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Distribution and forms of phosphorus in some red soils of Chotanagpur plateau, West Bengal

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Abstract : Distribution and forms of phosphorus in Alfisols and associated soils along a toposequence in Chotanagpur plateau (AESR 12.3) were determined by sequential extraction methods and examined their relationships with soil characteristics. The P fractions followed the order of abundance as reductant soluble phosphate (109 mg kg^{-1}) > iron phosphate (40.7 mg kg^{-1}) > occluded phosphate (18.3 mg kg^{-1}) > calcium phosphate (18.2 mg kg^{-1}) > aluminium phosphate (14.3 mg kg^{-1}) and decreased with depth. There was significant variation in concentrations of total P content in forest soil (533 mg kg^{-1}) than rice soils. These soils have low concentrations of saloid – P (<1 per cent of total P) and showed strong relation with organic carbon (r = 0.50**) and total P (r = 0.65**).

Additional key words: *Inorganic P fractions, sequential extraction, Chotanagpur plateau*

Introduction

The distribution of various inorganic P fractions and their relative change under continuous fertilization to differ according to soil and crop condition (Agrawal *et al.* 1987; Vig *et al.* 2000). The relative solubility of inorganic soil phosphorus fractions governs the replenishment of the labile pool when it is depleted by removal of P by plants. However, determination of available soil phosphorus, conventional method appears to extract a portion of all the chemical forms of soil-P, having either higher solubility or high specific surface area. However, fractionation of inorganic soil phosphorus into total amount of each discrete chemical forms permits not only the precise estimation of chemical status of native soil-P but also the fate of applied phosphatic fertilizer with or without the effect of cropping (Chang and Jackson 1958).

Distribution of different forms of soil phosphorus in surface soils of rice-growing in West Bengal was reported by Khan and Mandal (1973). Tiwari (2002) reported inorganic phosphorus to be the dominant part of total soil phosphorus in rice-growing soils of West Bengal. Langmuana *et al.* (2012) reported the dominance of reluctant soluble phosphate and iron phosphate and less amount of saloid bound phosphate and calcium phosphate in rice-growing surface soils of red and lateritic zone of West Bengal. However, information on distribution and forms of phosphorus in soils of Chotanagpur plateau region West Bengal is meager and hence present investigation was undertaken in Belpahari block of Jhargram subdivision in Paschim Medinipur district, West Bengal.

Materials and Methods

The study area (22°35'36" to 22°39'51" N; 86°42'51" to 86°47'02" E) located at Belpahari block of Jhargram sub-division in Paschim Medinipur district, West Bengal falling under Chotanagpur plateau region (Hot Dry Subhumid Agro-Ecological Subregion, 12.3) (Table 1). The dominant rock type of the region is granite-gneiss associated undulating plains and isolated hillocks. The mean annual temperature is 25°C with mean annual summer temperature of 32°C and winter temperature of 20°C. The area receives annual rainfall of 1300-1500 mm. In general, the area qualifies for *ustic* soil moisture and *hyperthermic* soil temperature regime with length of growing period (LGP) of 150 to 180 days.

A toposequence with upper, mid and lower slope was selected and five pedons occurring on residual hillocks under forest (P1), paddy-growing rolling uplands (P2), moderately sloping uplands (P3), gently sloping uplands (P4) and gently sloping plain (P5) were selected for their phosphorus fractions in relation to soil properties in the Chotanagpur plateau. The morphological characteristics of the soils were recorded as per field descriptions (Soil Survey Division Staff 2000) and classified up to family level (Soil Survey Staff 2010).

Physical and chemical analyses were carried out as per standard procedures (Jackson 1973). Sesquioxide content of the soils (Fe_2O_3 and Al_2O_3) was determined by fusion and total phosphorus determined by perchloric acid digestion (Jackson 1973). The sequential extraction of inorganic soil phosphorus fractions were determined as per Chang and Jackson (1957) subsequently modified by Petersen and Corey (1966). 1.0 g of soil sample (in duplicate) was treated with 1.0 *N* NH_4Cl to remove easily soluble and loosely bound phosphorus (Saloid – P). The NH_4 – soil was successively extracted with neutral 0.5 (*N*) NH_4F, 0.1 *N* NaOH and 0.5 *N* H_2SO_4 for Al-P, Fe-P and Ca-P. The soil sample after extraction of Ca – P was subjected to dithionite – citrate reduction for determination of RS – P and subsequently extracted with 0.1 (*N*) NaOH for determining occluded – P.

Results and Discussion

Soil properties and classification

The site characteristics of the area and soil taxonomy have been given in table 1. The forest soils (P1) occurring on residual hillocks (15 to 30% slope) is dark brown, well drained and had clay (27 to 28%) of organic carbon (>2%), cation exchange capacity (8.1 to 11.4 cmol kg^{-1}), Fe_2O_3 (17.2 to 18 .8%) and Al_2O_3 (13 to 15 %) (Table 2). The rice-growing soils on rolling uplands (P2), have reddish brown to dark reddish brown matrix with irregular distribution of organic carbon (4.8 to 9.3 gkg^{-1}) and downward decrease in CEC from 16.8 to 10.4 cmol kg^{-1} with slight variations in Fe_2O_3 and Al_2O_3 content. The soils on undulating uplands (P3) have light yellowish brown to yellowish brown matrix with silty clay loam to clay texture. The soils on undulating uplands (P4) is moderate to slightly acid, brown to dark brown matrix with gradational increase of clay (24.5 to 47.1 %), CEC (15.9 to 25.8cmol kg^{-1}), Fe_2O_3 (15 to 17.2%) and Al_2O_3 (13 to 14.7%). The soils on flat to gently sloping lands (P5) are moderately acid with light yellowish brown to brownish yellow matrix with organic carbon (5.5 to 8.3 gkg^{-1}), gradational increase of clay (18.5 to 54.2%), CEC (8.2 to 18.8 cmol kg^{-1}) and depth inflections of Fe_2O_3 (15.3 to 17.3%) and Al_2O_3 (12.6 to 14.4%). These soils have low available phosphorus (2.1 to 3.0 $mgkg^{-1}$) due to high contents of Fe and Al oxides and low active clays. These soils have low to medium amount of available K (32 to 43 mg kg^{-1}).

Total P

The total phosphorus content differ widely among the soils (Table 3).The weighted mean for total P soils vary from 333.3 mg kg^{-1} (P2) to 533.2 mg kg^{-1} (P1). The decreasing total P along toposequence is indicative of acceleration of weathering intensity in rice soils (Agbenin and Tiessen 1995). The depth functions total P in the profiles decreased with increase in Fe and Al (r= -0.43*). The total P and contradicted the findings of McCullum (1996) that P increased with finer fractions in soils. The leaching of Fe and Al oxides at the time of puddling and flooding might have influenced total P content in soils.

Table 1. Site characteristics of the area and soil taxonomy

Pedon	Location	Lat. & longitude	Landform	Slope (%)	Elevation (m)	Drainage	Erosion	Land use
P1	Jhakadanga Jhargram Dist.Paschim Medinipur	22°37′51″ N; 86°41′21″ E	Residual Hillock	15-30	200	Somewhat excessively drained	Very severe	Forest (F1)
P2	Radhamohanpur Jhargram Dist.Paschim Medinipur	22°37′44″ N; 86°44′33″ E	Rolling uplands	4-16	155	Well drained	Severe	Cultivated paddy (C1)
P3	Jamboni Jhargram Dist.Paschim Medinipur	22°37′29″ N; 86°44′47″ E	Undulating uplands	3-8	142	Imperfectly drained	Moderate	Cultivated paddy (C1)
P4	Sandhyapara Jhargram Dist.Paschim Medinipur	22°36′38″ N; 86°45′28″ E	Undulating uplands	3-8	125	Moderately well drained	Moderate	Cultivated paddy (C1)
P5	Muriada Jhargram Dist.Paschim Medinipur	22°35′36″ N; 86°47′03″ E	Flat to very gently sloping plains	1-3	110	Imperfectly drained	Slight	Cultivated paddy (C2)

F1: Thin forest, sparse vegetation; C1: Cultivated single crop, C2: Cultivated double crop

Inorganic P fractions

The inorganic phosphorus content in forest soil (P1) is 220.5 mg kg^{-1} in the surface horizon which decreased to 193.6 mg kg^{-1} in C horizon with mean of 198.9 mg kg^{-1} (Table 3).The mean per cent of inorganic P of the total P is 37.3 in P1 but its increased to 63.2 per cent to 73 per cent (P4). Similar distribution of inorganic P fractions with respect to total P in rice-growing soils of West Bengal was also reported (Tiwari 2002).The depth functions of inorganic P in paddy soils is irregular and not correlated with any soil properties.

Table 2. Important morphological, physical and chemical characteristics of the soils

Horizon	Depth (m)	Colour (M)	Structure	pH (aq)	O.C. gkg^{-1}	Clay (%)	CEC cmolkg^{-1}	$NaHCO_3$-P	NH_4OAc-K	Fe_2O_3	Al_2O_3
								---------mgkg^{-1}---------		--------%-------	
P1 (Jhakadanga) : Loamy-skeketal Lithic Ustothent											
A	0.00-0.10	2.5YR3/4	f1sbk	6.6	23.5	27.7	11.4	2.7	32	18.8	13.1
AC	0.10-0.33	2.5YR3/4	f1sbk	6.1	22.2	28.3	8.1	1.7	38	17.2	15.2
C	0.33-0.45	2.5YR3/4	-	6.1	16.8	22.6	5.2	1.7	44	17.3	13.5
P2 (Radhamohanpur) : Fine-loamy Typic Haplustept											
Ap	0.00-0.15	7.5YR5/6	f1sbk	5.8	7.6	44.6	15.2	3.0	37	15.3	13.0
Bw1	0.15-0.35	2.5YR4/4	m2sbk	5.7	9.3	43.0	16.8	2.0	38	15.6	12.8
Bw2	0.35-0.55	2.5YR4/4	m2sbk	5.8	4.8	34.5	12.8	1.7	35	15.7	13.1
Bw3	0.55-0.81	2.5YR3/4	m3sbk	5.7	7.8	28.9	11.6	2.0	36	15.7	13.7
Bw4	0.81-1.05	2.5YR4/4	m2sbk	5.9	6.2	27.8	11.3	1.9	33	16.3	14.2
Bw5	1.05-1.50+	2.5YR4/2	-	5.9	5.1	25.8	10.4	1.0	37	17.0	15.5
P3 (Jamboni) : Fine Typic Haplustept											
Ap	0.00-0.15	10YR6/4	f1sbk	5.5	6.4	39.7	22.2	2.5	37	15.0	13.2
Bw1	0.15-0.38	10YR5/4	m2sbk	5.3	5.1	43.4	21.8	2.5	40	16.0	13.5
Bw2	0.38-0.55	10YR5/6	m2sbk	5.3	4.6	46.6	22.4	1.5	37	17.3	14.1
Bw3	0.55-0.75	10YR6/6	m2sbk	5.7	4.5	42.2	17.9	1.5	41	17.1	14.1
Bw4	0.75-1.07	10YR5/4	-	6.4	4.3	48.4	23.1	1.3	41	17.5	15.6
Bw5	1.07-1.50+	10YR5/4	-	6.5	3.3	49.7	24.6	2.0	40	17.6	15.2
P4 (Sandhyapara): Fine Oxyaquic Haplustalf											
Ap	0.00-0.10	10YR5/3	f1sbk	6.0	4.7	24.5	15.9	1.7	43	15.0	13.0
Bt1	0.10-0.27	10YR5/3	m2sbk	6.2	7.2	32.6	20.6	1.5	42	15.9	13.2
Bt2	0.27-0.44	10YR5/3	m2sbk	6.4	6.5	36.5	20.4	2.2	42	16.6	14.2
Bt3	0.44-0.71	10YR4/2	-	6.4	6.3	44.8	20.4	1.5	42	17.2	14.7
2Bt4	0.71-1.01	10YR5/2	-	6.1	6.6	43.5	25.6	2.1	43	15.8	13.1
2Bt5	1.01-1.50+	10YR4/2	-	6.5	5.0	47.1	25.8	2.5	36	15.9	12.5
P5 (Muriada) : Fine Fluventic Haplustept											
Ap	0.00-0.15	10YR6/4	f1sbk	5.5	5.5	18.5	8.2	2.1	35	16.2	15.2
Bw1	0.15-0.28	10YR6/6	f2sbk	5.8	7.6	43.5	13.6	1.6	41	15.3	13.7
Bw2	0.28-0.49	10YR6/4	m2sbk	5.7	8.3	38.5	12.6	1.7	38	15.6	14.3
Bw3	0.49-0.58	10YR6/4	m2sbk	5.7	6.6	48.9	13.4	1.6	35	16.5	14.4
Bw4	0.58-1.02	10YR6/4	-	5.7	7.3	54.2	18.8	1.4	44	17.3	12.6

Table 3. Inorganic P fractions and total P content in soils

Depth (m)	S-P	Al-P	Fe-P	Ca-P	RS-P	Occl-P	Total-inorganic P	Total-P
	………………………… (mg kg^{-1})…………………………							
P1 (Jhakadanga) : Loamy-skeketal Lithic Ustothent								
0.00-0.10	2.0	13.5	48.8	28.5	104	17.0	220.5	546.9
0.10-0.33	2.8	12.5	43.8	27.0	84	22.5	192.3	532.5
0.33-0.45	3.6	11.5	45.0	22.5	91	15.4	193.6	523.2
PWM-P*	2.8	12.5	45.2	26.1	90.3	19.4	198.9	533.2
	(0.5)	(2.3)	(8.5)	(4.9)	(16.9)	(3.6)		
	[1.4]	[6.3]	[22.7]	[13.9]	[45.4]	[9.8]		
P2 (Radhamohanpur) : Fine-loamy Typic Haplustept								
0.00-0.15	1.8	13.0	71.3	17.5	135	16.0	260.0	456.2
0.15-0.35	2.8	13.5	67.3	12.0	121	20.8	242.6	378.3
0.35-0.55	2.0	10.8	42.5	14.0	94	18.0	185.5	337.2
0.55-0.81	2.0	18.9	48.8	10.2	100	15.5	197.7	328.7
0.81-1.05	1.5	13.3	46.3	17.0	128	16.0	224.1	303.0
1.05-1.50+	1.3	18.3	45.0	18.0	141	18.5	245.6	289.4
PWM-P	1.8	15.4	49.8	15.1	122.3	17.6	226.9	333.3
	(0.5)	(4.6)	(14.9)	(4.5)	(36.7)	(5.3)		
	[0.8]	[6.8]	[21.9]	[6.7]	[53.9]	[7.8]		
P3 (Jamboni) : Fine Typic Haplustept								
0.00-0.15	2.8	13.0	51.3	7.1	127	21.3	226.8	386.9
0.15-0.38	2.0	15.1	46.0	7.5	122	15.0	210.7	379.4
0.38-0.55	1.3	13.5	40.0	6.8	112	16.5	195.2	315.6
0.55-0.75	1.3	14.5	40.5	11.0	113	22.0	205.3	322.5
0.75-1.07	1.5	15.8	32.5	15.5	119	20.8	206.5	307.5
1.07-1.50+	1.3	16.8	33.7	21.0	137	26.8	238.3	287.5
PWM-P	1.6	15.3	38.7	13.4	123.8	19.5	216.8	323.6
	(0.5)	(4.7)	(12.0)	(4.1)	(38.3)	(6.0)		
	[0.7]	[7.1]	[17.9]	[6.2]	[57.1]	[9.0]		
P4 (Sandhyapara: Fine Oxyaquic Haplustalf								
0.00-0.10	2.5	13.3	32.6	15.8	129	23.8	220. 3	365.5
0.10-0.27	2.0	11.3	32.5	20.5	115	20.8	205.1	329.1
0.27-0.44	1.3	11.5	31.5	18.0	117	20.0	205.3	296.8

0.44-0.71	1.3	12.5	30.7	16.2	120	23.0	206.3	293.8
0.71-1.01	1.3	14.0	33.8	16.0	124	20.7	210.6	287.1
1.01-1.50+	1.3	16.3	32.7	22.0	130	20.3	224.4	265.1
PWM-P	1.5	13.8	32.4	18.7	123.8	21.1	213.7	292.2
	(0.5)	(4.7)	(11.1)	(6.4)	(42.4)	(7.2)		
	[0.7]	[6.5]	[15.2]	[8.8]	[57.9]	[9.9]		
P5 (Muriada) : Fine Fluventic Haplustept								
0.00-0.15	2.5	15.3	39.8	23.5	106	15.5	206.2	344.4
0.15-0.28	2.5	12.0	38.8	26.5	84	17.0	183.3	274.4
0.28-0.49	2.0	10.3	40.0	20.5	80	15.0	170.9	271.9
0.49-0.58	1.3	14.8	36.3	15.0	88	13.3	171.5	376.9
0.58-1.02	1.3	16.5	35.0	12.0	90	12.0	170.8	262.5
PWM-P	1.8	14.3	37.3	17.6	89.4	13.9	177.7	279.3
	(0.6)	(5.1)	(13.4)	(6.3)	(32.0)	(5.0)		
	[1.0]	[8.0]	[21.0]	[9.9]	[50.3]	7.8]		
	1.9	**14.3**	**40.7**	**18.2**	**109.9**	**18.3**	**206.8**	**352.3**
	(0.5)	**(4.1)**	**(11.6)**	**(5.2)**	**(31.2)**	**(5.2)**		
	[0.9]	**[6.9]**	**[19.7]**	**[8.8]**	**[53.1]**	**[8.8]**		

S-P:Saloid phosphate; Al-P:Aluminium phosphate; Fe-P:Iron phosphate; Ca-P:Calcium phosphate; RS-P:Reductant Soluble phosphate; Occl-P: Occluded phosphate; *PWM-P - Profile Weighted Mean phosphorus
Figures within ( ) indicates per cent to total P.
Figures within [ ] indicates per cent to total inorganic P.

The higher content of RS-P (89.4 mgkg^{-1} to 123 mgkg^{-1}) might be due to the presence of high content of Fe_2O_3, Al_2O_3 and clay (Mandal 2007; Lakshminarayana 2007). In general, rice-growing soils had higher content of PS-P than double the forest soils. Next to RS-P; Fe-P, Ca-P, occluded P and Al- P forms are dominant in these soils. The mean concentrations of Fe-P forms is in decreasing order as 49.8 mgkg^{-1} in P2 > 45.2 mgkg^{-1} in P1 > 38.7 mgkg^{-1} in P3 > 37.3 mgkg^{-1} in P5 and 32.4 mgkg^{-1} in P4. The mean Ca-P concentration in P3 is 13.4 mgkg^{-1} with gradual increase with depth (Table 3). The P2 had Ca-P (mean 15.1 mgkg^{-1}), occluded - P (mean 17.6 mgkg^{-1}) and Al-P is 15.4 mgkg^{-1} respectively. The overall mean of Fe - P (40.7 mgkg^{-1}) and A1-P (14.3 mgkg^{-1}) contributed 11.6% and 4.1% of total P make up in the available pool of soil-P. The he close association of Al - P and Fe - P with hydroxides of iron (15 to 18%) and aluminium (12 to 16%) might be due to the possible replacement of hydroxyl groups from structural Al atoms and linkage of P with Ca on exchange complex , forming a clay - Ca - PO_4 or oxide – Ca - PO_4 type linkage (Rokima and Prasad 1991). The mean Ca - P in rice soils is less than 10% of total P and less than 5% of inorganic P in P1, P2 and P3. The distribution of P fractions followed in the order Fe-P > Ca-P ˜ Occluded - P > Al-P > Saloid P which in agreement with the finding of Baskar *et al.*(2000). The saloid - P in pedons showed decreasing trends except in P1 and P2 (Table 3). The low concentrations of saloid-P in soils (mean of 0.6 to 1.8 mgkg^{-1}) soils might be due to presence of high P fixation and also due to transformation of soluble P forms into less soluble forms with time (Sheela 2006). The saloid - P is strongly related with organic carbon (r=0.50**) and negatively related with clay (r = 0.54**) and total P (r=0.65**).

Conclusions

The sequential extraction of various forms of phosphorus in rice-growing soils of Chotanagpur plateau, West Bengal showed 63 to 73 per cent of inorganic P fraction of the total P in rice soils as against 37 per cent in forest soil. Among inorganic fractions, reductant soluble - P was dominant over Fe - P , Ca-P, Occluded - P and Al-P. The low concentrations of saloid - P (less than 1 per cent of total P) was strongly related with organic carbon and total P in these soils.

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