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Full Length Research Paper

Effect of rock phosphate enriched compost and chemical fertilizers on microbial biomass phosphorus and phosphorus fractions

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The aim of this research work was to prepare rock phosphate enriched compost using low-grade mineral such as rock phosphate (RP) mixed with rice straw and *Aspergillus awamori* and to study their effect on microbial biomass phosphorus (MBP), phosphatase activity and phosphorus (P) fractions in a wheat-soybean cropping system. The experiment was carried out in a randomized block design with four treatments namely, control, recommended dose of NPK fertilizers (100% RDF), rock phosphate enriched compost (RPEC) at the rate of (5 t ha^{-1} and 50% RDF + Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}. Application of RPEC at 5 t ha^{-1} along with 50% recommended dose of chemical fertilizers (RDF) significantly improved microbial biomass P (MBP) (5.62 and 4.28 mg kg^{-1} soil) and alkaline phosphatase activity (194.0 and 174.0 µg PNP g^{-1} soil h^{-1}) in surface (0-15 cm) and sub-surface (15-30 cm) soil respectively, than unfertilized control plot after harvest of wheat. The magnitude of changes of P fractions as well as microbial activities was higher in surface soil than sub-surface soil. Data generated from the field study revealed that phosphorus (P) fractions significantly increased due to application of RPEC either alone or in combination of chemical fertilizers over unfertilized control plot. Application of RPEC plus chemical fertilizers significant increased Olsen P compared to unfertilized control plot after harvest of wheat and soybean. Treatment T_4 increased by 68.8 and 58.7% higher Olsen-P over control at 0-15 and 15-30 cm soil depth, respectively after wheat harvest.

Key words: Microbial biomass P, phosphatase enzyme, phosphorus fractions, Olsen P, rock phosphate, rice straw.

INTRODUCTION

Shortage of nutrients in soil particular to phosphorus (P) and high cost of chemical fertilizers in the present days has imposed an interest on recycling of agricultural and industrial waste for crop production; hence, research priorities have been directed toward finding alternative sources of P fertilizer. Over the past ten years, the global

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paddy rice output on an average was about 664.3 Mt (FAO 2013). However, the produced rice straw has limited use as an animal feed because of high silica content (Van Soest, 2006). Direct incorporation of the rice straw into soil is also limited as it may cause certain agronomic problems such as temporary immobilization of nutrients and associated crop yield reduction (Yadvinder-Singh et al., 2005). As a result, a large amount of produced straw is left as unutilized, which is mostly burnt on-farm, although burning of the straw in situ is the most discouraged option as it emits air pollutants and causes considerable carbon and nutrients loss.

The cost of phosphatic fertilizer is very high all over the India along the world. Presently, about 160 Million tonnes (Mt) of rock phosphate (RP) deposit is available in India (FAI, 2011). Unfortunately, most of them are designated as low-grade material containing less than 20% P_2O_5 and considered unsuitable for manufacturing of conventional commercial phosphatic fertilizers. Therefore, it is the need of the hour to find alternative indigenous sources of plant nutrients which could supply P for sustainable crop production, if not fully, but partially to reduce the reliance on costly chemical fertilizer. Attempts were made to recycling crop residues (rice straw) through composting with rock phosphate and bioinoculant which may serves as a supplement source of plant nutrients (Biswas and Narayanasamy, 2006).

The availability of P in rock phosphate thus could be mobilized through composting technology where unavailable P is expected to convert into plant available forms because of the acidic environment prevailing during composting, thereby improved the nutrient content of compost. Nishanth and Biswas, 2008). Moreover, farmyard manure (FYM) and traditional compost contain very small amount of nutrients, particularly P content and even difficult to obtain required quantity for substituting chemical fertilizers. Rock phosphate enriched compost prepared with rice straw and agro-based industrial wastes could be used as alternatives of FYM or traditional compost to sustain soil physical, chemical and biological quality.

The extent to which organic matter contributes to soil quality depend not only the quality of the organic matter but also on soil microbial activity and environmental conditions (Ouedraogo et al., 2001). Soil enzyme activities are very important component in agriculture for their role in the nutrient cycling and were considered to be early indicators of specific biochemical reactions in soil because of their relationship to soil biology and rapid response to changes in soil management (Bandick and Dick, 1999). Tarafdar and Jungk (1987) and Chen et al. (2002) suggested that higher phosphatase in the rhizosphere, compared to the bulk soil, can induce significant depletion of organic P forms in the rhizosphere. Phosphatase plays an important role in transforming organic phosphorus (P) into inorganic forms for plants, particularly when P availability limits plant productivity (Pan et al., 2013). Therefore, phosphatase activities have been regarded as an important factor for maintaining and controlling mineralization rate of soil organic P, and a good indicator of P-deficiency (Vance et al., 2003). Microbial biomass phosphorus (MBP) plays a key role in maintaining P availability in soil, particularly for highly weathered and P deficient soils. Soil MBP mediates P transformations between organic and inorganic pools, and is a major source of labile P in soil (Tate, 1984; Oberson et al., 2001).

Understandings on mineral phosphorus fractions are necessary to develop sustainable P management practices. The chemistry of P in soils is complex, and several fractionation procedures have been developed to quantify the various inorganic and organic forms of P in soils.

Soil P belongs to two broad groups: organic and inorganic. Organic P is found in plant residues, manures, and microbial tissues. Inorganic forms of soil P, which include iron-P (Fe-P), aluminum-P (Al-P), calcium-P (Ca-P), and occluded-P (Occl-P) (Peterson and Corey, 1963). Kuo (1996) presented a fractionation scheme that incorporated the original Chang and Jackson (1957) fractionation procedure and most of the subsequent modifications. Soils low in organic matter may contain less than 3% of their total P in the organic form, but high organic matter (OM) soils may contain 50% or more of their total P content in the organic form (Griffith, 2011).

Our hypothesis is that combining organic and inorganic nutrient sources may provide an efficient use of resources for maintaining higher activity of microbial biomass P and available pool of P. However, very little information is available at present on soil microbial activity and fractions of P in soils treated with rock phosphate enriched compost (RPEC) and chemical fertilizers and their effect on nutrient availability to crops.

MATERIALS AND METHODS

Site descriptions

The experimental area represents Indo-Gangetic plain and belongs to Mehrauli soil series of order Inceptisols. A field experiment was conducted during winter (*rabi*) season of 2009-2010 on wheat and monsoon (*kharif*) season of 2010 on soybean at the research farm of Indian Agricultural Research Institute (IARI), New Delhi, India. The soil of experimental site is sandy loam in nature and climate is semi-arid subtropical region showing hot summers (May-June) and cold winters (December-January) with an annual average maximum and minimum temperature of 40.5 and 6.5°C, respectively, and the average annual rainfall of 788 mm occurring mostly during the months of July to September. Before start of experiment initial soil samples were collected from surface (0-15 cm) and sub-surface soil (15-30 cm). Physico-chemical and biological properties of soil are presented in Table 1.

Experimental design and treatment details

The field experiment was laid out in a randomized block design with three replications having a plot size of 5.0 m × 4.5 m. The following

Table 1. Initial physico-chemical and biological properties of the experimental soil.

Parameter	Soil depth		Reference
	0-15 cm	15-30 cm	
Mechanical analysis			Bouyoucos (1962)
Sand (%)	56.4	56.3	
Silt (%)	25.0	26.0	
Clay (%)	18.6	17.7	
Texture	Sandy loam	Sandy loam	
CEC [cmol $_{(p+)}$ kg^{-1} soil]	11.68	6.7	Jackson (1973)
pH$_w$ (1:2.5)	8.0	8.0	Jackson (1973)
EC (dS m^{-1})	0.50	0.45	Jackson (1973)
Olson-P (kg ha^{-1})	22.1	18.1	Olsen et al. (1954)
Acid phosphatase (µg PNP g^{-1} h^{-1})	34.2	27.4	Tabatabai and Bremner (1969)
Alkaline phosphatase (µg PNP g^{-1} h^{-1})	120.1	70.8	Tabatabai and Bremner (1969)

Table 2. Characteristics of rock phosphate enriched compost (RPEC) prepared by using rice straw, rock phosphate and *Aspergillus awamori.*

Parameters	Enriched compost
pH$_w$ (1:5)	8.0 ± 0.09
Moisture %	7.92 ± 0.18
CEC [cmol(p+) kg^{-1} compost]	200.0 ± 14.0
Total carbon (%)	25.7 ± 0.29
Total N (%)	1.0 ± 0.07
C/N	25.7 ± 0.02
Total P (%)	3.2 ± 0.01
Water soluble P (WSP %)	0.031 ± 0.03
Citrate soluble P (CSP %)	1.98 ± 0.39
Total K (%)	1.6 ± 0.11
Total S (%)	0.61 ± 0.03
Total Ca (%)	2.83 ± 0.05
Total Mg (%)	1.99 ± 0.08
Total Fe (%)	0.22 ± 0.01
Total Mn (mg kg^{-1})	345.0 ± 15.0
Total Cu (mg kg^{-1})	55.0 ± 0.57
Total Zn (mg kg^{-1})	171.0 ± 14.0
Microbial parameters	
Microbial biomass carbon (g kg^{-1})	4.70 ± 0.24
Dehydrogenase (µg TPF g^{-1} h^{-1})	511.0± 1.00
Acid phosphatase (µg PNP g^{-1} h^{-1})	863.0 ± 37.0
Alkaline phosphatase (µg PNP g^{-1} h^{-1})	2070.0 ± 55.0

treatments were used for conducting the present field experiment. These are: T_1: Control; T_2: Recommended dose of NPK fertilizers (100% RDF); T_3: Rock phosphate enriched compost (RPEC) at the rate of (5 t ha^{-1}; T_4: 50% RDF + Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}. Wheat was grown as the first crop and soybean was grown as the succeeding crop. Recommended dose of NPK fertilizers applied to wheat were: 120:60:60 N, P_2O_5, and K_2O respectively. Urea and diammonium phosphate (DAP) were used as the source of nitrogen, while DAP and muriate of potash (MOP) were used as the source of phosphorus and potassium, respectively. These are collectively called recommended dose of NPK (RDF) fertilizers as per the crop requirement. The whole quantities of compost and fertilizer materials were applied to wheat before last ploughing and soybean was grown in the residual fertility.

Preparation of Rock phosphate enriched compost (RPEC)

Rock phosphate enriched compost (rice straw + Udaipur rock phosphate at 4% P + *Aspergillus Awamori*) was prepared in bulk and used for the present field experiments. Rice straw was mixed with required quantities of rock phosphate and *Aspergillus awamori* at 50 g fresh mycelia per 100 kg of rice straw. A uniform dose of urea solution (0.25 kg N per 100 kg of rice straw), fresh cow dung (5 kg per 100 kg of rice straw), *Trichoderma viride* (50 g fresh mycelia per 100 kg of rice straw) and *Aspergillus awamori* (50 g fresh mycelia per 100 kg of rice straw) was introduced into each composting mass to reduce C/N ratio, as natural inoculums, hasten the composting and P solubilise respectively. The composting was carried out in pots having 100 L capacity. Turning was done by manually at monthly intervals to provide adequate aeration. Moisture content (50 to 60% of field capacity) was maintained throughout the composting period. Composting was continued for 120 days.

Compost analysis

At maturity, fresh compost samples were collected after 120 days of composting and analyzed for total nutrients content. Total nutrient contents were determined as per the standard procedure (Jackson, 1973). Bio-available P consisting of water soluble P (WSP) and neutral *1 N* ammonium citrate soluble P (CSP) was determined as per the procedure outlined by Fertiliser (Control) Order (FCO, 1985). Microbial biomass carbon was determined by chloroform fumigation incubation method as outlined by Jenkinson and Powlson (1976), while dehydrogenase activity was determined by Klein et al. (1971) and acid and alkaline phosphatase by the method as outlined by Tabatabai and Bremner (1969). Chemical and biological characteristics of enriched compost are presented in Table 2.

Post harvest soil analysis

The plot-wise soil samples were collected from surface (0-15 cm) and sub-surface (15 -30 cm) soil after the harvest of wheat and

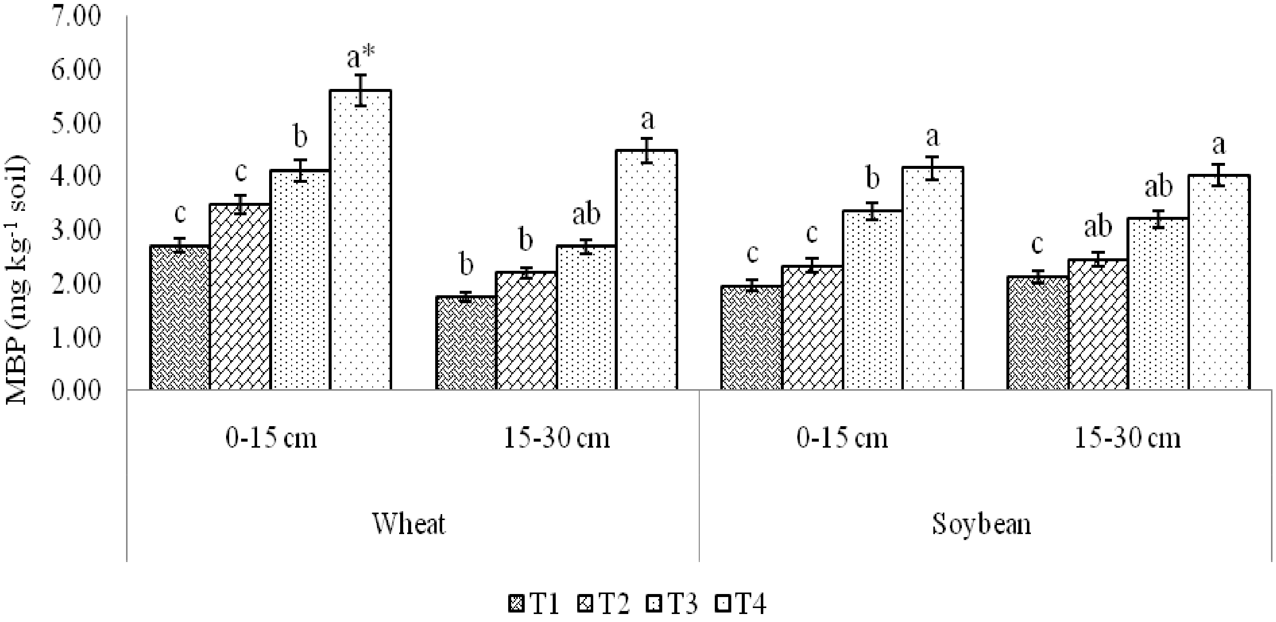

Figure 1. Microbial biomass phosphorus (MBP) under wheat and soybean (mg kg^{-1} soil) as affected by RPEC vis-a-vis and chemical fertilizers .T_1, Control; T_2, recommended dose of NPK fertilizers (100% RDF); T_3, Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}; T_4, 50% RDF + Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}. *For each parameter, different letters within the same column indicate that treatment means are significantly different at P<0.05 according to Duncan's Multiple Range Test for separation of means.

soybean. Immediately after sampling, a portion of the soil samples (~100 g) were kept at 4ºC in a refrigerator in plastic bags for a few days to stabilize the microbiological activity and analyzed for biological properties. Another portion of soil samples were air-dried in shade ground and passed through 2-mm sieve using a wooden pestle and analyzed for Olsen-P (Olsen et al., 1954). Soil phosphorus was fractionated into various inorganic fractions by modified P fractionation scheme of Peterson and Corey (1963). Microbial biomass phosphorus (MBP) was determined by fumigation method as given by Brookes et al. (1982). Acid and alkaline phosphatase activities were determined by the method as outlined by Tabatabai and Bremner (1969).

Statistical analysis

Data generated from the field experiments were subjected to the statistical analyses of appropriate variance to the experimental design. Data were analysed by Duncan's multiple range tests with a probability *P*<0.05 Duncan, 1995). Least significant differences (LSD) between means were calculated using the SPSS program (SPSS version 16.0; SPSS, Inc., Chicago, IL, USA).

RESULTS

Microbial biomass phosphorus (MBP)

Microbial biomass phosphorus (MBP) significantly increased due to integrated use of RPEC and chemical fertilizers (Figure 1) in surface soil (0-15 cm) after wheat harvest. However, no significant differences were found between T_2 and T_3. The values of MBP in surface soil varied from 2.7 mg kg^{-1} in unfertilized control to 5.6 mg kg^{-1} in treatment T_4 after wheat harvest. Unfertilized control plot (T_1) was statistically at par with treatment that received 100% RDF (T_2) in surface soil after soybean harvest. Significant (*P*<0.05) build-up in microbial P due to combined use of inorganic fertilizers and RPEC which clearly indicates the beneficial effect of integrated nutrient management for enhancing microbial P in surface soil after wheat and soybean.

Acid phosphatase

Data in Figure 2 shows that combined use of RPEC along with chemical fertilizers significantly increased the acid phosphatase activity than that of the unfertilized control plot in surface and sub-surface soil after wheat harvest. The lowest value of 29.7 µg PNP g^{-1} soil h^{-1} of acid phosphatase was found in unfertilized control plot which increased to 72.9 µg PNP g^{-1} soil h^{-1} in treatment T_4 in surface soil after wheat.

Data showed no significant differences in acid phosphatase activity under treatments receiving alone chemical fertilizers and RPEC after soybean harvest in both the soil surface (Figure 2). It is evident that acid phosphatase activity ranged from 23.4 to 49.7 and 21.9 to 47.8 µg PNP g^{-1} soil h^{-1} in surface and sub-surface soil respectively, after soybean harvest; the lowest being with unfertilized control plot (T_1).

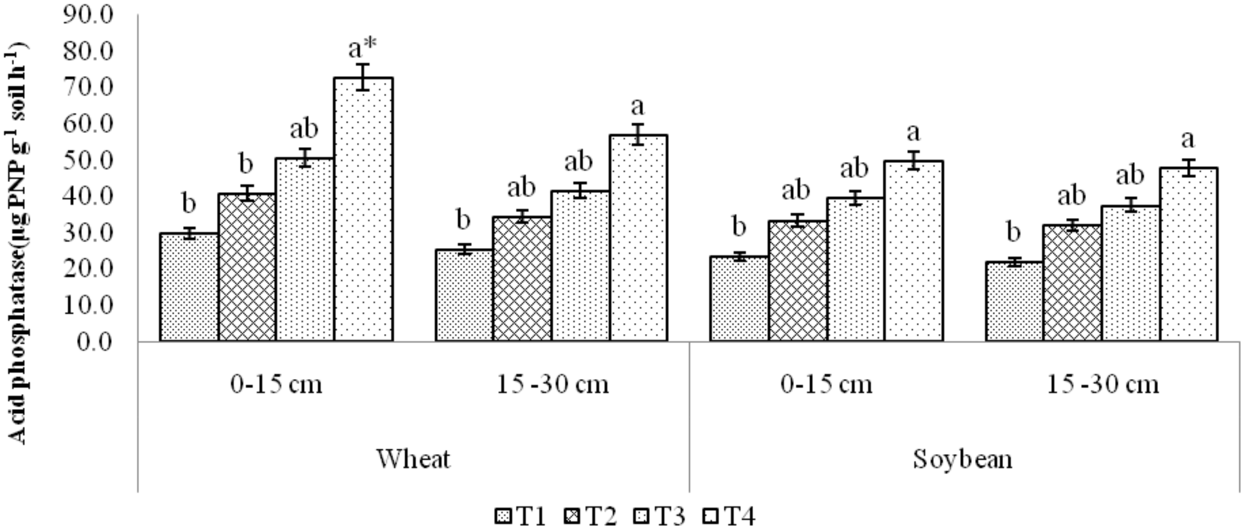

Figure 2. Acid phosphatase activity as affected by RPEC vis-a-vis chemical fertilizers after wheat and soybean harvest .T_1, Control; T_2, recommended dose of NPK fertilizers (100% RDF); T_3, Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}; T_4, 50% RDF + Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}. *For each parameter, different letters within the same column indicate that treatment means are significantly different at $P<0.05$ according to Duncan's Multiple Range Test for separation of means.

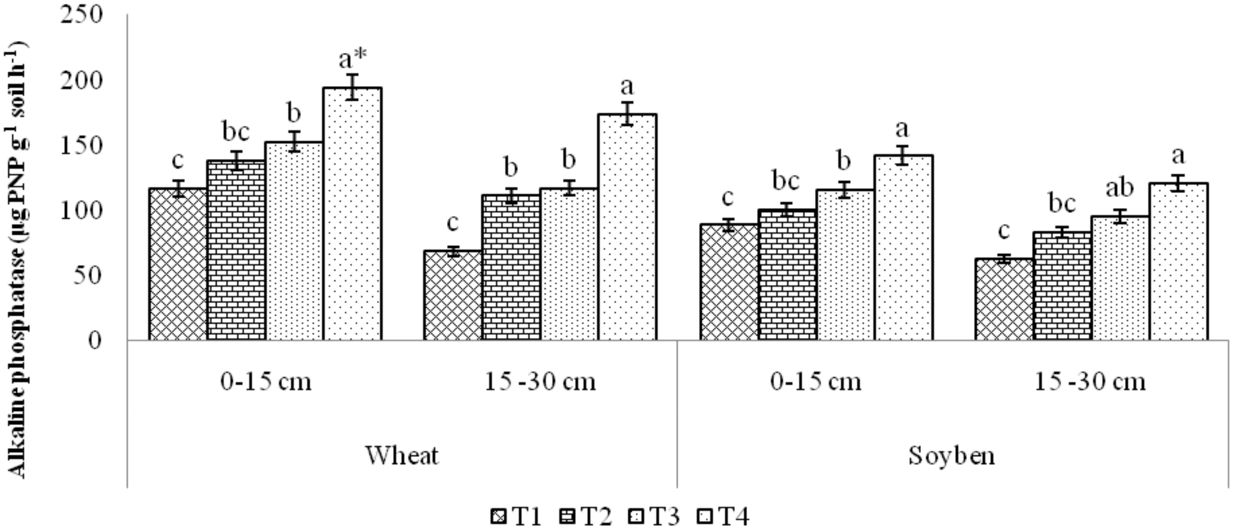

Figure 3. Effect of RPEC and chemical fertilizers on alkaline phosphatase activity after wheat and soybean harvest. T_1: Control; T_2: Recommended dose of NPK fertilizers (100% RDF); T_3: Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}; T_4: 50% RDF + Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}.*For each parameter, different letters within the same column indicate that treatment means are significantly different at $P<0.05$ according to Duncan's Multiple Range Test for separation of means.

Alkaline phosphatase

There was no significant difference between unfertilized control (T_1) and use of 100% RDF (T_2) in surface soil after wheat harvest (Figure 3). Data pertaining to alkaline phosphatase activity after wheat and soybean clearly illustrated that application of RPEC improved in alkaline phosphatase activity over unfertilized control plot in surface as well as sub surface soil. Significant change in alkaline phosphatase activity was found in treatment receiving conjoint use of RPEC along with chemical fertilizers in surface as well as sub-surface soil after

Table 3. Effects of RPEC and chemical fertilizers on sequential fractionation of P (mg kg^{-1}) after wheat and soybean harvest.

Treatments	Surface soil (0-15 cm)					Sub-surface soil (15-30 cm)				
	After wheat harvest									
	Saloid-P	Fe -P	Al-P	Ca-P	Ocl-P	Saloid-P	Fe -P	Al-P	Ca-P	Ocl-P
T1	9.8^{b*}	13.8^{b}	21.7^{b}	149.5^{c}	14.6^{c}	9.1^{c}	21.2^{a}	15.3^{c}	107.4^{c}	15.7^{c}
T2	20.9^{a}	25.0^{a}	23.6^{b}	186.4^{bc}	15.6^{c}	17.2^{b}	25.0^{a}	$19.4b^{c}$	189.0^{b}	19.7^{bc}
T3	19.6^{a}	25.6^{a}	20.4^{b}	210.1^{ab}	23.9^{b}	17.8^{b}	24.9^{a}	25.3^{ab}	199.6^{b}	21.1^{b}
T4	23.6^{a}	34.1^{a}	34.2^{a}	244.4^{a}	32.5^{a}	20.7^{a}	27.9^{a}	29.6^{a}	230.7^{a}	26.8^{a}
LSD (P=0.05)	3.99	10.3	4.9	36.0	6.8	2.5	8.8	8.4	12.0	3.8
After soybean harvest										
T1	8.7^{b}	15.2^{d}	17.3^{c}	94.0^{c}	13.5^{b}	8.4^{c}	10.0^{d}	16.6^{c}	88.8^{c}	13.0^{c}
T2	16.0^{a}	25.0^{c}	28.8^{b}	132.4^{bc}	17.3^{b}	14.0^{b}	19.0^{c}	29.8^{b}	124.9^{b}	16.3^{b}
T3	16.6^{a}	28.3^{b}	30.4^{ab}	175.9^{ab}	17.3^{b}	12.7^{ab}	27.7^{b}	26.3^{b}	144.3^{b}	18.3^{ab}
T4	19.8^{a}	33.0^{a}	36.0^{a}	222.8^{a}	33.7^{a}	16.5^{a}	31.5^{a}	36.1^{a}	197.7^{a}	20.6^{a}
LSD (P=0.05)	3.9	2.5	5.3	56.1	9.3	2.80	3.48	5.80	21.3	2.9

T_1, Control; T_2, Recommended dose of NPK fertilizers (100% RDF); T_3, Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}; T_4, 50% RDF + Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}. *For each parameter, different letters within the same column indicate that treatment means are significantly different at P<0.05 according to Duncan's Multiple Range Test for separation of means.

soybean harvest than 100% RDF.

Sequential fractionation of P

Data pertaining to the P fractions were affected differentially due to nutrient management practices using RPEC and chemical fertilizers over the unfertilized plot (T_1) after the wheat harvest (Table 3). Application of 100% RDF maintained significantly ($P<0.05$) higher amount of saloid-P, Fe-P, over unfertilized control plot in surface soil after wheat harvest. Combined use of chemical fertilizers and RPEC maintained significantly higher amount of all P fractions namely, saloid–P, Al–P, Ca–P and Occl–P in surface soil as compared to unfertilized control plot after wheat.

The residual effect of RPEC and chemical fertilizers on Saloid-P, Fe-P and Al-P fractions after soybean harvest (Table 3) were higher than the unfertilized plot (T_1) in both surfaces. Treatment that received RPEC + 50% RDF (T_4) maintained significantly highest amount of all fractions such as saloid–P, Fe–P, Al–P, Ca–P and occluded-P than unfertilized plot in surface and sub-surface soil. However, saloid-P was at par with treatment T_2, T_3 and T_4. The relative distribution of P fractions after soybean followed the same trend as in first crop of wheat that is in the order of saloid–P < Fe–P < Al–P < occluded–P < Ca–P in increasing order.

Olsen-P

Application of rock phosphate enriched compost (RPEC) as well as recommended dose of fertilizers applied either alone or in combination maintained significantly ($P<0.05$) higher Olsen-P in soil after wheat and soybean harvest (Table 4) in surface (0-15 cm) and sub-surface (15-30 cm) soil depth as compared to the unfertilized control plot (T_1). Treatment T_4 receiving RPEC at 5 t ha^{-1} along with 50% RDF maintained higher values of Olsen-P by 68.8 and 58.7% over control at 0-15 and 15-30 cm soil depth, respectively after wheat harvest.

Table 4. Effect of RPEC and chemical fertilizers on Olson-P after wheat and soybean harvest.

Treatments	Wheat		Soybean	
	0-15 cm	15-30	0-15 cm	15-30 cm
T_1	17.1^{d*}	15.6^{b}	15.0^{c}	14.8^{c}
T_2	25.9^{b}	21.2^{a}	22.3^{b}	20.1^{b}
T_3	23.7^{c}	21.5^{a}	21.8^{b}	19.1^{b}
T_4	28.8^{a}	24.7^{a}	25.8^{a}	22.8^{a}
LSD (P=0.05)	1.1	3.9	2.0	2.1

T_1, Control; T_2, Recommended dose of NPK fertilizers (100% RDF); T_3, Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}; T_4, 50% RDF + Rock phosphate enriched compost (RPEC) at 5 t ha^{-1}. *For each parameter, different letters within the same column indicate that treatment means are significantly different at P<0.05 according to Duncan's Multiple Range Test for separation of means.

Similar trend in build-up of available P was maintained after the soybean crop grown on residual fertility with the application of RPEC and chemical fertilizers (Table 4). In general, the values of Olsen-P in soil after soybean are lower as compared to wheat, irrespective of treatments and soil depths. Treatment T_2 maintained significantly higher Olsen-P by 48.7 and 35.9% over unfertilized control in surface and sub-surface soil depth, respectively after soybean harvest.

DISCUSSION

Microbial biomass phosphorus (MBP)

In general, the amount of MBP accounts for 2-10% of total P in soil, which is much larger than the percentage for Olsen-P, and annual P flux through the turnover of the microbial biomass is estimated to be much more than in its standing stock, based on previous measurements made in arable, grassland, and forest soils in both temperate and tropical zones (Brookes et al., 1984; Srivastava and Singh, 1988). Oberson et al. (2001) reported that rapid turnover of P in the microbial pool may contribute a major source to the available P pool, as P released from the microbial biomass is highly available to plant uptake, and also the microbial immobilization of inorganic P protects the P from fixation. In the present study, we found a significant build-up in microbial P due to combined use of inorganic fertilizers and RPEC which clearly indicates the beneficial effect of integrated nutrient management in enhancing microbial P in soils after the first crop of wheat in surface as well as sub-surface soil. It is also evident that MBP was significantly increased in surface soil than sub-surface soil after both wheat and soybean harvest. This may be due to higher microbial activity in the surface soil than the sub-surface soil because of higher amounts of organic matter in case of former.

Acid phosphatase

Application of RPEC significantly increased the phosphatase activity over the application of 100% RDF. This is obvious because organic P present in the compost material is mineralized into inorganic P in presence of phosphatase enzyme which is produced by plants and/or microorganisms and is able to hydrolyze organic P into inorganic P. Acid and alkaline phosphomonoesterases and phosphodiesterases are considered as the predominant phosphatases in most types of soil and litter (Tabatabai, 1994). Wu et al. (2007) studied the effects of sewage or compost on soil P turnover in a short-term incubation experiment and evaluated the relationships that may occur between P availability, bacteria densities and phosphatase activities in a degraded Mediterranean soil characterized by low levels in SOM and N and P nutrients.

Alkaline phosphatise

The present field study clearly indicates that alkaline phosphatase activity in the unfertilized plot declined due to high intensive agriculture as in the present wheat–soybean cropping sequence. Application of 100% RDF increased alkaline phosphatise activity than the unfertilized plot in surface as well as sub-surface soil after wheat and soybean harvest. However, conjoint use of RPEC and chemical fertilizers maintained highest activity of alkaline phosphatase in soil than the sole application of compost or chemical fertilizers, indicating their better enzyme activity which in turn, helps in supplying P to crops.

Sequential fractionation of P

It is clearly seen from the data that P fractions in all the fertilized plots increased than the unfertilized plot. This indicates that there is a build-up of all the P fractions in soil due to application of RPEC and chemical fertilizers. However, treatment receiving combined application of chemical fertilizers and RPEC maintained higher amount of all fractions of P *viz*., saloid–P, Fe–P, Al–P, Ca–P and occluded–P in surface as well as sub-surface soil after wheat harvest. Out of these P fractions, the Ca–P was the dominant fraction found in surface as well as sub-surface soil. Saloid–P, which is considered the most important fraction of P in soil for plant growth, decreased in sub-surface soil. There were no significant treatment effects on Fe-P in sub-surface soil after wheat harvest which may be due to alkaline soil pH of the experimental soil where Fe bound P is very low. The availability of P depends on the soil pH as it governs the occurrence and abundance of those metal cations that are prone to precipitate with P ions in the soil solution, namely Ca, Fe and Al. Hence, in neutral to alkaline soils, P ions rather precipitate as dicalcium or octacalcium phosphates, hydroxyl apatite and eventually least soluble apatites (Hinsinger, 2001).

Olsen-P

Significant build–up in available P due to combined use of chemical fertilizers and RPEC clearly indicates the beneficial effect of integrated nutrient management in enhancing available P in soils after the first crop of wheat. This may be explained as during decomposition of OM lot of organic acids, namely citric, oxalic, tartaric, *etc*. are produced, which in turn, enhanced the dissolution of P from RP, thereby increased P availability (Biswas and Narayanasamy, 2006). It was also evident that higher amounts of available P is present in the surface soil compared to sub-surface soil, indicating that the added P were restricted mainly to surface layer (0-15 cm) and lesser amounts of P have been moved to sub-surface layer (15-30 cm). Availability of Olsen-P was increased in plots receiving organic amendments either alone or in combination with 50% RDF over control unfertilized plot it might be due to the release of organically bound P during decomposition of organic matter, solubilization of soil P by organic acids. This result corroborates the findings of Moharana et al. (2012).

Conclusions

This study clearly indicated that RPEC along with chemical fertilizers maintained higher amount of MBP, phosphatase enzyme activity and P fractions namely, Saloid-P, Fe-P, Al-P,Ca-P and Ocl-P (occluded) than alone the use of 100% RDF after wheat and soyben harvest. Higher concentration of Olsen-P, was registered under treatments receiving integrated use of RPEC along with 50% RDF than the alone use of chemical fertilizers and RPEC in surface and sub-surface soil depth after wheat and soybean harvest. Thus, RPEC could be an alternative and cost effective option in place of costly chemical P fertilizers.

Conflict of interest

Author did not declare any conflict of interest.

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