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Distribution of phosphorus fractions in different soil orders of Indo-Gangetic plains of India

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ABSTRACT

The status and distribution of phosphorus fractions in some soil orders and their relationship with soil characteristics under Indo-Gangetic plains of India was studied at Mohanpur, Nadia (W.B.). Soil samples were collected from three depths (0-15, 15-30 and 30-45 cm) covering Entisols, Inceptisols and Alfisols during 2016. Results revealed that soil pH and clay content increased whereas EC and organic carbon tended to decrease with increasing soil depth. Among different phosphorus fractions, Ca-P was dominant contributing 35% and 20% of total phosphorus content in Entisols and Inceptisols, respectively followed by Fe-P, RS-P and OC-P. In Alfisol, Fe-P fraction constituted 21% of the total soil P followed by Ca-P, RS-P and Al-P. The fractions Al-P, RS-P and Ca-P increased whereas organic P decreased with increasing soil depth. Soil pH was positively correlated with Ca-P and negative with Al-P, Fe-P of all the soil orders. Calcium-P was the highest in Entisols (35%) and Inceptisols (20%) while Fe-P (21%) in Alfisols. Among the inorganic P fractions, Ca-P was the dominant contributor to the availability of phosphorus in Entisols and Inceptisols. The dominant fraction for the release of P in Alfisols was iron phosphate. In general, inorganic P fractions increased while organic available P decreased with soil depth. Various P fractions also had relationships among themselves.

Key words: Phosphorus fractions, soil depth, soil orders, soil properties

INTRODUCTION

Distribution pattern of different inorganic P fractions help in better understanding of phosphorus transformation in soil and manipulation of the applied P fertilizers towards achieving better utilisation efficiency of applied P fertilisers. Phosphorus is mainly present in soil in two major forms *i.e.* organic and inorganic. Organic P, which is mainly confined to the surface layer, is mineralized into inorganic forms. Only 10 to 30 per cent of the freshly applied phosphate is utilized by crop plants and the rest is transformed into different P compounds of varying solubility, behaviour and fate in soils and may serve as potential source of P for plants at later stages. Saloid-P, Al-P, Fe-P and Ca-P fractions are the main source of P for plants. Inorganic P is associated with hydrous sesquioxides; amorphous and crystalline Al and Fe compounds in acidic, non-calcareous soil and Ca compounds in alkaline and calcareous soils (Gupta *et al.* 2020). Strongly weathered soils usually are dominated by Al-P, Fe-P and RS-P. Neutral and slightly acid soils usually contain all five fractions in comparable amounts. Alkaline and calcareous soils are often dominant in Ca-P. Organic matter, calcium carbonate and sesquioxides contents of soil appear to be the guiding factors in determining distribution of different forms of P. Since, the different forms of soil P have different solubility, availability and thus P uptake by plants largely depend on the amounts of different fractions present in soil. Soils of indo-Gangetic plains are medium to high organic matter content and a soil development mainly by alluvial material (Alluvial soils). In this situation, Ca-P is the main fraction of phosphorus and may constitute up to 50% of inorganic P fractions that could be divided into labile, pedogenic and lithogenic Ca–P compounds. Similarly, Fe-P is the major constituent (more than 50%) of inorganic P fraction in red soils (Alfisols). Phosphorus fractions other than instantly soluble P could not be available to the plants due to variation in soil reaction. Therefore, knowledge of phosphorus forms, cropping history and soil characteristics plays a vital role to assess the mineral nutrition of plants. With this background, the present study was formulated to determine different phosphorus fractions and their relationship with soil properties in different soil orders of the Indo-Gangetic plains of India.

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MATERIALS AND METHODS

Study areas of present investigation comprised of three soil orders *viz* Entisols, Inceptisols and Alfisols. The area under study lies between north to central, and central to eastern part *i.e.* Indo-Gangetic plain of India. Soil samples were collected from 10 locations at three depths (0-15, 15-30, 30-45cm) from each soil order. The soil samples were analysed for pH by Ph meter and electrical conductivity with the help of Conductivity meter. Organic carbon in soil was determined using method as described by Walkley and Black (1934). The CEC of soil was analysed by 1N neutral NH_4OAc solution (Jackson, 1973). The particle size analysis of soil was determined by Bouyoucous hydrometer method. The sequential extraction of inorganic soil phosphorus fractions was determined as per Chang and Jackson (1957) method, subsequently modified by Petersen and Corey (1966). Total P in soil was determined using 60% perchloric acid digestion method as suggested by Piper (1966) and available soil P by Olsen *et al.* (1954) for alkaline soil pH. Organic P was determined as the difference between total P and Inorganic P. The data were analysed using the statistical package from social science (SPSS-20) and Excel-2007 tools. Simple correlation coefficient analyses between soil properties and fractions of P were computed by standard statistical methods.

RESULTS AND DISCUSSION

Physico-chemical properties

The soil pH ranged from 7.61 to 8.74 in Entisols, 6.87 to 8.77 in Inceptisols and 4.94 to 7.96 in Alfisols (Table 1).

Table 1: Physio-chemical properties of some selected soil orders of India

Depth (cm)	pH	EC (dSm^{-1})	OC ($g\ kg^{-1}$)	CEC ($Cmol\ (P^+)\ kg^{-1}$)	Sand (%)	Silt (%)	Clay (%)
Entisols							
0-15	6.6-8.7 (7.8)	0.09-0.99 (0.27)	4.8-9.6 (7.4)	2.8-53.0 (28)	36-68 (49)	12-40 (24)	16-41 (27)
15-30	7.8-8.7 (8.3)	0.08-0.78 (0.26)	1.5-9.3 (4.9)	0.38-74.2 (31)	32-68 (49)	14-32 (22)	18-48 (29)
30-45	7.5-8.8 (8.2)	0.09-0.62 (0.21)	0.7-6.9 (4.4)	3.4-39.0 (18)	32-58 (48)	12-24 (18)	24-48 (34)
Inceptisols							
0-15	6.6-8.6 (8.0)	0.08-0.97 (0.27)	5.4-19.5 (9.2)	5.6-44.0 (18)	35-59 (47)	12-40 (26)	20-37 (27)
15-30	6.2-8.8 (8.2)	0.07-0.69 (0.2)	4.8-16.2 (7.3)	4.4-37.60 (20)	40-66 (49)	12-28 (22)	20-38 (29)
30-45	7.6-8.8 (8.3)	0.1-0.58 (0.2)	3.3-12.3 (6.6)	5.01-36.0 (19)	32-52 (42)	12-28 (22)	28-40 (36)
Alfisols							
0-15	4.8-7.8 (5.8)	0.05-0.2 (0.13)	3-20.4 (8.7)	2.2-54.2 (17)	35-76 (49)	8-24 (16)	16-48 (35)
15-30	4.7-8.0 (5.9)	0.03-0.37 (0.12)	0.2-18.6 (6.9)	5.4-53.8 (21)	44-76 (54)	8-20 (13)	16-44 (33)
30-45	5.0-8.0 (6.0)	0.03-0.24 (0.1)	0.2-11.4 (4.8)	6.2-53.4 (21)	40-82 (50)	8-24 (16)	10-42 (34)

Soil pH increased with increase in soil depth. Lower pH values in the surface soils than sub surface soils indicated removal of base forming cations (mainly Ca and Mg) by leaching which can be explained by the higher sand content in upper layers and silt in lower layers (Lungmuana *et al.* 2015). The electrical conductivity ranged from 0.09 to 0.55 in Entisols, 0.12 to 0.59 in Inceptisols and 0.04 to 0.27 dSm^{-1} in Alfisols. These soils are non-saline in nature and it might be due to availability of enough rainfall to leach out the soluble salts of the root zone or down the profile. Organic carbon content ranged from 2.7-7.1 in Entisols, 4.5-15.6 in Inceptisols and 1.7-14.9 $g\ kg^{-1}$ in Alfisols. Both EC and OC showed decreasing trend with increase in the soil depth. Cation exchange capacity of soils ranged from 3.6 to 54.5 in Entisols, 5-37.4 in Inceptisols and 4.6-53.8 cmol (p+) kg^{-1} in Alfisols. The average values of CEC in Entisols and Inceptisols were higher as compared to Alfisols which might be due to presence of more exchangeable cations *i.e.* Ca and Mg. The soils were categorised under clay loam, sandy clay, sandy loam, loam, sandy clay loam in Entisol, clay loam and sandy clay loam in Inceptisols whereas Alfisols had clay, clay loam, sandy clay, sandy loam and sandy clay loam in texture. Irrespective of soil depth, clay content increased with increasing soil depth in Entisol and Inceptisol while no regular pattern was noted in Alfisols.

Phosphorus fractions

The saloid P (commonly referred as soil bound P) ranged from 1.4 to 14.3, 0.2 to 16.4 and 0.5 to 7.8 mg kg^{-1} in Entisols, Inceptisols and Alfisols contributing 2.3, 1.3 and 1.4% of total P, respectively. Among these orders, soils of Entisols contained relatively higher S-P than those of other orders (Table 2). Saloid P in soil was significantly correlated with P fractions and pH and negatively with CEC and organic P (Table 3). Similar results were reported by Devra *et al.* (2014). Saloid P in soil indicates the water soluble or readily soluble fraction among all the phosphorus pools. Saloid P increased with depth in all the soils of different orders. The non-occluded Al-P was also a very small fraction of the total P. It ranged from trace to 20.8, trace to 20.6 and trace to 14.3 mg kg^{-1} in Entisols, Inceptisols and Alfisols which contributed about 2.3, 1.2 and 3.5% of total P, respectively.

Table 2: Distribution of phosphorus fractions (mg kg^{-1}) of some selected soil orders of India

Depth (cm)	S-P	Al-P	Fe-P	RS-P	OC-P	Ca-P	Organic P	Available P	Total P
					Entisols				
0-15	1.4-7.8 (4.5)	0-1.9 (5.8)	4.7-95.6 (34.5)	1.0-23.7 (7.8)	1.1-17.5 (7.4)	13.0-155.9 (88.8)	5.5-160.5 (54.1)	4.3-26.7 (10.2)	186.1-386.1 (296.8)
15-30	2.8-13.1 (6.5)	0-14.3 (6.0)	11.1-105.1 (41.1)	3.9-24.6 (10.1)	2.1-23.2 (9.4)	11.7-144.8 (91.1)	13.9-90.3 (38.8)	3.2-8.3 (5.7)	173.0-336.3 (257.0)
30-45	4.6-14.3 (7.2)	0-20.8 (6.4)	10.3-103.2 (38.1)	4.5-20.9 (11.1)	2.8-28.4 (12.1)	10.7-162.3 (96.8)	11.0-54.3 (29.7)	2.4-18.5 (6.2)	136.4-311.8 (246.4)
					Inceptisols				
0-15	0.2-16.4 (3.3)	0-8.5 (2.4)	1.2-90.8 (22.8)	1.9-25.3 (12.5)	0.4-14.3 (4.1)	1.9-108.3 (48.7)	5.0-202.2 (72.0)	3.6-31.3 (9.7)	140.5-472.0 (309.1)
15-30	0.4-13.2 (3.8)	0-19.9 (3.6)	1.57-85.04 (22.2)	2.1-30.6 (14.7)	0.2-18.9 (4.7)	4.9-118.4 (52.4)	16.3-86.9 (42.7)	3.4-21.6 (7.0)	106.2-416.5 (257.3)
30-45	0.2-10.8 (3.6)	0-20.6 (3.7)	0.7-79.3 (21.7)	2.2-31.8 (15.9)	0.4-26.7 (6.3)	7.3-127.8 (57.2)	6.8-94.5 (34.8)	3.4-13.8 (7.2)	90.9-380.2 (228.0)
					Alfisols				
0-15	0.5-6.8 (2.1)	0.2-10.2 (5.6)	10.8-95.6 (37.7)	0.2-13.6 (6.4)	2.1-10.6 (6.0)	4.1-45.8 (14.8)	24.9-133.7 (70.0)	3.7-9.7 (6.4)	97.1-354.8 (215.9)
15-30	0.9-7.2 (2.8)	0.2-14.3 (7.2)	19.7-90.1 (42.3)	0.6-14.8 (7.8)	1.4-14.8 (7.1)	2.3-60.7 (17.9)	15.6-102.1 (54.5)	3.2-13.6 (6.0)	116.6-307.5 (189.4)
30-45	0.6-7.8 (3.4)	0-11.3 (7.5)	13.1-85.9 (40.5)	0-18.7 (8.9)	0.4-17.8 (5.8)	1.6-49.9 (19.0)	15.9-91.7 (43.8)	3.2-11.9 (5.7)	106.9-275.0 (182.2)

Figure within () indicates average

Low quantity of Al-P may result due to higher soil pH, wherein phosphate ions cannot readily combine with Al^{3+} and Fe^{3+} as under acidic condition. Soils of Alfisols contained relatively higher Al-P than those other soil orders. Al-P had highly significant positive correlation with Fe-P, organic carbon and sand and negative one with pH , silt and Ca-P. These results were supported by Gupta *et al.* (2020). In general, this form of P tended to increase with soil depth. Iron P (Fe-P) varied from 4.7 to 105.1, 0.7 to 90.8 and 10.8 to 95.6 mg kg^{-1} in Entisols, Inceptisols and Alfisols and contributed about 14.2, 8.4 and 20.5 % of total P, respectively. Among all the fractions, it was the most dominant fraction in soils of Alfisols. Fe-P was positively correlated with organic carbon, CEC and clay content in soil whereas negatively with pH and sand. Similar finding was reported by Sarkar *et al.* (2013). Iron P increased with increase in soil depth upto 15-30cm followed by a reduction at 30-45cm depth. Reductant soluble phosphate (RS-P) is the form of phosphorus in which P remains occluded or adsorbed by oxides or hydroxides of iron and/or aluminium. It ranged from 01 to 24.6, 1.9 to 31.8 and trace to 18.7 mg kg^{-1} in Entisols, Inceptisols and Alfisols it contributed 3.6, 5.4 and 3.9 % of total P, respectively. Among these orders, soils of Inceptisols contained relatively higher RS-P than those of other orders. RS-P was positively correlated with pH, organic carbon and silt whereas negatively with CEC and clay content in soil. This statement agreed with the observation of Devra *et al.* (2014). Reductant soluble P increased with soil depth in all the soils of Indo-Gangetic plains of India.

The occluded P is the unavailable form which is accumulated in the soil. Among soil orders, it ranged from 1.1 to 28.4, 0.2 to 26.7 and 0.4 to 17.8 mg kg^{-1} in Entisols, Inceptisols and Alfisols that contributed 3.6, 1.9 and 3.2 % of total P, respectively. Overall, soils of Entisols contained relatively higher OC-P than other soil orders. It was positively correlated with CEC and clay while negatively with sand content in soil. Similar results were reported by Sarkar *et al.* (2014). Ca-P is the major P fraction to contribute available phosphorus to the plants. It ranged from 10.7 to 162.3, 1.9 to 127.8 and 1.6 to 60.7 mg kg^{-1} in Entisols, Inceptisols and Alfisols and contributed 34.6, 19.9 and 8.8 % of total P, respectively. Among these order, Entisols contained comparatively higher amount of Ca-P than those of other orders. Ca-P was strongly and positively correlated to Saloid-P, RS-P, pH, sand and silt and negatively with Al-P, Fe-P, OC-P, clay content in soil (Table 3). These results were supported by Lungmuana *et al.* (2012). Ca-P increased with increasing soil depth in all soils of different orders.

Table 3: Correlation Coefficient (r) between soil properties and phosphorus fractions

	pH	OC	CEC	Sand	Silt	Clay	S-P	Al-P	Fe-P	RS-P	OC-P	Ca-P	Org-P	Av-P
S-P	0.21**	NS	-0.19**	NS	NS	NS								
Al-P	-0.33**	0.21**	NS	0.17**	-0.30**	NS	0.19**							
Fe-P	-0.37**	0.34**	0.27**	-0.24**	NS	0.34**	0.21**	0.72**						
RS-P	0.16**	0.18**	-0.28**	NS	0.18**	-0.14*	0.17**	NS	NS					
OC-P	NS	NS	0.30**	-0.30**	NS	0.35**	0.17**	0.36**	0.49**	NS				
Ca-P	0.63**	NS	NS	0.13*	0.21**	-0.33**	0.22**	-0.16*	-0.20**	0.19**	-0.12*			
Org-P	-0.15*	0.13*	0.26**	NS	NS	NS	-0.20**	NS	NS	-0.15*	NS	-0.15*		
Av-P	-0.45**	0.47**	0.40*	-0.18**	NS	0.28**	0.75**	-0.22*	-0.49**	NS	NS	-0.66**	-0.24**	
Total-P	0.26**	0.35**	NS	-0.15*	0.34**	NS	0.22**	NS	0.20**	0.16**	NS	0.45**	0.36**	0.16*

** Significant at 5 per cent level, ** Significant at 1 per cent level*

As compared mineral P, organic P contributed smaller amount of phosphorus to total P. It ranged from 5.5 to 15.3, 5.0 to 202.2 and 15.6 to 133.7 mg kg^{-1} in Entisols, Inceptisols and Alfisols respectively and that contributed 15.3, 18.8 and 28.6 % of total P. It was positively correlated with organic carbon, CEC and negatively with Saloid-P, RS-P, Ca-P and pH (Table 3). Similar results were reported by Lungmuana *et al.* (2015). Organic-P decreased with increasing soil depth in different orders (Table 2). Available P ranged from 2.4 to 26.7, 3.4 to 31.3 and 3.2 to 13.6 mg kg^{-1} in Entisols, Inceptisols and Alfisols and contributed 2.8, 3.0 and 3.1 % of total P, respectively. Among these orders, soils of Alfisols contained relatively higher available P than those of other orders. Available P was highly and positively correlated with Saloid-P, organic carbon, CEC, sand, clay and negatively with Al-P, Fe-P, Ca-P, organic-P and pH. Similar results were reported by Sarkar *et al.* (2014) and Lungmuana *et al.* (2015). In general, available P content was higher in 0-15cm and minimum in lower depth. Total P ranged from 136.4 to 386.1, 90.9 to 472.0 and 97.1 to 354.8 mg kg^{-1} in Entisols, Inceptisols and Alfisols, respectively. Among these ordesr, soils of Entisols contained relatively higher amount of total P than those of other orders. Total P in soils was positively correlated with all P fractions except Al-P and OC-P, pH, organic carbon and silt and negatively with sand. Similar results were reported by Lungmuana *et al.* (2015). Total P in soil indicates the reserve of P which might eventually available to plants in due course of time. Total P decreased with increasing soil depth of different soil orders.

It may be concluded from the results that the Ca-P fraction was dominant in Entisols and Inceptisols while Fe-P was dominant in Alfisols.

The Fe-P, Al-P and Ca-P were major contributor of available P in soils. The P forms in general, decreased with soil depth except organic and available P of Indo-Gangetic plains. The various fractions of P were associated with soil properties. All the fractions P had some kind relationships among themselves.

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