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Inorganic P Fractionation in Typical Vertisols and Associated Soils of Central India: A Case Study

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Abstract: Inorganic P fractions in shrink-swell soils representing six soil series of Adan river basin, Darwha tehsil, Yavatmal district, Maharashtra were studied to understand the relationship between P fractions and soil properties. These clayey soils were neutral to strongly alkaline (pH 6.70 – 9.34), calcareous and low to medium in organic carbon. The sequential extraction of inorganic soil P fractions indicated relative abundance as Ca_2-P<Fe-P<Al-P<O-P<Ca_8-P<Ca_{10}-P. The plant available forms of P (Ca_2-P, Al-P and Fe-P) contributed nearly 10 per cent of total inorganic P, while, the rest was in unavailable forms. The correlation matrix indicated that plant available forms of P had significant negative correlation with soil pH, EC and $CaCO_3$ and significant positive correlation with organic carbon. The P fractions showed significant correlation among each other which implies that available P forms are constantly replenished by other forms of P pools in the soils.

Keywords : *P Pools, Inorganic P fractions, Shrink- swell soils*

Introduction

In general, the Indian Vertisols and Vertic intergrades are deficient in phosphorus, which becomes one of the limiting factor in crop production. However, shrink-swell soils formed on basalts have very high P status compared to those soils formed from sedimentary rocks (Mehmood *et al.* 2010) but adsorption and precipitation phenomenon restrict the phosphorus mobility in soils and limits its availability to plants. In black soils, inorganic P contributes 54 to 84 per cent of total P, whereas the share of organic P varies from 16 to 46 per cent (Hinsinger 2001). As P exist in different forms and in-turn it affects the P availability, the present study was carried out to investigate the inorganic P fractions in swelling clay soils and their relationship with different soil properties in some representative soils of Adan river basin of Yavatmal.

Materials and Methods

Study area

The study area (20^0 15' 47'' to 20^0 20' 42'' N; 77^0 35' 27'' to 770 42' 54'' E) covers the part of Adan river basin in Darwha tehsil of Yavatmal district, Maharashtra (Fig. 1) . The area falls under North Deccan Plateau and is agro-climatically placed under hot moist semi-arid eco-sub-region and represents western parts of Darwha block to eastern part of Wani with 889 to 1100 mm of rainfall and 28.3^{0}C of mean annual temperature.

Selection of Soils

A detailed field survey was carried out at Bandegaon site of Adan river basin, Darwha tehsil, Yavatmal district Maharashtra using the visual interpretation of CARTOSAT merged IRS-P6 LISS-IV satellite data on 1:10,000 scales. Based on the detailed soil survey, six soil series were identified in Adan river basin *viz.,* Arunavati, Moregaon, Adan, Kalamb, Apti and Sangvi. The horizon-wise soil samples were collected from representative pedons of these series and processed and analyzed for pH of saturated paste by glass electrode and EC of saturation extract by conductivity meter (Jackson 1973), $CaCO_3$ by rapid titration method (Piper 1966), organic carbon by wet-oxidation method (Walkey and Black 1934), particle-

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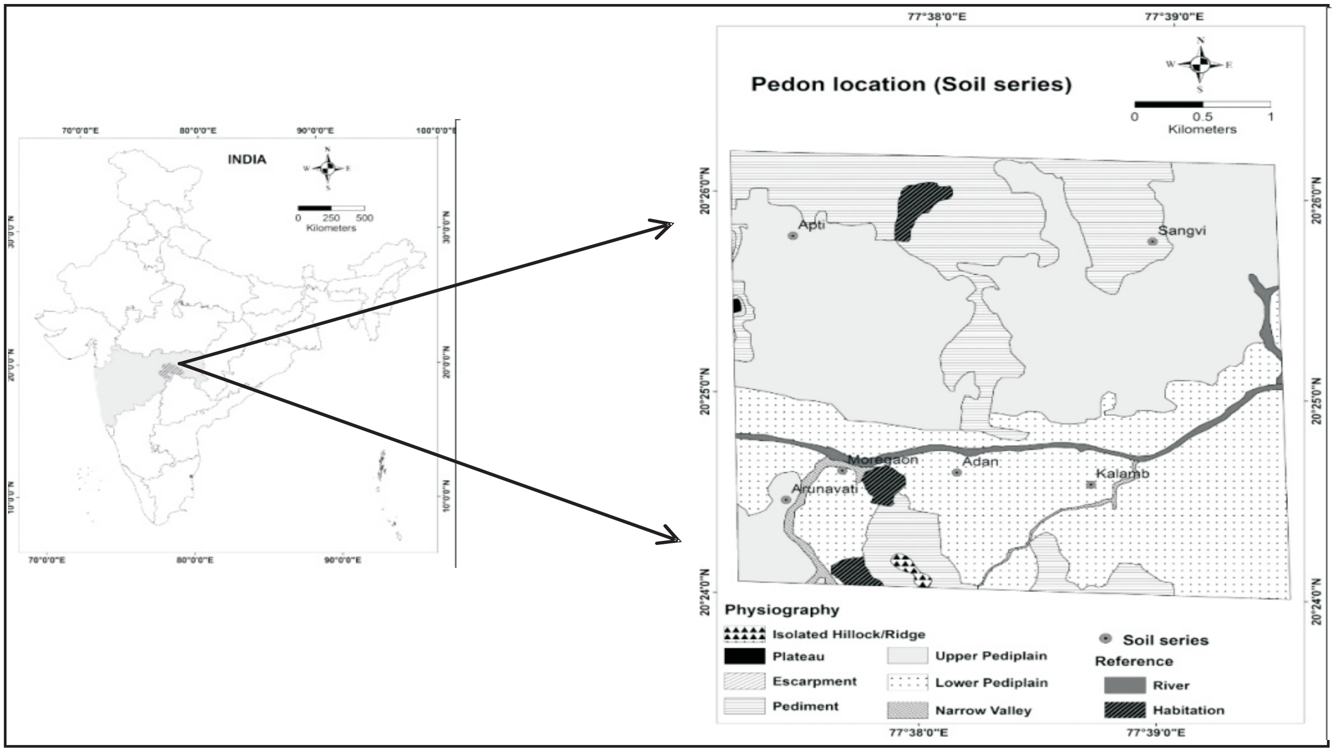

Fig. 1. Study area

size distribution by International Pipette Method (Jackson 1967) and cation exchange capacity by ammonium acetate procedure (Jackson 1973).

The sequential extraction method described by Jiang and Gu (1989) was used to determine different forms of soil inorganic P (Fig. 2). Each extracted fractions subsequently determined on spectrophotometer (UV-VIS 2450) with 660 nm wave length.

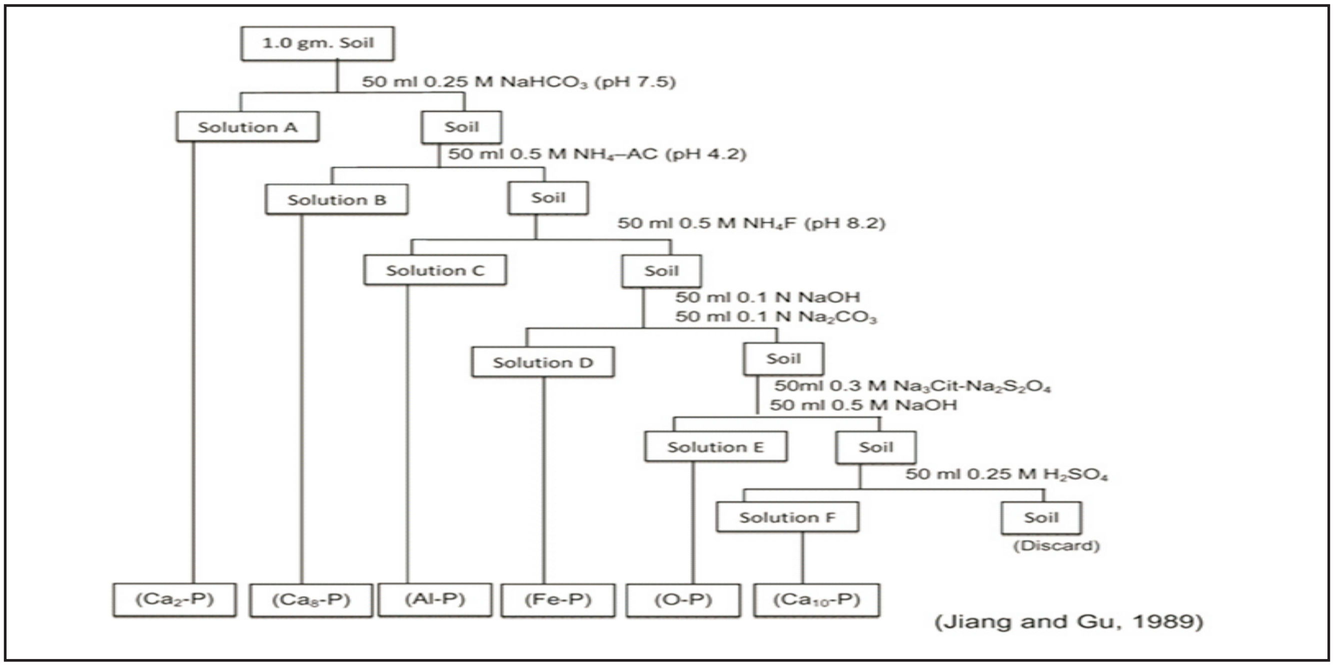

Fig 2. Flow chart of sequential extraction of inorganic phosphorus fractions

Results and Discussion

The physical and chemical properties of soils are presented in table 1. These swelling clay soils had pH ranging from 6.70 to 9.34 and increased with depth. The EC of the pedons ranged from 0.11 to 0.48 dSm^{-1}. The soils were calcareous (2.40 to 14.3 % $CaCO_3$). The organic carbon content of soils was low to medium (0.06 to 0.97 %). The cation exchange capacity of soils ranged from 38.1 to 60.3 $cmol(P^+)kg^{-1}$.

P fractionation

Fractionation of soil phosphorus has been proved to be extremely useful in the field of soil genesis, soil chemistry and fertility (Chang and Jackson, 1957) and is most widely used to interpret native inorganic P and the applied P in the soils. In the present study, the phosphorus fractions were found in the order of Ca_2-P<Fe-P<Al-P<O-P<Ca_8-P<Ca_{10}-P (Table 2).

Table 1. Physical and chemical properties of soils

Depth (cm)	Particle Size Distribution (%)			pH	EC (dSm^{-1})	OC (%)	$CaCO_3$ (%)	CEC $cmol(P^+)kg^{-1}$
	Sand	Silt	Clay					
Pedon 1 (Arunavati): Fine, smectitic, hyperthermic Typic Haplustepts								
0–21	2.30	40.4	57.3	7.99	0.22	0.69	3.83	49.8
21–38	3.14	36.6	60.3	8.21	0.22	0.42	6.22	54.6
38–59	17.3	28.9	53.8	8.23	0.21	0.21	8.38	45.0
59–92	21.2	32.4	46.4	8.47	0.18	0.24	9.34	41.8
92–130	23.3	34.3	42.4	8.32	0.19	0.21	9.08	38.1
Pedon 2 (Moregaon): Fine, smectitic, hyperthermic Typic Haplustepts								
0–21	12.0	34.2	53.8	8.25	0.17	0.30	11.9	46.9
21–49	7.60	33.1	59.3	8.60	0.15	0.09	12.9	57.2
49–71	5.90	31.6	62.5	8.46	0.19	0.06	12.5	60.3
71-110	6.40	30.8	62.8	8.61	0.16	0.09	12.8	60.1
Pedon 3 (Adan): Fine, smectitic, hyperthermic Typic Haplustepts								
0–22	7.90	34.1	58.0	8.12	0.20	0.54	12.9	51.1
22–41	2.80	36.1	61.1	9.17	0.48	0.12	13.2	55.9
41–69	1.60	35.2	63.2	9.31	0.33	0.36	13.8	57.0
69–105	1.40	36.4	62.2	9.34	0.39	0.06	14.3	57.6
105–155	3.60	37.2	59.2	8.81	0.28	0.09	13.6	54.2
Pedon 4 (Kalamb): Fine, smectitic, hyperthermic Typic Haplusterts								
0–24	2.50	39.3	58.2	8.17	0.23	0.15	8.74	52.0
24-47	1.10	37.9	61.0	9.10	0.38	0.39	8.83	54.1
47–70	1.60	39.1	59.3	9.15	0.30	0.37	9.22	48.1
70–92	1.30	35.4	63.3	9.22	0.31	0.09	9.42	55.9
92–130	2.90	38.8	58.3	9.33	0.35	0.12	9.56	49.4
Pedon 5 (Apti): Fine, smectitic, hyperthermic Vertic Haplustepts								
0–18	8.70	40.0	51.3	7.61	0.20	0.70	4.06	43.5
18–46	5.30	38.2	56.5	7.78	0.13	0.58	5.75	45.7
46-61	3.30	37.8	58.9	7.85	0.12	0.42	6.23	46.8
61–75	7.80	36.9	55.3	7.91	0.19	0.30	6.6	40.6
Pedon 6 (Sangvi): clayey, smectitic, hyperthermic Typic Ustorthents								
0–16	22.6	31.4	46.0	7.36	0.20	0.97	3.11	42.8
16–35	10.7	31.2	58.1	6.70	0.11	0.36	2.40	50.9
35-50	Weathered (or) soft bedrock.							

Table 2. Inorganic P fractions and total inorganic P content in soils

Depth (cm)	Ca_2-P	Ca_8-P	Al-P	Fe-P	O-P	Ca_{10}-P	Total Inorganic P (ppm)
	(ppm)						
Pedon 1 (Arunavati): Fine, smectitic, hyperthermic Typic Haplustepts							
0–21	7.43 (1.47)	67.3 (13.4)	26.4 (5.23)	14.8 (2.93)	35.3 (7.00)	353 (70.0)	504
21–38	6.80 (1.28)	69.3 (13.0)	23.0 (4.32)	17.0 (3.20)	37.8 (7.11)	378 (71.1)	532
38–59	6.19 (1.38)	69.1 (15.3)	23.5 (5.22)	16.6 (3.68)	32.3 (7.18)	302 (67.2)	450
59–92	4.38 (1.05)	73.2 (17.6)	20.5 (4.92)	11.3 (2.70)	30.1 (7.23)	277 (66.5)	416
92–130	4.95 (1.40)	72.2 (20.4)	19.3 (5.47)	10.3 (2.93)	26.8 (7.59)	220 (62.2)	353
Pedon 2 (Moregaon): Fine, smectitic, hyperthermic Typic Haplustepts							
0-21	6.83 (1.48)	68.4 (14.8)	23.3 (5.05)	15.9 (3.44)	35.8 (7.78)	310 (67.4)	460
21-49	3.25 (0.63)	82.3 (15.9)	20.1 (3.89)	17.1 (3.31)	41.8 (8.10)	352 (68.1)	517
49-71	4.53 (0.79)	74.9 (13.1)	22.9 (4.02)	20.0 (3.51)	44.6 (7.81)	403 (70.7)	570
71-110	3.08 (0.53)	88.4 (15.2)	19.6 (3.36)	19.3 (3.31)	43.3 (7.43)	410 (70.2)	583
Pedon 3 (Adan): Fine, smectitic, hyperthermic Typic Haplustepts							
0–22	7.03 (1.32)	69.9 (13.1)	24.2 (4.54)	14.6 (2.74)	38.8 (7.28)	378 (71.0)	533
22–41	3.13 (0.54)	91.8 (16.0)	19.6 (3.41)	19.3 (3.35)	42.3 (7.36)	399 (69.4)	575
41–69	2.75 (0.45)	101 (16.5)	18.9 (3.10)	21.1 (3.45)	46.8 (7.65)	421 (68.8)	612
69–105	2.48 (0.41)	102 (16.9)	18.0 (2.98)	22.8 (3.80)	46.1 (7.66)	410 (68.2)	601
105–155	3.03 (0.53)	90.1 (15.8)	27.2 (4.77)	18.7 (3.28)	42.3 (7.42)	389 (68.2)	570
Pedon 4 (Kalamb): Fine, smectitic, hyperthermic Typic Haplusterts							
0-24	7.25 (1.35)	70.6 (13.1)	24.4 (4.52)	15.7 (2.91)	40.6 (7.53)	380 (70.6)	539
24-47	3.23 (0.56)	94.4 (16.2)	20.1 (3.46)	19.5 (3.35)	42.9 (7.37)	401 (69.0)	581
47-70	3.15 (0.56)	91.6 (16.2)	19.6 (3.46)	17.3 (3.05)	40.4 (7.15)	393 (69.6)	565
70-92	2.97 (0.49)	96.0 (15.9)	20.8 (3.45)	20.7 (3.43)	46.5 (7.70)	416 (69.0)	603
Pedon 5 (Apti): Fine, smectitic, hyperthermic Vertic Haplustepts							
0-18	9.43 (2.15)	63.0 (14.4)	29.3 (6.66)	12.2 (2.77)	34.6 (7.88)	291 (66.2)	439
18-46	8.85 (1.85)	66.3 (13.9)	29.0 (6.07)	12.4 (2.58)	35.6 (7.45)	326 (68.2)	478
46-61	8.05 (1.48)	66.3 (12.2)	27.9 (5.12)	14.1 (2.60)	39.2 (7.20)	389 (71.4)	544
61-75	7.35 (1.56)	68.3 (14.5)	27.0 (5.74)	12.8 (2.73)	35.8 (7.61)	319 (67.8)	471
Pedon 6 (Sangvi): clayey, smectitic, hyperthermic Typic Ustorthents							
0-16	12.1 (2.81)	60.2 (14.0)	31.9 (7.43)	11.5 (2.67)	33.3 (7.75)	280 (65.3)	429
16-35	13.8 (2.56)	54.6 (10.2)	33.6 (6.25)	15.9 (2.95)	38.2 (7.11)	381 (71.0)	537
35-50	Weathered (or) soft bedrock.						

Value in parenthesis () indicate percent of total

Di-calcium phosphate is the prime form of inorganic P and most readily soluble P fraction (bio-available P) which contributes only about 1 to 2 per cent of the total inorganic P and, in general, decreased with depth. The Ca_2-P in pedon 1,2,3,4 and 5 ranged from 2.48 to 9.43 mg kg^{-1}. However, pedon 6 had high amount of Ca_2-P (12.1 to 13.8 mg kg^{-1}) which may be due to neutral to slightly alkaline soil reaction (Murthy *et al.* 2002).

The octa-calcium phosphate is the second most abundant form after Ca_{10}-P which contributes 14 to 15 per cent of the total inorganic P with increasing with depth (except pedon 6) which may be due to accumulation of secondary carbonates or long-term inorganic P fertilizer application (Samadi and Gilkes 1998). The Ca_8-P is partially unavailable form of P to the plants (Adhami *et al.* 2006) and it ranged from 54.6 to 102 mg kg^{-1}.

The Al-P is more readily available source of P to the plants than Fe-P and contributes 4 to 6 per cent of the total inorganic P (Osodeke and Kamula 1992). The Al-P in these pedons ranged from 18.0 to 33.6 mg kg^{-1} and decreased with soil depth which may be due to intense weathering in lower horizons (Westin and Brito 1969).

The Fe-P is 3 to 4 per cent of the total inorganic P varied from 10.3 to 22.8 mg kg^{-1} and gradually increased with soil depth which could be probably due to high Fe in the parent material or intensive weathering in soils (Osedeke and Uba 2006). Phosphorus associated with crystalline Fe oxides such as goethite is referred to as occluded phosphate (Adhami *et al*. 2006; Shen *et al*. 2004), which is non-available form of P to the plants and contributes 7 to 8 per cent of the total inorganic P and shows an irregular pattern with depth. The O-P varied from 26.8 to 46.8 mg kg^{-1} in these pedons.

The apatite (H_2SO_4 extractable-P) is the most abundant form of inorganic P compared to other fractions in the calcareous soils (Solis and Torrent 1989). The Ca_{10}-P is non-available form of P and contributes 68 to 70 per cent of the total inorganic P. The Ca_{10}-P in these pedons ranged from 220 to 421 mg kg^{-1} and increased with soil depth and its content was higher in pedon 2, 5 and 6 than pedon 1, 3 and 4. Such high amount of Ca_{10}-P may be due to unweathered apatite mineral in calcareous soils (Garbouchev *et al*. 1968). The total inorganic phosphorus was calculated by the sum of all fractions. It varied from 353 to 612 mg kg^{-1} in

Table 3. Correlation matrix between soil properties and inorganic P fractions

	Ca_2-P	Ca_8-P	Al-P	Fe-P	O-P	Ca_{10}-P	Total Inorganic P
pH (1:2)	-0.958**	0.948**	-0.885**	0.666**	0.590**	0.478*	0.548**
EC (dSm^{-1})	-0.616**	0.776**	-0.572**	0.593**	0.512**	0.451*	0.518**
OC (%)	0.695**	-0.565**	0.632**	-0.569**	-0.452*	-0.376*	-0.403*
$CaCO_3$ (%)	-0.806**	0.723**	-0.727**	0.628**	0.545**	0.412*	0.462*
Sand	0.385	-0.534**	0.227	-0.665**	-0.807**	-0.860**	-0.853**
Silt	-0.102	0.165	-0.003	-0.049	0.145	0.184	0.183
Clay	-0.419*	0.566**	-0.280	0.853**	0.916**	0.960**	0.951**
CEC	-0.345	0.454*	-0.252	0.816**	0.793**	0.782**	0.782**
Ca_2-P	1	-0.894**	0.904**	-0.612**	-0.515**	-0.406*	-0.469*
Ca_8-P		1	-0.783**	0.767**	0.719**	0.599**	0.680**
Al-P			1	-0.505**	-0.364	-0.272	-0.321
Fe-P				1	0.890**	0.841**	0.880**
O-P					1	0.934**	0.961**
Ca_{10}-P						1	0.992**
Total Inorganic P							1

* Correlation is significant at the 0.05 level, ** Correlation is significant at the 0.01 level

different pedons.

The depth-wise distribution of inorganic P fractions in soils is presented in figure 3 (a & b). The distribution of P fractions in these pedons was observed in the order of Ca_2-P<Fe-P<Al-P<O-P<Ca_8-P<Ca_{10}-P. The Ca_{10}-P, O-P and Fe-P shows gradual increase with depth barring pedon 1 may be due to low clay content down to depth. The Ca_8-P shows gradual increase with depth in these pedons, however in pedon 6 there was a decreasing trends with depth. The Al-P and Ca_2-P decreased with depth except in pedon 6.

Correlation among parameters indicated that Ca_2-P was negatively and significantly correlated with soil pH (r= -0.958**) and Ca_{10}-P (r= -0.406*) because of high pH, $CaCO_3$ (Table 3). A positive and significant correlation was found between Ca_8-P with soil pH (r= 0.948**) and clay (r= 0.566**). Re-adsorption of Ca_8-P by clay particle increases its concentration in soils (Adhami *et al.* 2013). The Al-P was negatively and significantly correlated with soil pH (r= -0.885**) whereas its relationship was significantly positive with organic carbon (r= 0.632**). This type relationship is in agreement with the findings of Dutta and Mukhopadhyay (2007) and Roy *et al*. (2016). A negative

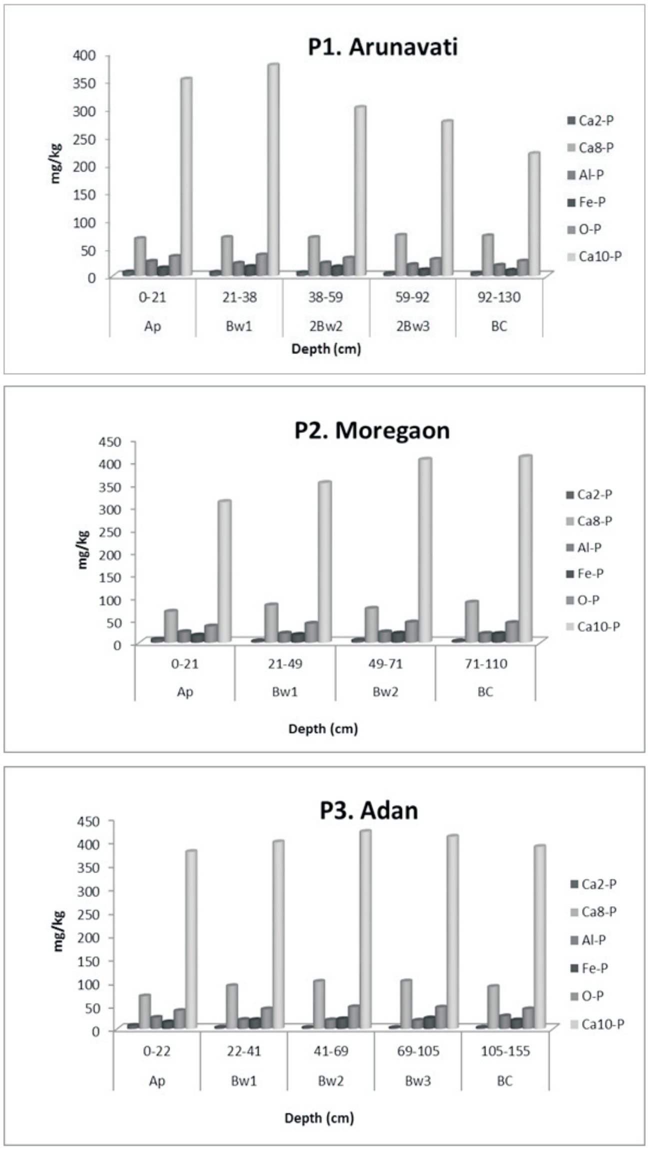

Fig. 3 (a). Distribution of inorganic P fraction at different horizons of pedons

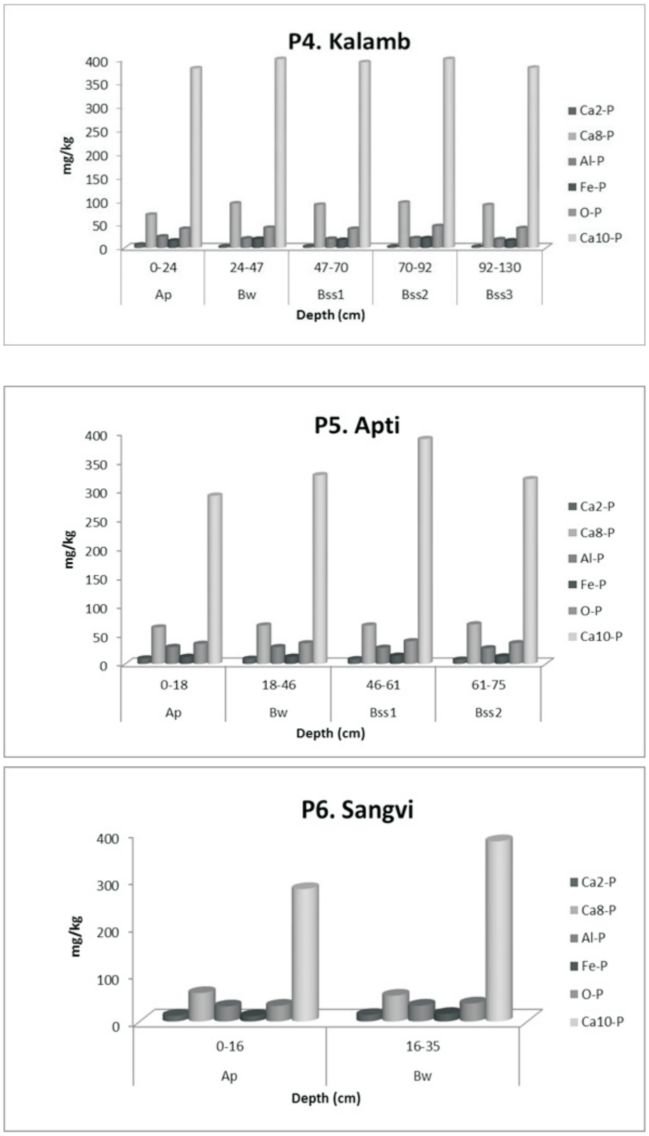

Fig. 3 (b). Distribution of inorganic P fraction at different horizons of pedons and significant correlation was found between Al-P with EC (r= -0.572**). Mostashari *et al.* (2008) also reported

A positive and significant correlation was found between Ca_2-P with Al-P (r= 0.904^{**}). The Ca_8-P was positively and significantly correlated with Fe-P (r= 0.767^{**}) and O-P (r= 0.719^{**}). This relationship was also corroborated by Mostashari *et al.* (2008). The Ca_{10}-P showed positive and significant correlation with CEC (r= 0.782^{**}), clay (r= 0.960^{**}) and total inorganic P (r= 0.992^{**}) whereas negative and significant correlation with organic carbon (r= -0.376^{*}). This relationship is in agreement with the findings of Adhami *et al.* (2014) and Jamil *et al.* (2016). The total inorganic P showed positive significant correlation with Ca-P (Ca_8-P, r= 0.680^{**}; Ca_{10}-P, r= 0.961^{**}) indicating their dominance in contribution of P pools in the soils. Similar relationship was also noticed by Roy *et al.* (2016).

Higher amount of inorganic phosphorus was observed in the form of Ca_{10}-P followed by Ca_8-P, Fe-P and O-P whereas minimum in Al-P and Ca_2-P. The dominance of Ca_{10}-P in the soils is due to unweathered apatite minerals, Ca_8-P due to long term inorganic P fertilizer application and O-P due to adsorption by crystalline Fe oxides respectively (Samadi and Gilkes 1998; Adhami *et al.* 2006). The low content of Al-P and Ca_2-P is due to high soil pH and $CaCO_3$ content in the soils. The plant unavailable forms of P (Ca_{10}-P, Ca_8-P and O-P) contributed 90 per cent of total inorganic phosphorus whereas plant available forms (Ca_2-P, Al-P and Fe-P) contributed only 10 per cent of total inorganic phosphorus which indicates that soil is deficient in available phosphorus. Such deficiency of P in the area is due to influence of different soil properties and the conventional crop management practices followed during cultivation (Jalali and Tabar 2011). The depth-wise distribution P fractions indicated that large amount of P fractions lies in the order of Ca_2-P<Fe-P<Al-P<O-P<Ca_8-P<Ca_{10}-P.

The plant available forms of P (Ca_2-P and Al-P) had significantly negative correlation with soil pH, EC and $CaCO_3$ whereas it was significantly positive relation with organic carbon. However, Fe-P is had significantly positive and correlation with soil pH and clay due to clay being rich in Fe ions. The plant unavailable forms of P (Ca_{10}-P, Ca_8-P and O-P) correlated significantly positive with soil pH, EC and $CaCO_3$ whereas, it had significant negative correlation with organic carbon. However, under alkaline environment, 2:1 layer silicates suffer congruent dissolution (Pal 2016) and hardly has any possibility for creation of positively charged hydroxides that can fix added P under existing semi-arid pedo-environment. Most of the P fractions in soils had significant correlation among each other which show available soil P pools is constantly replenished through action of dissolution or desorption of stable inorganic P compounds present in the soils (Tiessen and Moir 1993).

Conclusions

The foregoing results emphasise that a marked variation exists among the various inorganic P forms in pedons of Adan river basin which was based on soil depth, stage of soil weathering and soil physical and chemical properties. The dominance of Ca bound phosphate (Ca_{10}-P and Ca_8-P) in soils was due to the unweathered apatite mineral or long-term P fertilizer application. However, plant available of P forms was only found 10 per cent of total P indicates soils were deficient in available phosphorus. Therefore, proper P management is required for sustainable crop production and adequate soil fertility.

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