
T <sub>5</sub>	50% recommended NPK dose through fertilizers + 50% N through paddy straw	100% recommended NPK dose through fertilizers
T <sub>6</sub>	50% recommended NPK dose through fertilizers + 50% N through green organic matter (green manuring)	100% recommended NPK dose through fertilizers
T <sub>7</sub>	Conventional farmers practice (the amount of fertilizers used in new alluvial zone (50:30:20 kg ha <sup>-1</sup> ))	Conventional Farmers practice (conventional) (60:20:20 kg ha <sup>-1</sup> )

single super phosphate and muriate of potash. Their amounts in the NPK plus organics were adjusted on the basis of nutrients contained in the added organics for each treatment. On an average the nutrients content on dry weight basis were as follows (moisture level 20.0%) of FYM (N:P:K(%) = 0.58:0.36:0.3), PS (N:P:K = 0.81:0.22:0.52), and GM (N:P:K = 2.65:0.16:0.46) during the experimental period. Conventional farmers' practice used as solely application of fertilizers used in different regions was recorded as 50–30–20 (kg ha<sup>-1</sup>) for rice and 60–20–20 (kg ha<sup>-1</sup>) for wheat, respectively.

### Soil sampling

Three representatives' field-moist soil samples were collected from each of the treatments in each replication from 0–0.20 m depths with a bucket auger. They were pooled together to make a composite sample for each depth and replication. Bulk samples were taken to the laboratory in bags. After removing visible pieces of crop residues and roots from the field-moist soil samples, all samples were passed through 2.0 mm and allowed to air dry for 72 h before analysis. The air-dried sub-sample of each sample was then hand crushed, passed through 2 mm sieve and was stored for determination of various physical and chemical properties. For organic carbon and total P analysis, the 2 mm sieved soil samples were subjected to further grinding and passed through 0.5 mm sieve.

### Analytical procedure

The pH of the soil was determined in 1:2.5 (soil:water) suspension by using a digital pH meter (Jackson 1973). The electrical conductivity of the soil saturation extract was determined with the help of a Wheatstone conductivity bridge (Jackson 1973). The clay content of the soil was determined by the Boyoucou hydrometer method (Gee & Bauder 1986). The bulk density was determined by the core sampler method following the method of Blake and Hartge (1986). The mean weight diameter (MWD) of the soil was calculated using the formula given by Van Bavel (1949). The available N was estimated by the alkaline permanganate method (Subbiah & Asija 1956). Organic carbon in soil was determined by methods described by Walkley and Black (1934). The available potassium of the soil samples was extracted with neutral ammonium acetate solution. Potassium contents of the soil extracts were measured using a Flame photometer (Jackson 1973). The available and total P content of the soil was measured by the methods describe by Jackson (1973). Soil inorganic P was extracted by the procedure outlined by Peterson and Corey (1966) and determined by the ascorbic acid method. The methodology for extraction of inorganic P fractions is presented in Figure 1.

Percent (%) change of different P forms (mg kg<sup>-1</sup>) over control and percent contribution of various forms of inorganic P to total P under various treatments were estimated using the following equations.

$$(\%) \text{ change over control} = \frac{(\text{Treatment}_{\text{P content}} - \text{Control}_{\text{P content}})}{\text{Control}_{\text{P content}}} \times 100 \quad (1)$$

$$(\%) \text{ contribution to total P} = \frac{\text{Treatment}_{\text{Inorganic P content (mg kg}^{-1}\text{)}}}{\text{Treatment}_{\text{Total P content (mg kg}^{-1}\text{)}}} \times 100 \quad (2)$$

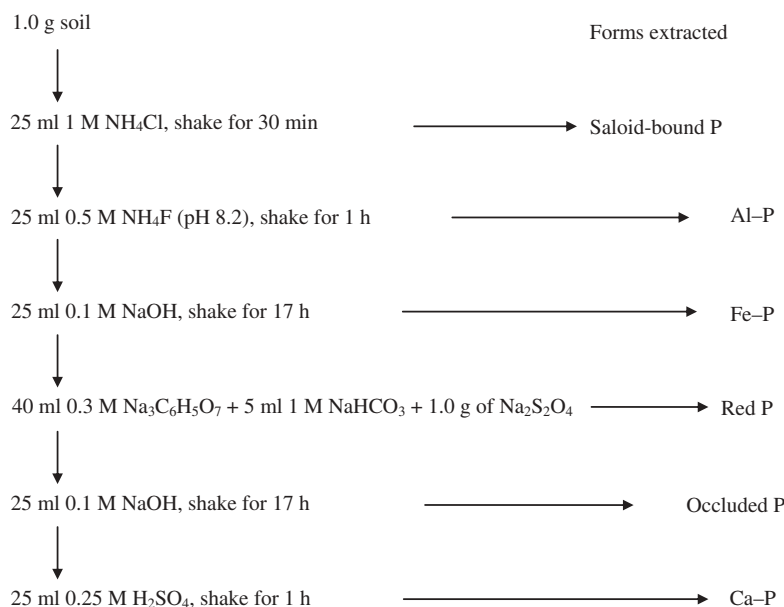


Figure 1. Sequential extraction of inorganic phosphorus fractions (Peterson & Corey 1966).  
 Notes: Fe-P, iron phosphorus fraction; Al-P, aluminum phosphorus fraction; Ca-P, calcium phosphorus fraction; red P, reductant soluble phosphorus fraction.

### Yield of rice

From each experimental plot, the grains were separated by threshing and dried under sun for a few days. After that the grains were winnowed and cleaned and then the weight of the grains per net plot was recorded. The grain yield per ha was computed and expressed in tons per hectare from the net plot values. The straw weight from each net plot was calculated after complete drying under sun for a few days and expressed in tons per hectare. The values of the harvest index and the sustainable yield index were calculated from grain and straw yields using the following formula

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (t ha}^{-1}\text{)} \times 100}{\text{Total biomass (t ha}^{-1}\text{)}} \quad (3)$$

$$\text{Sustainable yield index (SYI)} = (Y - \sigma) / Y_{\max} \quad (Y = \text{yield, } \sigma = \text{std.deviation}) \quad (4)$$

### Statistical analysis

Statistical analyses i.e. simple correlation coefficients, regression equations, the Duncan multiple range test (DMRT) and principle component (PC) analysis were performed by windows based Statistical Package for the Social Sciences (SPSS) program (ver. 16.0, SPSS Inc) to evaluate the relationship among the variables. The analysis of variance (ANOVA) was carried out by randomized block design. The least significant difference (LSD) test was applied to evaluate the significance of the differences between the variables and treatments.

## Results

### *Response of long-term manuring and fertilization on the yield of rice*

The results revealed that there was a significant response of grain and straw yield of rice towards long-term application of NPK, FYM, and paddy straw and green manuring. The responses varied from 100 to 193% over the control. The highest grain yield was recorded with FYM treated soil ( $4.08 \text{ t ha}^{-1}$ ) followed by green manuring ( $3.87 \text{ t ha}^{-1}$ ), crop residue treated plot ( $3.75 \text{ t ha}^{-1}$ ), and 100% recommended dose of fertilizer ( $3.70 \text{ t ha}^{-1}$ ). The yield benefits of rice from FYM and green manuring compared with the full recommended inorganic fertilizer were 10.2 and 4.59%, respectively. In comparison to control, 50% substitution of N by FYM, paddy straw, and green leaf manuring increases rice grain yields by  $2.66 \text{ t ha}^{-1}$ ,  $2.31 \text{ t ha}^{-1}$ , and  $2.45 \text{ t ha}^{-1}$ , respectively (Table 2). An increase in grain yield with green manuring and FYM application had also been reported by Swarup (1991). The straw yield of the rice also maintained the similar trend. Although the highest straw yield was observed in green manured soil ( $5.50 \text{ t ha}^{-1}$ ). The results also showed that 50% substitution of N by FYM and paddy straw had significant effects on the straw yield of rice. The harvest index is a ratio of grain yield to total harvestable biomass of above ground portion of the plant. The harvest index was more or less similar throughout the treatments and ranged from 0.40 to 0.43. Sustainable yield index (SYI) values for different treatment also followed a positive response on FYM, green leaf manuring and paddy straw applications over inorganic treatments. The values of the sustainable yield index varied from 0.49 to 0.72 with a mean value of 0.61. The relative performance of different treatments for SYI over control was as follows  $T_4 > T_6 > T_5 = T_3 > T_7 > T_1$ .

### *Response of long-term manuring and fertilization on physical and chemical properties of soil*

The bulk density of the experimental soil varied from  $1.33$  to  $1.39 \text{ g cm}^{-3}$  under different treatments with the mean value of  $1.35$ . With respect to soil reaction (pH), all the treatments showed nearly neutral pH, the value ranging from  $7.01$  to  $7.50$  with a mean value of  $7.19$ . The organic carbon content of the soils under different treatments varied from  $5.2$  to  $7.83 \text{ g kg}^{-1}$  with a mean value of  $6.83 \text{ g kg}^{-1}$  (Table 3). The highest and the

Table 2. Yield of rice as influenced by long-term manuring and fertilization.

Treatment	Yield of paddy ( $\text{t ha}^{-1}$ )		Harvest index (HI)	Sustainable yield index (SYI)
	Grain	Straw		
Control ( $T_1$ )	1.42 <sup>g</sup>	2.07 <sup>f</sup>	0.40	0.53
50% NPK ( $T_2$ )	2.39 <sup>f</sup>	3.49 <sup>e</sup>	0.40	0.68
100% NPK ( $T_3$ )	3.70 <sup>bc</sup>	5.07 <sup>c</sup>	0.42	0.69
50% NPK + 50% N through FYM ( $T_4$ )	4.08 <sup>a</sup>	5.36 <sup>ab</sup>	0.43	0.73
50% NPK + 50% N through paddy straw ( $T_5$ )	3.75 <sup>bc</sup>	5.33 <sup>ab</sup>	0.41	0.68
50% NPK + 50% N through green manure ( $T_6$ )	3.87 <sup>ab</sup>	5.50 <sup>a</sup>	0.41	0.72
Conventional farmers practice ( $T_7$ )	3.22 <sup>d</sup>	4.72 <sup>c</sup>	0.40	0.56
LSD ( $P \leq 0.05$ )	0.215	0.187	—	—

Note: Yield values, in a column, followed by a common letter are not significantly different at  $P \leq 0.05$  based on DMRT.



Table 3. Soil properties under influence of long-term manuring and fertilizations in rice–wheat rotation.

Treatment	Bulk density (g cm <sup>-3</sup> )	Mean weight diameter (mm)	pH (1:2.5)	Organic carbon (g kg <sup>-1</sup> )	Avail N (kg ha <sup>-1</sup> )	Avail P (kg ha <sup>-1</sup> )	Avail K (kg ha <sup>-1</sup> )	Total P (mg kg <sup>-1</sup> )
Initial	1.39	0.67	7.50	9.40	110.0	15.0	120.0	398.4
Control (T <sub>1</sub> )	1.38	0.63	7.01	5.20	154.0	34.5	180.0	458.3
50% NPK (T <sub>2</sub> )	1.36	0.65	7.03	5.50	215.6	48.8	398.7	630.2
100% NPK (T <sub>3</sub> )	1.34	0.80	7.03	6.30	246.6	63.3	450.3	734.4
50% NPK + 50% N through FYM (T <sub>4</sub> )	1.33	1.10	7.21	7.83	308.0	81.9	494.3	850.4
50% NPK + 50% N through paddy straw (T <sub>5</sub> )	1.33	0.97	7.35	7.80	287.5	69.4	479.0	807.3
50% NPK + 50% N through green manure (T <sub>6</sub> )	1.33	0.94	7.23	7.20	297.7	71.3	486.0	845.6
Conventional farmers practice (T <sub>7</sub> )	1.36	0.79	7.19	5.40	215.6	46.4	391.3	688.8
Mean	1.35	0.82	7.19	6.83	229.3	53.8	374.9	676.6
LSD ( <i>P</i> ≤ 0.05)	0.17	0.12	0.12	0.42	51.6	8.41	75.8	37.7

lowest values of organic carbon were found in the soil treated with 50% NPK + 50% compost and in control, respectively, although the values are lower than initial organic carbon content of the experimental soil. The increase in organic carbon content upon fertilizer addition over the control was markedly pronounced when the NPK fertilizer was incorporated into combination with FYM (50.6%) or paddy straw (50%) or green manuring (38.4%). The available N content of the soil under different treatments varied from 154 to 308 kg ha<sup>-1</sup>. With an increase in the percentage of applied inorganic fertilizer, the available N content was increased over control but the addition of organic residues along with inorganic fertilizers caused an increase in higher magnitude as compared to the sole application of inorganic fertilizers. The magnitude of increases was higher over control in the case of 50% NPK + 50% N through FYM than 100% fertilizer treatment. Again 50% NPK + 50% N through FYM caused an increase in available N content of 17.1% over paddy straw and 2.4% over green manure. On the other hand, 50% NPK + 50% N through green manuring contributed more available N than 50% NPK + 50% N through paddy straw due to the high N content of the green manure plant. The treatments were statistically different in the available K content and varied from 180 to 494.3 kg ha<sup>-1</sup>, with a mean value of 374.9 kg ha<sup>-1</sup>. The available P content of the experimental soils ranged from 34.5 (7.5 % of total P) to 81.9 (9.6% of total P) kg ha<sup>-1</sup>. The continuous or long-term application of inorganic fertilizer incorporation with FYM, paddy straw and green manure, significantly increased the available P status of the soil over control and application of full dose of inorganic fertilizers. The magnitude of increase was higher with FYM (137.3 and 29.3%) followed by green manuring (106.9 and 12.6%), and paddy straw (101.4 and 9.7%) over control and 100% fertilizer, respectively. The total P content of the experimental soil under different treatments significantly different and ranged from 458.3 to 850.4 mg kg<sup>-1</sup>, with a mean value of 723.6 mg kg<sup>-1</sup>. The total P content of the soil treated with different organic amendments in the order of FYM (compost) > green manure > paddy straw consisting of 85.4, 84.5, and 76.1%, respectively, over control when 50% NPK + 50% N was applied through such organic materials (Table 3).

### ***Response of long-term manuring and fertilization on inorganic fractions of soil P***

Saloid-bound P was generally considered as solution P and it was easily available to plants. The saloid-bound P under different treatments varied from 6.2 to 9.9 mg kg<sup>-1</sup> with a mean value of 8.30 mg kg<sup>-1</sup> (Table 4). Among other inorganic P fractions, saloid-bound P recorded the lowest value. The application of inorganic fertilizers caused increases in their amount (9–36.7%) over the control. But, the higher magnitude of increase was found when 50% fertilizers apply with 50% organic material either FYM, paddy straw or green manure. The highest magnitude of increases was found with incorporation of 50% NPK with 50% N through FYM (60.6%), green manure (58.2%), paddy straw (50.8%), respectively, over control (Table 4). Fe bound P (iron phosphorus fraction (Fe-P)) of soil under different treatments ranged from 105.6 to 194.9 mg kg<sup>-1</sup> with the mean value of 160.1 mg kg<sup>-1</sup>. The results indicated that only fertilizer application caused an increase in the amount of Fe-P over control (32.4 to 57.5%), but the magnitude of increases was higher (74.1 to 84.5%) when inorganic fertilizers were applied in combination with organic materials such as FYM, paddy straw, green manure (Table 5). Aluminum bound P (Al-P) ranged from 37.4 to 63 mg kg<sup>-1</sup>. The results indicated that only fertilizer application caused an increase in the amount of aluminum phosphorus fraction (Al-P) (24.3 to 28.8%) over control (Table 5) but the magnitude of increases was higher (55.0 to 68.4%) when inorganic fertilizers applied in combination with organic materials. The

Table 4. Effects of long-term manuring and fertilization on soil inorganic phosphorus pool ( $\text{mg kg}^{-1}$ ).

Treatment	Saloid P	Fe-P	Al-P	Occluded P	Red P	Ca-P	Total P
Control ( $T_1$ )	6.20	105.6	37.4	59.7	101.2	23.5	458.3
50% NPK ( $T_2$ )	6.76	139.9	46.5	63.8	116.7	24.6	630.2
100% NPK ( $T_3$ )	8.48	166.3	48.2	73.7	146.5	49.3	734.4
50% NPK + 50% N through FYM ( $T_4$ )	9.96	194.9	63.0	86.6	167.4	54.9	850.4
50% NPK + 50% N through paddy straw ( $T_5$ )	9.35	183.9	58.0	83.6	165.2	49.3	807.3
50% NPK + 50% N through green manure ( $T_6$ )	9.81	186.1	61.0	85.6	166.3	49.3	845.6
Conventional farmers practice ( $T_7$ )	7.21	144.3	44.2	69.7	132.1	28.0	688.8
Mean	8.3	160.1	51.2	74.7	142.2	39.8	716.4
LSD ( $P \leq 0.05$ )	1.43	27.72	3.59	3.24	3.48	2.05	37.7

Notes: Fe-P, iron phosphorus fraction; Ca-P, calcium phosphorus fraction; red P, reductant soluble phosphorus fraction; Al-P, aluminum phosphorus fraction.

Table 5. Percent change of different P forms in soil under various treatments over control measured in soil under rice-wheat cropping system.

Treatments	Saloid P	Fe-P	Al-P	Occluded P	Red P	Ca-P	Avail P	Total P
50% NPK ( $T_2$ )	9.03	32.4	24.3	6.92	15.3	4.36	41.5	37.5
100% NPK ( $T_3$ )	36.77	57.4	28.8	23.4	32.9	109.0	83.5	60.2
50% NPK + 50% N through FYM ( $T_4$ )	60.65	84.5	68.4	45.1	51.9	132.7	137.3	85.5
50% NPK + 50% N through paddy straw ( $T_5$ )	50.81	74.1	55.0	40.1	49.9	109.0	101.3	76.1
50% NPK + 50% N through green manure ( $T_6$ )	58.23	76.2	63.1	43.4	50.9	109.0	106.8	84.5
Conventional farmers practice ( $T_7$ )	16.29	36.6	18.1	16.7	19.8	18.77	34.6	50.2
Mean	38.6	60.2	43.0	29.3	36.8	80.5	84.2	65.7

Notes: Fe-P, iron phosphorus fraction; Ca-P, calcium phosphorus fraction; red P, reductant soluble phosphorus fraction; Al-P, aluminum phosphorus fraction.

effect was more pronounced with FYM followed by green manure and paddy straw. The magnitude of increases was 68.4, 63.1, and 55% over control with  $\frac{1}{2}$  NPK +  $\frac{1}{2}$  N through FYM,  $\frac{1}{2}$  NPK  $\frac{1}{2}$  N through green manure +  $\frac{1}{2}$  NPK +  $\frac{1}{2}$  N through paddy straw, respectively. The occluded P under different treatment ranged from 59.7 to 86.7  $\text{mg kg}^{-1}$ . The results showed that soil treated with organic materials in combination with inorganic fertilizers caused a higher proportion of this fraction of P. The highest magnitude of increase was found in treatment  $T_4$ , i.e. 45%, followed by  $T_6$  i.e. 43.4% and  $T_5$  by 40.1% over control. Whereas, application of 100% NPK through fertilizer causes 23.3% more occluded P over control. Reductant soluble phosphorus fraction (red P) in the experimental soil ranged from 101.2 to 167.4  $\text{mg kg}^{-1}$  under different treatments. Among the treatments, organic residues showed their dominancy over NPK in increasing P content in this form of P. Among the residues, 50% N through FYM + NPK was superior to green manure and

Table 6. Percent contribution of different forms of inorganic-P to total P in soil under various treatments.

Treatments	Saloid P	Fe-P	Al-P	Occluded P	Red P	Ca-P
Control (T <sub>1</sub> )	1.35	23.04	8.16	13.03	22.08	5.14
50% NPK (T <sub>2</sub> )	1.07	22.20	7.38	10.13	18.52	3.91
100% NPK (T <sub>3</sub> )	1.15	22.65	6.56	10.04	19.95	6.72
50% NPK + 50% N through FYM (T <sub>4</sub> )	1.17	22.92	7.41	10.19	19.68	6.46
50% NPK + 50% N through paddy straw (T <sub>5</sub> )	1.16	22.78	7.18	10.36	20.46	6.11
50% NPK + 50% N through green manure (T <sub>6</sub> )	1.16	22.01	7.21	10.13	19.67	5.83
Conventional farmers practice (T <sub>7</sub> )	1.05	20.95	6.42	10.12	19.18	4.07
Mean	1.16	22.36	7.19	10.57	19.93	5.46

Notes: Fe-P, iron phosphorus fraction; Ca-P, calcium phosphorus fraction; red P, reductant soluble phosphorus fraction; Al-P, aluminum phosphorus fraction.

paddy straw at the same rate of application. Treatment T<sub>4</sub> caused 51.9% increases of red P, followed by T<sub>6</sub> (50.9%) and T<sub>5</sub> (49.9%) over control. Whereas the application of 100% NPK fertilizers caused 32.9% higher reductant soluble P than control plot. The results showed that application of 50% NPK + 50% N through FYM increases 14.2% of that fraction over 100% fertilizer alone. The calcium bound fraction of P varied from 23.54 (5.1% of total P) to 54.9 mg kg<sup>-1</sup> (6.46% of total P) under different treatments. The 100% NPK application increases this fraction (109%) over control (Table 4). But the magnitude of increases was higher (109–132.7%) with the addition of organic residues with inorganic fertilizers. The increase of calcium phosphorus fraction (Ca-P) was highest when 50% NPK apply with 50% N through FYM. But the percentage of magnitude of increase among treatment T<sub>3</sub> (100% NPK), T<sub>6</sub> (50% NPK + 50% N through green manure), T<sub>5</sub> (50% NPK + 50% N through paddy straw) were more or less similar. The overall results therefore revealed that the among the different fraction of soil P, the saloid-bound P recorded the lowest amount (1.16% of total P) whereas Fe-P was recorded the highest value (22.4% of total P), followed by reductant soluble P (19.9% of total P) and occluded P (10.6% of total P), respectively, in respect to all the treatments under the influence of long-term application of manures and fertilizers (Table 6) The relative abundance of all the fractions of inorganic P in the experimental soil influenced by long-term application of manures and fertilizers was as follows: Fe-P > red-P > occluded P > Al-P > Ca-P > saloid P.

### ***Relationship between yield and inorganic P fractions***

The relationships between different fractions of inorganic P with available and total P were studied using regression analysis. The results showed (Figure 2) that the available P had a significant and positive correlation with the saloid-bound P ( $R^2 = 0.69$ ), Al-P ( $R^2 = 0.78$ ), Fe-bound P ( $R^2 = 0.61$ ), Ca-P ( $R^2 = 0.70$ ), and occluded P ( $R^2 = 0.76$ ). Besides these it was also observed that available P showed a positive and significant linear relationship with total P ( $R^2 = 0.79$ ). Among the soil properties soil pH bears a significant and positive correlation with Fe-P ( $R^2 = 0.594$ ), saloid-bound P ( $R^2 = 0.64$ ), and total P ( $R^2 = 0.624$ ). However, bulk density showed a negative correlation with all the fractions of inorganic P as well as Total P. Mean weight diameter (MWD) and organic carbon

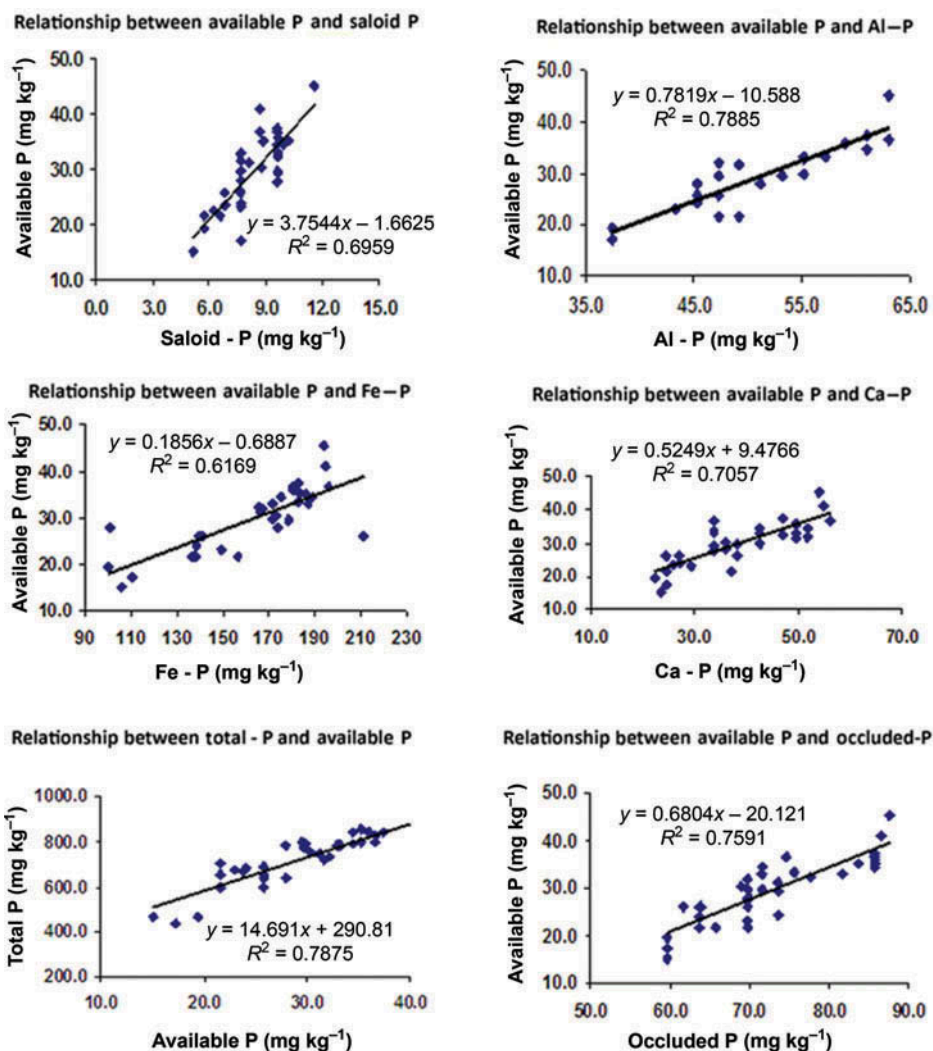


Figure 2. Relationship between various forms of inorganic P fractions and available P.

content of the soil showed a highly significant positive correlation with all the forms of inorganic P and total P (Table 7). In order to assess relationship between various P fractions with grain yield and sustainable yield index, stepwise multiple regression equations were compared (Table 8). The results showed that 92% variation ( $R^2 = 0.92$ ) of grain yield could be accounted for variations in total P and Mean weight diameter of the soil. Among the inorganic fractions of P, Fe-P was dominating for variation (97%) of the total P level ( $R^2 = 0.97$ ). The next variability factor includes Al-P and Organic C. Saloid-bound P could account for 92% variation for determining available P ( $R^2 = 0.92$ ). Inclusion of Fe-P, Al-P, Ca-P, and organic carbon improved  $R^2$  values of available P to 0.97. This indicated that phosphate ions were adsorbed on organic colloids through metal bridging (ligands) or coadsorption (Tan 1998). PC analysis based on the correlation matrix was followed to extract the PC on the basis of Eigen values  $> 1$ . The regression factors

Table 7. Simple correlation coefficient (*r*) between soil properties and various forms of phosphorus.

Soil property	Different inorganic fractions of P (mg kg <sup>-1</sup> )					Total P
	Saloid P	Fe-P	Al-P	Ca-P	Occluded P	
pH	0.640*	0.594*	0.553	0.416	0.422	0.624*
Clay (%)	0.381	0.386	0.391	0.400	0.526	0.336
Bulk density (g cm <sup>-3</sup> )	-0.824**	-0.910**	-0.822**	-0.732**	-0.770**	-0.895**
Mean weight diameter (mm)	0.905**	0.916**	0.909**	0.816**	0.908**	0.897**
Organic carbon (g kg <sup>-1</sup> )	0.935**	0.908**	0.828**	0.811**	0.897**	0.863**

\*Correlation is significant at the 0.05 level (2-tailed).

\*\*Correlation is significant at the 0.01 level (2-tailed).

Notes: Fe-P, iron phosphorus fraction; Ca-P, calcium phosphorus fraction; Al-P, aluminum phosphorus fraction.

Table 8. Stepwise regression between yield, soil properties and various fractions of phosphorus.

	Equation	$R^2$	Adjusted $R^2$	Error estimate
Yield	$= -1.37 + 0.01 \text{ total P} - 1.08 \text{ MWD}$	0.920	0.920	0.22
Total P	$= 30.01 + 4.28 \text{ Fe-P}$	0.972	0.969	19.8
	$= 32.35 + 4.35 \text{ Fe-P} + 3.58 \text{ Al-P} - 30.6 \text{ Org C}$	0.985	0.979	16.0
	$= 10.49 + 4.54 \text{ Fe-P} + 3.72 \text{ Al-P} - 0.862 \text{ Ca-P}$ $-28.3 \text{ Org C}$	0.987	0.980	15.9
Avail P	$= -21.56 + 9.72 \text{ Saloid P}$	0.927	0.920	3.77
	$= -23.79 + 0.17 \text{ Fe-P} + 0.57 \text{ Al-P} + 0.28 \text{ Ca-P}$ $+2.37 \text{ Org C}$	0.972	0.956	2.79
	$= -13.67 + 0.13 \text{ Fe-P} + 0.90 \text{ Al-P} + 0.43 \text{ Ca-P}$ $-0.46 \text{ Occl P} + 3.39 \text{ Org C}$	0.978	0.959	2.70

Notes: MWD, mean weight diameter; Fe-P, iron phosphorus fraction; Al-P, aluminum phosphorus fraction; Org C, organic carbon; Ca-P, calcium phosphorus fraction.

Table 9. Coefficient of component matrix in principal component analysis.

Variable	Component			
	1	2	3	4
pH	0.56	-0.51	-0.58	-0.04
Rice yield	0.94	-0.27	0.04	0.04
Available K	0.92	-0.21	0.24	-0.10
Total P	0.98	-0.17	0.03	0.04
Fe-P	0.99	-0.08	-0.04	0.05
Available N	0.99	-0.04	-0.03	0.06
Saloid P	0.96	-0.02	-0.17	0.16
Al-P	0.95	0.01	-0.03	0.11
Bulk density	-0.92	0.05	-0.15	0.20
Available P	0.97	0.06	-0.02	0.18
Mean weight diameter	0.92	0.12	-0.13	0.15
Organic C	0.93	0.21	-0.26	0.00
Ca-P	0.87	0.23	0.02	0.14
Occluded P	0.93	0.28	-0.01	0.13
Sustainable yield index	0.59	0.28	0.17	-0.01
Eigen value	16.09	1.86	1.62	1.31
% of variance	69.96	8.10	7.06	5.69
Cumulative %	69.96	78.06	85.12	90.81

Notes: Fe-P, iron phosphorus fraction; Al-P, aluminum phosphorus fraction; Ca-P, calcium phosphorus fraction.

scores were calculated with the help of component matrix resulted by these analysis (Table 9). Total four components were extracted depicting 90.8% of total variation.

Component 1 alone explained 69.96% of total variation and here all variables (including all forms of P) except bulk density were positively loaded. Such associations of the variables were manifested intensely due to application of FYM, paddy straw and green manures. Principal component 2 (PC2) further explained 8.1% variation where SYI, occluded P, Ca-P, organic carbon, mean weight diameter and available P were the positively loaded in contrast to negatively loaded variables like pH, rice yield, available

K, avail N and total P. Considering both these it can be told that the preferring treatments was FYM followed by paddy straw and green manuring.

## Discussion

### *Effects of organics on soil properties*

The organically amended plots had a comparatively lower bulk density compare to the control and the magnitude of decreases from 2.9 to 3.6%. The decrease was due to incorporation of organic residues. Similar finding had also reported by Tadesse et al. (2013) This is may be due to the fact that bulk density was negatively correlated with organic matter attributes, as organic matter generally lowers the mean density of soils (Hillel 1998; Gülser 2006). On average NPK treated soil had slightly lower pH values as compared to initial pH as well as organically amended soils. This is due to the fact that organic matter buffers the soils against major swings in pH by either taking up or releasing  $H^+$  ion into the soil solution, making the concentration of soil solution  $H^+$  ion more constant resulting into a stable pH, close to neutral or suitable for the specific crop to be grown (Brady & Weil 2002). The differences in organic carbon content among the organically treated plot might be due to the fact that more amount of lignin and polyphenol content in FYM which were more resistant to decomposition than other two organics (paddy straw and green manure). On the other hand, green manure having high N and low C content, contributes less soil organic carbon than paddy straw or FYM (Bronson et al. 1998). The highest available N content in 50% NPK + 50% N through FYM is probably due to the fact that decomposition of FYM produces some organic ligands which helps to increase its availability to plants and at the same time due to mineralization of FYM, N is released in the soil (Sheeba & Chellamuthu 1999). These results are in conformity with the finding of Thamaraiselvi et al. (2012). According to the observation the partial substitution of inorganic N through FYM and green manure was effective to increase the available K content over control (Walia et al. 2010) as well as over only inorganic fertilizer applications which could be due to the greater capacity of organic colloids to hold  $K^+$  on the exchange site (Sheeba & Chellamuthu 1999). The results indicated that the long-term application of balanced fertilizers with partial substitution of inorganic nitrogen with organic ones either FYM or green manure could be very much effective to increases the availability of P in soil. This is due to the following fact: Incorporated organic residues in soil undergo decomposition process and produce some organic acids, the availability of P increases due to the dissolution effect of the organic acids (Meena & Biswas 2014). Organic compounds released organic acids during decomposition of organic compound may increase P availability by blocking P adsorption site or via anion exchange (Lee et al. 2004; Park et al. 2004; Alok & Yadav 2005). Decomposition of organic material leads to  $CO_2$  releases, which forms carbonic acid and solubilize certain primary minerals containing P (Sharma & Verma 2000). The increases in availability of P upon manure application might be related partly to the decrease P sorption due to competition between  $PO_4^{3-}$  ions and organic molecules for P retention sites in the soil (Xie et al. 1991). The total P content of the studied soil under various treatments maintained the similar trend like available P content of the soil. The input of P in the treatment could be the main reason of high accumulation and this result indicates that compost plus chemical fertilizer application leads to large amount of unutilized P. This is consistent with the results obtained by Pizzeghello et al. (2011) and Yin and Liang (2013).



### ***Effects of organics on inorganic P fractions***

Among the organic amendments, incorporation of paddy straw showed lower magnitude of increases in saloid P over FYM and green manure due to the wide C:N ratio of paddy straw, related to immobilization of P. The addition of organic matter increased Fe-P content significantly and consistently. Yin and Liang (2013) also reported the similar view. The carbon dioxides released during the decomposition of organic matter that also help in building up of the status of Fe-P concentration in soil. The main reason behind the higher Fe-P content of the soil treated with inorganic fertilizers in combination with organics particularly FYM and other due to the fact that: during decomposition of FYM organic acid produced which act as ligands to form iron bound P in soil and caused highest value in this form of P (Bhattacharyya et al. 2005). Park et al. (2004) reported the relative dominancy of Fe-P over other fraction in the paddy soil after long-term annual application of compost and chemical fertilizers. Laxminarayan and Rajagopal (2004) also reported that Fe-P was the major contributing P fraction to the P nutrition in paddy soil to the rice crop. The lowest value of Ca-P observed under control i.e. cultivation without fertilizers which might be due to continuous removal of P from soil P reserve without any replenishment through fertilizers. The higher magnitude of increases of Ca-P due to FYM incorporation over other treatment due to the fact, that addition of P in soil upon mineralization of FYM, since cattle manure is the potential source of P and contains 0.16% of P (Reddy et al. 1999). The addition of FYM increased the proportion of Ca-P, which was related to the increased solubility of P in presence of FYM. On the other hand, the incorporation of organic residues increases the proportion of Ca-P in the soil under different treatments over control or application of fertilizers singly, due to the fact that organic residues upon decomposition produce humic and fulvic acid and other organic acids which compete with solution P for sorption sites of clay mineral (Meena & Biswas 2014) as well as for goethite and gibbsite at low pH as a result most of the P added through fertilizer react with Ca and form of Ca-P. Similar findings had also reported by Wang et al. (2010). The amount of P recovery in Ca-P form, Al-P and solid P increased significantly with application of inorganic fertilizers (Manimaran 2014) and their combination with organic materials (Singh et al. 2005). Jalali and Ranjbar (2010) reported that different types of P fractions may differ remarkably in mobility, bioavailability and chemical behavior and can be transformed under certain conditions. Stevenson (1982) postulated that P might have been released through the acidifying effect of CO<sub>2</sub> and the action of organic chelates produced by microbial decomposition of FYM. Park et al. (2004) also reported the similar findings where they reported that compost, chemical fertilizer or both materials significantly increased the Al-P in comparison to the control.

### ***Effects of organics on yield of rice crop***

Long term manuring and fertilization may have some yield-increasing effect on crops (Wang et al. 2010). The incorporation of paddy straw (50% substitution) had a significant difference over FYM and green manure application in respect to grain yield of rice. The C:N ratio of paddy straw is very high (97.7) compared with FYM (66.6) and green manure (24.3) which causing net mineralization of organic N during crop growing season might be the reason of higher yield in such treatments. Sidhu and Beri (1989) reported that incorporation of wheat straw (C:N ratio of 100:1) adversely affected grain yield of the rice because of N deficiency caused by N immobilization. The results therefore revealed that substitution of N by FYM as

well as green leaf manuring would be helpful not only for increasing the yield of rice but also for sustaining the crop productivity. Similar findings were also noted by Balaguravaiah et al. (2005). The world's oldest classical experiment which was conducted at Broadbalk field (Rothamsted from 1841 to till date) reported that the effect of organic matter addition was superior to NPK mineral fertilizers resulting in the highest degree of stability in crop yield. Significant higher grain yield of rice was recorded in treatments having manure over no manure by several researchers (Regmi et al. 2002; Rahaman et al. 2012). Organic amendments had positive impact on straw yield of rice. The reason may probably due to efficient utilization of nutrients during vegetative phase of rice (Hossaen et al. 2011).

## Conclusion

The results of the study indicate that application of inorganic fertilizers solely is not adequate to maintain the level of various P fractions under long-term rice–wheat rotation. Although long-term integrated application of farm yard manure, paddy straw and green manuring along with inorganic fertilizers over a period of time resulted in buildup of total and available P as well as other nutrients in soil. Long-term manuring and fertilization increased inorganic P fractions as well as available P level in soil which was related to total P and P input. Saloid-bound P account for 92% variation in available P, where as high level of total P in such soil also maintained due to fixed forms of P with Fe, Al and Ca. Fe–P was the major contributing fraction to the total P concentration in studied soil which in turn related to the yield of rice crop. The increases in availability of P upon application of organics might be related partly to the decrease in P sorption due to competition between phosphate ions and organic molecules for P retention sites in the soil which can be available to growing crops further leads to better yield.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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