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Chemical fractions of phosphorus and their relationship with rice yield and P uptake under continuous addition of organics and chemical fertilizers in an acid Alfisol

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Abstract: The effect of continuous application of organics and chemical fertilizers under rice-wheat system was studied on various forms of soil phosphorus in an Alfisol in an on-going long-term field experiment at Palampur, H.P. India. The soil samples collected from 0-0.15 and 0.15-0.30 m soil depth after the harvest of wheat (2008-09) were analyzed for different fractions of phosphorus by following a sequential extraction procedure. Different P fractions were correlated with rice yield and P uptake. Application of 50% NPK through chemical fertilizers + 50% N through FYM to rice followed by 100% NPK to wheat recorded highest values of all the fractions of phosphorus in both the depths, which was significantly superior over application of 100% NPK through chemical fertilizers to both the crops and control. Surface layer (0-0.15 m) recorded higher content of all the fractions of phosphorus than subsurface (0.15-0.30 m) layer; however, the trend was almost similar in both the depths. Residual-P was found to be the most dominant P fraction and total-P followed almost similar trend as its constituent fraction. A highly significant positive correlation of all the fractions of phosphorus was observed with both the grain and straw yield of rice and P uptake. The degree of correlation in respect of yield and phosphorus uptake was highest with NaOH-Pi indicating maximum contribution of this fraction. All the fractions of phosphorus were positively and significantly correlated to one another at both 0-0.15 and 0.15-0.30 m soil depths, showing interdependency of various chemical pools of phosphorus suggesting dynamic equilibrium among these fractions.

Key words*: Integrated nutrient management, long-term, organics, rice-wheat cropping sequence, substitution of nitrogen*

Introduction

About 33 per cent of the soils in Himachal Pradesh are acidic in nature (Anonymous 1997) and are characterized by high phosphorus fixing capacity. Phosphorus becomes one of the most important yield limiting nutrients in such soils as most of the phosphate added through chemical fertilizers reacts with Fe and Al compounds and is transformed into relatively insoluble compounds. With time, the solubility of these compounds decreases, rendering it unavailable for plant uptake. The first products formed would be amorphous aluminium and iron phosphates as well as some calcium phosphates. The amorphous Al and Fe phosphates gradually change into compounds that resemble crystalline variscite and strengite, which are generally not available to plants. Of late, the partial factor productivity of chemical fertilizers has also been declining as evident from stagnant foodgrain production despite of increased fertilizer use in the country. The only alternative to sustain the crop yields and maintain soil health is the use of organics. Although they can contribute little to P replenishment due to their

low P content, organic materials may increase P availability through other phenomena. Firstly, P can be released from decomposition and mineralization of plant materials (Palm 1995), directly increasing soil solution P. Secondly, organic anions produced during decomposition may compete with P for adsorption sites in soil, resulting in increased P availability (Easterwood and Sartain 1990; Hue 1991).

Addition of organic materials besides supplying plant nutrients, also affects the availability of native as well as the applied nutrients through chemical fertilizers. Nutrient uptake is thus improved resulting in increased nutrient use efficiency. A part of the removed nutrients is recycled back as biomass in the form of roots, stubbles, leaves, and so forth. Differences in the nature of root exudates, root activity, and management practices could lead to diverse changes in the chemical as well as the biochemical changes in soil. All these factors exert a strong influence on the various labile fractions or chemical pools of nutrients in soil affecting their availability.

Materials and Methods

A long-term field experiment has been in progress since 1991 at Padhiarkhar experimental farm of College of Agriculture, Palampur, Himachal Pradesh (32°06' N latitude, 76°03´ E longitude and 1223.7 m altitude) to investigate the effects of long-term addition of chemical fertilizers alone and along with different organics *viz*. FYM, wheat straw and green manure (*Sesbania aculeata*) on phosphorus fractions in soil. The experimental area falls under wet temperate zone with annual average rainfall of 2500-3000 mm, of which 80 per cent is received during wet season (July to October). The experimental soil (*Typic Hapludalf*) was silty clay loam in texture with pH 5.5, organic carbon 6.0 g kg^{-1} and available N, P, K were 675, 21.9 and 221 kg ha^{-1}, respectively. Rice and wheat were grown in sequence at the same site with 8 treatments in randomized block design having four replications. The treatment details were T_1-Control, T_2-100% NPK to both rice and wheat, T_3-50% NPK+50% N through FYM to rice followed by 100% NPK to wheat, T_4-75% NPK+25% N through FYM to rice followed by 75% NPK to wheat, T_5-50% NPK+50% N through wheat straw to rice followed by 100% NPK to wheat, T_6-75% NPK+25% N through wheat straw to rice followed by 75% NPK to wheat, T_7-50% NPK+50% N through green manure to rice followed by 100% NPK to wheat, T_8-75% NPK+25% N through green manure to rice followed by 75% NPK to wheat.

The recommended doses of fertilizer (100% N, P and K) were 90, 17, 33 and 120, 26 25 kg ha^{-1}, for rice and wheat, respectively. The chemical sources of N, P and K were urea, single superphosphate and muriate of potash, respectively. Different organics *viz*. FYM, wheat straw and green manure (*Sesbania aculeata*) were applied only in *kharif* season of each year. Soil samples were collected from surface (0-0.15 m) and subsurface (0.15-0.30 m) depths after the harvest of wheat (2008-09) and different fractions of P were estimated following sequential extraction procedure as given by Sui *et al.* (1999). This procedure aims at quantifying plant available (H_2O- or $NaHCO_3$- extractable P), Ca-associated (HCl-extractable), Fe-oxide- and Al-oxide-associated inorganic P (NaOH-extractable), as well as labile and stable organic P. Rice grain and straw yields were recorded after the harvest in *kharif* 2009. Grain and straw samples of rice were collected, processed and analyzed for phosphorus content. An attempt has also been made to correlate different fractions of soil phosphorus among themselves and also with rice grain and straw yield and P uptake.

Results and Discussion

Water extractable-P (H_2O-P)

The water extractable-P differed significantly under different treatments in both the depths (Table 1). In surface (0-0.15 m) depth it varied from 7.50 to 12.00 mg kg^{-1} under T_1 (control) and T_3, where 50 % NPK+ 50 N through FYM to rice followed by 100% NPK to wheat were applied. Application of 100% of recommended dose of NPK through chemical fertilizers during both the seasons for 18 years (T_2) increased the H_2O-P content in soil by 38% over control (T_1).

Table 1. Effect of continuous application of organics and chemical fertilizers on different fractions of phosphorus after wheat harvest

Treatment	Olsen-P (kg ha^{-1})	Different P fractions (mg kg^{-1})															
		H_2O-P		$NaHCO_3$-Pi		$NaHCO_3$-Po		NaOH-Pi		NaOH-Po		HCl-P		Residual-P		Total-P	
	0-0.15 m	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m
T_1	21.01	7.50	4.50	12.15	10.20	25.35	12.30	80.25	78.00	46.50	46.50	7.50	6.00	341.25	230.25	521	388
T_2	80.57	10.35	8.25	37.05	34.95	43.95	34.80	108.75	106.50	203.63	198.75	21.00	19.80	618.75	555.00	1043	958
T_3	90.83	12.00	10.80	46.35	44.10	67.65	59.40	119.25	117.00	413.25	228.25	33.90	31.80	686.25	660.00	1379	1151
T_4	86.12	11.10	9.45	38.85	36.45	62.40	52.05	112.50	111.00	168.75	184.13	31.80	27.00	656.25	622.50	1082	1043
T_5	76.14	11.70	10.35	37.65	35.25	59.85	51.75	117.00	114.75	188.25	195.75	33.30	30.90	682.50	645.00	1130	1084
T_6	68.80	10.80	9.00	34.50	31.65	51.00	45.60	110.25	107.25	154.88	137.25	30.90	28.50	645.00	615.00	1037	974
T_7	78.99	11.40	9.90	37.05	34.95	60.45	52.05	115.50	113.25	175.88	162.63	32.40	29.40	678.75	637.50	1111	1040
T_8	67.79	10.65	8.70	33.90	31.20	50.10	43.80	109.50	106.50	145.50	132.00	29.40	27.00	630.00	600.00	1009	949
CD(0.05)	*5.76*	*1.12*	*1.30*	*2.54*	*2.46*	*9.55*	*9.49*	*4.66*	*4.68*	*48.42*	*23.95*	*3.20*	*3.66*	*22.31*	*27.56*	*58.0*	*35.4*
Buffer	21.90	12.75	9.50	28.0	25.50	64.00	52.00	86.00	71.00	108.00	88.50	25.50	21.75	458.00	426.00	782	694

T_1-Control, T_2-100% NPK to both rice and wheat, T_3-50% NPK+50% N through FYM to rice followed by 100% NPK to wheat, T_4-75% NPK+25% N through FYM to rice followed by 75% NPK to wheat, T_5-50% NPK+50% N through wheat straw to rice followed by 100% NPK to wheat, T_6-75% NPK+25% N through wheat straw to rice followed by 75% NPK to wheat, T_7-50% NPK+50% N through green manure to rice followed by 100% NPK to wheat, T_8-75% NPK+25% N through green manure to rice followed by 75% NPK to wheat

The 50% N substitution through organics was superior over its 25% rate, the differences, however, were not significant in surface layer (0-0.15 m). Different organic sources also behaved at par in respect of this fraction of nitrogen. The content of H_2O-P under subsurface followed almost similar trend in all the treatments as was observed under surface layer though the average values were comparatively lower in subsurface layer which varied from 4.5 mg kg^{-1} under control to 10.80 mg kg^{-1} under T_3. The positive effect of organic manures on phosphorus availability is probably due to the release of organic anions produced during decomposition which might have competed with inorganic PO_4^{3-} ions resulting in their lower fixation (Werner and Scherer 1995).

0.5 M $NaHCO_3$ extractable inorganic-P ($NaHCO_3$-Pi)

Fraction $NaHCO_3$-Pi increased significantly over control with the application of both the chemical fertilizers alone or along with different organics. In surface layer (0-0.15 m) application of 100% NPK alone (T_2) caused 205 % increase in this fraction. Significantly highest content of $NaHCO_3$-Pi (46.35 mg kg^{-1}) was recorded in treatment T_3 where 50% NPK + 50% N through FYM to rice followed by 100% NPK to wheat was applied. In subsurface layer (0.15-0.30 m), there was an overall decline in the content, the trend, however, was almost same as that in surface layer. As compared to the buffer plots, all the plots except control (T_1) recorded higher $NaHCO_3$-Pi in both the depths. Increase in $NaHCO_3$-Pi with the addition of fertilizers alone or along with organic materials may be attributed to its addition through these sources (Zhang and Mackenzie, 1997a).

0.5 M $NaHCO_3$ extractable organic-P ($NaHCO_3$-Po)

A perusal of the data in table 1 reveals that 0.5 M $NaHCO_3$ extractable organic-P in 0-0.15 m depth varied from 25.35 mg kg^{-1} in (T_1) to 67.65 mg kg^{-1} in T_3 where 50% NPK + 50% N through FYM to rice followed by 100% NPK to wheat was applied. Amongst integrated nutrient management treatments (T_3 to T_8), substitution of 50% N through any of the organics recorded higher amount of this fraction as compared to 25% N substitution, the differences, however, were significant only in case of green manuring (T_7-T_8). As compared to buffer plots, all the treatments recorded a decrease in $NaHCO_3$-Po content, except T_3 in both the depths. In the subsurface layer $NaHCO_3$-Po varied from 12.3 mg kg^{-1} in control to 59.4 mg kg^{-1} in T_3 having almost similar effect as in the surface layer and the highest content recorded in T_3 was at par with its value in T_4, T_5 and T_7. Decline in $NaHCO_3$-Po in control plots may be due to continuous cropping without external addition of P.

0.1 M NaOH extractable inorganic-P (NaOH-Pi)

The 0.1 M NaOH extractable inorganic-P in surface layer (0-0.15 m) varied from 80.25 mg kg^{-1} in T_1 to 119.25 mg kg^{-1} in T_3, recording an increase of about 48.6 % over control. Application of 100% NPK through chemical fertilizers also increased this form by 35.5 % over control. Amongst the organic manure treated plots, 50% substitution resulted in significantly higher values over 25% substitution in their respective sources. In comparison to buffer, all the treatments showed increase in NaOH-Pi except control. In the subsurface, the NaOH-Pi content varied from 78.0 in control to 117.0 mg kg^{-1} in T_3 and the treatment-wise pattern was almost same as that observed in case of surface soil. Decline in NaOH-Pi content in non fertilized plots may be due to its continuous removal through cropping. The NaOH extractable inorganic P was the major sink of excessive added P, but desorption was there to maintain the levels of plant available P (Zhang and Mckenzie 1997b).

0.1 M NaOH extractable organic-P (NaOH-Po)

The data in table 1 revealed that 0.1 M NaOH extractable organic-P in 0-0.15 m depth ranged from 46.50 mg kg^{-1} in control (T_1) to 413.25 mg kg^{-1} in plots receiving 50% NPK + 50% N through FYM during *kharif* followed by 100% NPK through inorganic fertilizers during *rabi* (T_3). Application of 100% NPK alone to both the crops registered an increase of 338 % over control. Amongst the treatments consisting of different organics, the plots receiving 50% N substituted through FYM recorded significantly highest NaOH-Po in comparison to rest of the treatments. Similarly, in case of subsurface layer (0.15-0.30 m), NaOH-Po varied from 46.5 mg kg^{-1}

in control (T_1) to 228.25 mg kg^{-1} in T_3 where 50% NPK + 50% N through FYM was applied in *kharif* followed by 100% NPK in *rabi*. Like other P forms, there was a decline in the content of this form with soil depth, however, the trend was almost same as that in surface layer. Increase in NaOH extractable organic-P with the addition of fertilizers along with manures was also reported by Sharma *et al*. (2005).

0.1 M HCl Extractable-P (HCl-P)

The content of HCl-P in surface layer (0-0.15 m) ranged from 7.50 to 33.90 mg kg^{-1} in control and 50% NPK + 50% N through FYM in *kharif* followed by 100% NPK in *rabi* (T_3), respectively (Table 1). Application of organic manures in conjunction with chemical fertilizers (T_3-T_8) resulted in significant increase in this fraction of P over control (T_1) and chemical fertilizer alone treated plots (T_2). The highest HCl-P content (33.90 mg kg^{-1}) recorded in T_3 was at par with its contents in T_4, T_5, T_6 and T_7. In comparison to buffer plots values of HCl-P were also higher when chemical fertilizers were applied along with different organic sources. The contents of HCl-P under subsurface (0.15-0.30 m) followed almost similar trend in all the treatments as was observed under surface layer, however, the content decreased with depth.

Residual-P

The residual-P was found to be dominant fraction of P in soil and in 0-0.15 m depth it varied from a minimum of 341.25 mg kg^{-1} under control (T_1) to 686.25 mg kg^{-1} under the treatment receiving 50% NPK + 50% N through FYM during *kharif* followed by 100% NPK during *rabi* (T_3). Application of organic manures along with chemical fertilizers also increased the residual-P content of soil significantly over control and 100% NPK except in treatment T_8, where the increase was not significant over 100% NPK treated plots. In comparison to buffer plots, all the treatments showed higher values of residual P except control which showed significant reduction. The variation in residual-P content in the subsurface layer was from 230.25 to 660.00 mg kg^{-1} in T_1 and T_3, respectively. The treatment-wise pattern was almost similar to the surface layer. Irrespective of the treatments, the contents of residual-P were lower in subsurface than surface layer. Continuous cropping without P fertilization (T_1) resulted in decline in residual-P. Sharma *et al*. (2005) also reported similar results.

Total-P

In surface layer total-P varied from 521 mg kg^{-1} in T_1 to 1379 mg kg^{-1} in T_5. Application of 100% NPK continuously for 18 years during both the seasons significantly increased the total-P content in soil by about 100 % control. Amongst organic treatments substitution of N (50 or 25%) through any of the organic sources registered significant increase in total-P content over control, however, in comparison to 100% NPK treatment T_3, T_5 and T_7 could result significant increase showing higher value under 50% substitution in comparison to 25% substitution rate. When different organics were compared, FYM at 50% substitution rate (T_3) was found to be superior over rest of the treatments. In subsurface layer also, the total-P varied from 388 mg kg^{-1} in T_1 to 1151 mg kg^{-1} in T_3 and the treatment-wise trend was almost similar to surface layer. Like other fractions, total-P in subsurface soil layer was lower as compared to surface layer in all the treatments. The increase in total-P content with continuous application of fertilizers alone or in combination with organic manures for 18 years may be ascribed to the increase in different fractions of phosphorus.

Olsen-P

A perusal of the data revealed that Olsen-P varied from 21.01 kg ha^{-1} in control to 90.83 kg ha^{-1} in plots which received 50% NPK+ 50% N through FYM in *kharif* followed by 100% NPK in *rabi* through inorganics. There was an increase in available P contents in all the treatments where P was added over its initial value (and buffer) of 21.9 kg ha^{-1}. Amongst integrated nutrient management treatments, application of 50% NPK+50% N through FYM in *kharif* followed by 100% NPK in *rabi* (T_3) recorded highest Olsen-P content of 90.83 kg ha^{-1} which was at par only with Olsen-P content in T_4 showing thereby superiority of FYM over rest of the organic sources tried. Application of 100% NPK to both the crops

for 18 years registered 80.57 kg ha^{-1} Olsen-P against 20.01 kg ha^{-1} in control. Substitution of 25% N through either of the organic sources resulted in significantly lower available P content in comparison to their 50% substitution except in FYM where the difference was not significant. Buildup of available phosphorus with the application of NPK fertilizers alone or in conjunction with organics might be due to the release of organic acids during decomposition which in turn helped in releasing phosphorus through solubilizing action of native phosphorus in the soil (Gupta *et al*., 2006; Urkurkar *et al.* 2010). The organic matter also forms a cover on sesquioxides and makes them inactive and thus reduces the phosphate fixing capacity of the soil, which ultimately, helps in release of ample quantity of phosphorus

Relationship of Phosphorus Fractions with Rice Yield and P uptake

Correlation with yield and phosphorus uptake

The data in table 2 revealed that grain and straw yield of rice exhibited positive and significant correlation with all the fractions of phosphorus. Maximum correlation of grain yield of rice was observed with residual-P (r = 0.756) followed by NaOH-Pi (r = 0.708). While in case of straw yield of rice, maximum correlation was observed with NaOH-Pi (r = 0.704) followed by $NaHCO_3$-Pi (r = 0.700). These findings are in conformity with those of Sood and Bhardwaj (1992) who also reported significant and positive correlation of grain and straw yields of rice with Olsen-P and all the P forms.

Further, the data revealed that phosphorus uptake in grain and straw of wheat and total P uptake was positively and significantly correlated with all the fractions of P. Maximum correlation (r = 0.815) of P uptake by rice grain was found with residual-P followed by NaOH-Pi (r = 0.789) and $NaHCO_3$-Pi (r = 0.779). Similarly, P uptake in straw had maximum correlation with residual-P (r = 0.717) followed by NaOH-Pi and $NaHCO_3$-Pi (r = 0.758). In case of total P uptake, maximum correlation (r = 0.822) was found with NaOH-Pi followed by $NaHCO_3$-Pi (r = 0.819). Sood and Bhardwaj (1992) and Setia and Sharma (2007) also reported a significant and positive relationship between Olsen-P and P uptake by wheat.

The data with respect to correlations of different phosphorus fractions with Olsen phosphorus status were positively and significantly correlated with all the fractions (Table 2). The highest correlation of Olsen phosphorus was found with $NaHCO_3$-Pi (r = 0.921) followed by residual-P (r = 0.891). Setia and Sharma (2007) also reported significant and positive correlation of Olsen-P with all the inorganic P fractions.

Table 2. Correlation coefficients (r) of different phosphorus fractions (0-0.15 m) with rice yield, phosphorus uptake and Olsen-P

P-Fraction	Yield		P-Uptake			Olsen-P
	Grain	Straw	Grain	Straw	Total	
H_2O-P	0.627**	0.587**	0.682**	0.645**	0.703**	0.730**
$NaHCO_3$-P_i	0.697**	0.700**	0.779**	0.758**	0.819**	0.921**
$NaHCO_3$-P_o	0.534**	0.579**	0.619**	0.654**	0.690**	0.727**
NaOH-P_i	0.708**	0.704**	0.789**	0.758**	0.822**	0.866**
NaOH-P_o	0.593**	0.615**	0.639**	0.644**	0.689**	0.629**
HCl-P	0.599**	0.598**	0.690**	0.677**	0.729**	0.736**
Residual-P	0.756**	0.664**	0.815**	0.717**	0.798**	0.891**

**Significant at 1% level

Relationship among Different Fractions of Phosphorus

A perusal of the data in table 3 indicates that all the fractions of phosphorus were positively and significantly correlated to each other at both the depths. In surface layer maximum correlation of H_2O-P was found with residual-P (r = 0.826) followed by $NaHCO_3$-Pi (r = 0.812) and least (r = 0.535) with NaOH-Po. While maximum correlation of $NaHCO_3$-Pi was found with NaOH-Pi (r = 0.931) followed by residual-P (r = 0.923). $NaHCO_3$-Po had maximum correlation with HCl-P (r = 0.872) followed by NaOH-Pi (r = 0.793) and maximum correlation of NaOH-Pi was found with residual-P (r = 0.923) followed by HCl-P (r = 0.866). NaOH-Po also had maximum correlation (r = 0.601) with residual-P.

In subsurface layer all the fractions of phosphorus had almost similar trend as in the surface layer. Maximum correlation (r = 0.858) of H_2O-P was found with residual-P followed by HCl-P (r = 0.856) and least (r = 0.682) with NaOH-Po. $NaHCO_3$-Pi had maximum correlation with NaOH-Pi (r = 0.926) followed by residual-P (r = 0.894). While $NaHCO_3$-Po and NaOH-Pi had maximum correlation with residual-P (r = 0.919 and 0.903) followed by HCl-P (r = 0.878 and 0.867, respectively).

Table 3. Correlation coefficients (r) of different phosphorus fractions among themselves

P-Fraction	H_2O-P	$NaHCO_3$-P_i	$NaHCO_3$-P_o	NaOH-P_i	NaOH-P_o	HCl-P
			(0-0.15 m)			
$NaHCO_3$-P_i	0.812**					
$NaHCO_3$-P_o	0.788**	0.799**				
NaOH-P_i	0.773**	0.931**	0.793**			
NaOH-P_o	0.535**	0.709**	0.545**	0.631**		
HCl-P	0.788**	0.822**	0.872**	0.866**	0.500**	
Residual-P	0.826**	0.923**	0.790**	0.923**	0.601**	0.851**
			(0.15-0.30 m)			
$NaHCO_3$-P_i	0.776**					
$NaHCO_3$-P_o	0.796**	0.841**				
NaOH-P_i	0.791**	0.926**	0.861**			
NaOH-P_o	0.682**	0.813**	0.584**	0.749**		
HCl-P	0.856**	0.843**	0.878**	0.867**	0.635**	
Residual-P	0.858**	0.894**	0.919**	0.903**	0.646**	0.946**

** Significant at 1% level

Conclusions

From these findings, it is clear that all the P fractions declined in both surface and sub-surface soil when no fertilizer or manure was applied. As compared to the control and buffer plots, marked increase in all the fractions of phosphorus was observed with use of chemical fertilizers alone or along with organics continuously for eighteen years. All the P fractions were highly correlated with Olsen P, rice yield and P uptake by rice grain and straw. Phosphorus fractions, *viz*., $NaHCO_3$-Pi, NaOH-Pi and Residual-P had higher values of correlation coefficients with Olsen-P showing their highest contribution towards availability of phosphorus in soil. While rice grain yield had highest values of correlation coeffients with residual-P, followed by NaOH-Pi and $NaHCO_3$-P. Residual P and Total P were the two most dominant P fractions in soil.

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