



Forms of Phosphorus in Some Acidic Entisols of Subtropical Eastern India

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Authors' contributions

This work was carried out in collaboration between all authors. Authors DS and PM designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors DS and SR performed the analyses and the statistical analysis of the study. Author AKS managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2017/36408

Editor(s):

(1) Kursat Korkmaz, Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Ordu University, Turkey.

Reviewers:

(1) Shaon Kumar Das, National Organic Farming Research Institute, India.

(2) Aweng Eh Rak, Universiti Malaysia Kelantan, Malaysia.

Complete Peer review History: <http://www.sciencedomain.org/review-history/21441>

Short Communication

Received 27th August 2017

Accepted 9th October 2017

Published 17th October 2017

ABSTRACT

Information about the phosphorus (P) forms in soils of *Terai* agro-ecological region of Cooch Behar (where P fertilizers have been applied for a long time), and their influence on the availability of P in soils is meagre. A study was undertaken to evaluate the status of different P forms in twenty five soils (0-0.15 m; acidic Entisols) collected from rice growing areas spread over the district of Cooch Behar, West Bengal, and their relationships with salient soil properties. Results reveal that total inorganic phosphorus (TIP) as the predominant form constituted 78.47% of the total phosphorus (TP) on average, and maintained equilibrium with TP and available phosphorus (AP) in these soils. Significant positive correlation of AP (Bray-1 extractable) with organic phosphorus (OP) and organic carbon (OC) content suggests reversible association between extractable P and organic matter, and further indicates non-stabilization of phosphorus-organic matter complexation in the soils (Entisols) studied.

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Keywords: P forms; equilibrium; extractable P; non-stabilization; complexation; Entisols.

1. INTRODUCTION

Phosphorus (P) is the most important essential element in plant nutrition, next to nitrogen. Although P is abundant in many soils, paradoxically, it is a major critical nutrient for plant growth because of its least solubility in solution phase and high inaccessibility to plant roots for uptake [1]. The total P content in Indian soils is reported to vary from 44 mg kg⁻¹ to more than 3500 mg kg⁻¹; however, for most agricultural soils, it ranges within the limit of 120 to 2166 mg kg⁻¹ [2]. Soils developed on granite gneiss generally contain the highest, while those on quartzite group of minerals usually are lowest in total P [3]. Total P hardly shows any correlation with available P, and thus, it is seldom considered in assessment of soil fertility, whereas inorganic P as the predominant fraction, is the major contributor of P to the growing plants and generally contributes 54 to 84% of the total P, and the share of organic P varies from 16 to 46% in Indian soils [4]. The chemistry of P in soil is considered very complex due to the processes it undergoes: solubilization, insolubilization, sorption, and desorption [5]. Phosphorus bound to aluminium (Al-P), iron (Fe-P), and calcium (Ca-P) constituting the major active forms of soil inorganic P, and Al-P and Fe-P as more abundant in acid soils have been suggested by several workers [6-8]. Transformation of inorganic P forms from Ca-P to Al-P and sesquioxide bound P as the weathering proceeds from younger to older age, and variation in P fraction as a function of pedogenic manifestation, stage of soil development and age of soils have also been documented [9,10].

Soil texture is considered as one of the important characteristics influencing P reserves and equilibrium of its different forms. Texture has its impact on P dynamics and its availability as consequences of its mineral physicochemical properties, its influence on phosphate adsorption-desorption-diffusion processes, and through soil organic matter (SOM) mineralization-immobilization by microbial activity [11]. Although, P in its all forms is retained at higher level in fine textured soils than in coarse ones, P forms in particle size fractions showed different tendencies: in the fine fraction more stable organic P (Po) and the more available P (Pi); in the coarse fraction (different sizes of sand) labile

or moderately labile Po, with the presence of Pi in the bigger minerals, presumably with less possibility to transform into available form in the short term [12]. Nutrients including P stored in the coarse particle fractions of surface soil layers are reportedly more sensitive than those retained in the fine fraction to soil recovery [13]. Precise information on different P forms, their relative proportions and associations with soil characteristics is of paramount importance in decision making in P fertilizer practice and effective P management for crop production as well. This research reports the results of different forms of P in some acidic Entisols under high rainfall region and their relationships with salient soil properties.

2. MATERIALS AND METHODS

2.1 Site Selection and Soil Sampling

Twenty five representative soil samples (0-0.15 m) were collected from different rice fields across the Cooch Behar (26°19'N, 89°23'E; 43 m above mean sea level) district located in eastern Sub-Himalayan plains and representing the *Terai* agro-ecological zone of West Bengal in subtropical eastern India. The climate of the zone is subtropical and perhumid in nature with moderate temperature in summer, cold in winter, and monsoonal rainfall. The area receives a mean annual rainfall of 3113.2 mm, about 80% of which occurs between June to October; the mean maximum and minimum air temperatures are recorded as 29.7°C and 18.8°C, respectively (average of 15 years data: 2001-2015). After collection of sub-samples from 5 to 6 uniform cores for each location, all stubbles, residues, root biomass and extraneous substances were removed and then sub-samples of individual site were mixed together thoroughly to form one composite soil sample for each location. Composite soil samples were air dried at room temperature in the laboratory, ground in wooden mortar, sieved through a 2 mm nylon mesh and preserved with care in covered polythene containers till analyses were done. The sampling area covered seven blocks of Cooch Behar district, viz., Cooch Behar – 1 (Sl. No. 1-3), Cooch Behar – 2 (Sl. No. 4-9), Dinhata – 2 (Sl. No. 10-13), Mathabhanga – 1 (Sl. No. 14-16), Mathabhanga – 2 (Sl. No. 17-19), Toofanganj – 2 (Sl. No. 20-23), Toofanganj – 1 (Sl. No. 24-25).

2.2 Soil Analysis

pH of the soil suspension (1:2) was measured potentiometrically by using a glass electrode-pH meter [14]. The particle size analysis was determined by following the sedimentation procedure with hydrometer as described by Bouyoucos [15]. The rapid titration method of Walkley and Black [16] was used for the determination of organic carbon of the soil samples [14]. For exchangeable bases, the soil samples were extracted by neutral normal ammonium acetate extractant (in a 1:25 ratio), and exchangeable Ca^{2+} and Mg^{2+} were determined by EDTA (0.005 M) titrimetric method [17], whereas exchangeable K was measured by flame photometry [18]. For exchangeable acidity ($\text{H}^+ + \text{Al}^{3+}$), soil extracted with 1 M KCl in a soil:extractant ratio of 1:15 was titrated with 0.1 M NaOH using phenolphthalein as an indicator [19]. Effective cation exchange capacity (ECEC) was indirectly measured by summation of exchangeable bases and exchangeable acidity [20]. For determining available P, the soil samples were extracted with Bray-1 extractant (0.03 N NH_4F and 0.025 N HCl solution) in soil:extractant ratio of 1:10 as described by Bray and Kurtz [21], and P from the soil extract was measured colorimetrically (at 880 nm) by ammonium molybdate – ascorbic acid blue colour method of Watanabe and Olsen [22] as outlined by Page et al. [23]. The total P was extracted from the soil samples by a pre-treatment with nitric acid followed by perchloric acid digestion [14], and P in the digest was estimated using the same procedure as in case of available P. For determining Organic P, two sets of 1 g soil were weighed, one in a porcelain crucible and the other in a 100 ml centrifuge tube. The crucible was placed in a muffle furnace at 550°C for 1 hr. followed by shaking of both sets with 50 ml of 1 N H_2SO_4 for 16 hrs. Suitable aliquot was drawn, 5 drops of 0.25% *p*-nitrophenol were added and neutralized with 5 N H_2SO_4 , and P content was measured colorimetrically by the method prescribed by Watanabe and Olsen [22]. Organic P was worked out from the difference in P content between the ignited and unignited soil sample [24]. Total inorganic P was indirectly estimated by subtracting total P and organic P.

2.3 Statistical Analysis

Pearson correlation test was used to work out the degree of association among the variables by using MS Excel 2013.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Properties of the Experimental Soils

Some relevant physicochemical properties of the soils used in the study are presented in Table 1. The soils are acidic in reaction with pH ranging from 4.73 to 5.69. The organic carbon content varied widely among the soils, and ranged from 5.04 to 11.01 g kg^{-1} with a mean of 7.26 g kg^{-1} . Exchangeable acidity (1 M KCl extractable) differs from 0.44 to 1.53 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ with an average of 0.93 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$. Exchangeable bases (Ca^{2+} and Mg^{2+}) ranged from 0.75 to 4.13 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$. Soils are sandy loam in texture with a relative proportion of 43.94 to 67.64% sand, 22.74 to 42.38% silt, and 7.44 to 15.56% clay. Out of 25 number of samples tested, more than 80% contained less than 14% clay, while 64% samples had more than 30% silt.

3.2 Total Phosphorus

The Total P (TP) content of our soils varied from 241.61 to 1463.09 mg kg^{-1} with an average value of 612.79 mg kg^{-1} (Table 2). This form of P in the soil indicates its reserves and depends primarily on the parent material and management practices. Soils developed on the parent material rich in P contain higher amount of TP, and it is generally highest in soils derived from granite gneiss [3]. Continued long-term application of P fertilizers in the soil and low crop use efficiency can lead to accumulate large reserves of residual P in surface layers [25]. In majority of crop lands of the study area, rice-based multiple cropping and addition of varied quantities of P fertilizers particularly in winter season crops have been practiced over the years. The fairly high total P content in surface layers (0-0.15 m) of soil in our study is attributed partly to the continuous addition of P fertilizers in plow layer. The results are in close conformity with the findings of Mondal et al. [26] for acid soils in rice-based areas and of Malakar et al. [27] in tea garden areas of West Bengal. Correlation coefficients between TP and soil properties showed no significant association between the former and latter ones (Table 3). The correlation analysis further revealed that TP had significant positive relations with available P, total inorganic P, and organic P content of soils suggesting that release of P in different pools is depended on total soil P [28].

Table 1. Physicochemical properties of soils

Sl. No.	Soil location	pH	Organic carbon (g kg ⁻¹)	Soil texture			ECEC [cmol(p ⁺)kg ⁻¹]	Exch. acidity [cmol(p ⁺)kg ⁻¹]	Exch. bases [cmol(p ⁺)kg ⁻¹]
				Sand (%)	Silt (%)	Clay (%)			
1	Akrarhat	5.12	6.72	54.46	30.80	14.74	3.67	1.31	2.36
2	Atialiguri	5.34	7.01	51.94	34.80	13.26	3.19	1.15	2.04
3	Sipaituri	5.13	9.15	53.94	34.26	11.80	3.23	0.80	2.43
4	Baudia Danga	4.73	7.73	47.94	38.74	13.32	4.67	1.00	3.67
5	Baro Rang Rash	4.90	5.04	51.52	36.74	11.74	3.31	0.82	2.49
6	W. Ghughumari	5.23	6.42	55.40	32.98	11.62	2.95	1.02	1.93
7	Panishala	5.30	6.22	48.94	36.80	14.26	3.41	1.13	2.28
8	Takoamari	4.96	5.61	55.88	30.80	13.32	2.84	0.72	2.12
9	Natkobari	5.52	6.83	53.70	32.98	13.32	4.82	0.69	4.13
10	Maghfala	4.97	6.06	49.76	34.98	15.26	3.69	1.53	2.16
11	Rasik Bill	5.43	6.54	49.40	38.98	11.62	3.67	0.64	3.03
12	Manabari	5.40	7.11	57.46	28.80	13.74	3.69	0.62	3.07
13	Bairagirhat	5.12	6.76	59.76	26.74	13.50	3.24	1.22	2.02
14	Gobindapur	4.78	6.53	47.76	40.74	11.50	3.33	1.06	2.27
15	Bhaberhat	5.44	6.32	55.58	33.10	11.32	3.90	0.44	3.46
16	Baman Hat	5.06	6.05	60.40	25.16	14.44	3.47	1.02	2.45
17	Durgabari	5.13	7.13	43.94	42.38	13.68	3.57	0.72	2.85
18	Boxirhat	5.19	11.01	59.64	24.80	15.56	4.13	1.31	2.82
19	Ghorarpar	5.69	5.44	61.64	24.92	13.44	4.51	0.85	3.66
20	Choto Rang Rash	5.13	7.12	55.88	32.62	11.50	2.98	1.13	1.85
21	Shibpur	5.36	8.92	61.94	26.80	11.26	4.37	0.71	3.66
22	Taterkuthi	5.04	6.51	67.64	24.92	7.44	1.96	1.21	0.75
23	Patkirpar	5.22	10.12	63.70	22.74	13.56	3.16	0.64	2.52
24	Panigram	5.41	10.62	57.88	30.56	11.56	3.81	0.76	3.05
25	Nayarhat	4.74	8.61	61.88	26.68	11.44	3.63	0.90	2.73
Range		4.73-5.69	5.04-11.01	43.94-67.64	22.74-42.38	7.44-15.56	1.96-4.82	0.44-1.53	0.75-4.13
Mean		5.17	7.26	55.52	31.75	12.73	3.57	0.93	2.63
SD		0.25	1.59	5.78	5.52	1.72	0.63	0.27	0.74

Table 2. Different forms of P in soils

Sl. No.	Soil location	Total P (mg kg ⁻¹)	Total inorganic P (mg kg ⁻¹)	Organic P (mg kg ⁻¹)	Available P (mg kg ⁻¹)
1	Akrarhat	304.25	165.81 (54.50)	138.44 (45.50)	5.34 (1.76)
2	Atialiguri	393.74	249.12 (63.27)	144.62 (36.73)	5.8 (1.47)
3	Sipaituri	248.32	121.87 (49.08)	126.45 (50.92)	6.5 (2.62)
4	Baudia Danga	241.61	135.87 (56.24)	105.74 (43.76)	7.19 (2.98)
5	Baro Rang Rash	407.16	339.21 (83.31)	67.95 (16.69)	9.51 (2.34)
6	W. Ghughumari	639.82	472.31 (73.82)	167.51 (26.18)	10.21 (1.60)
7	Panishala	516.78	445.56 (86.22)	71.22 (13.78)	10.44 (2.02)
8	Takoamari	798.66	679.47 (85.08)	119.19 (14.92)	13.69 (1.71)
9	Natkobari	384.79	319.02 (82.91)	65.77 (17.09)	15.08 (3.92)
10	Maghfala	561.52	383.1 (68.23)	178.42 (31.77)	16.47 (2.93)
11	Rasik Bill	492.17	384.25 (78.07)	107.92 (21.93)	19.95 (4.05)
12	Manabari	662.19	580.43 (87.65)	81.76 (12.35)	19.95 (3.01)
13	Bairagirhat	378.08	209.48 (55.41)	168.6 (44.59)	20.65 (5.46)
14	Gobindapur	897.09	711.04 (79.26)	186.05 (20.74)	21.58 (2.41)
15	Bhaberhat	422.82	356.32 (84.27)	66.5 (15.73)	22.27 (5.27)
16	Baman Hat	416.11	339.08 (81.49)	77.03 (18.51)	22.51 (5.41)
17	Durgabari	454.14	360.39 (79.36)	93.75 (20.64)	26.45 (5.82)
18	Boxirhat	489.93	351.49 (71.74)	138.44 (28.26)	27.15 (5.54)
19	Ghorarpar	521.25	391.53 (75.11)	129.72 (24.89)	27.84 (5.34)
20	Choto Rang Rash	888.14	791.12 (89.08)	97.02 (10.92)	29.93 (3.37)
21	Shibpur	1096.2	878.54 (80.14)	217.66 (19.86)	35.03 (3.20)
22	Taterkuthi	673.38	569.82 (84.62)	103.56 (15.38)	38.05 (5.65)
23	Patkirpar	724.83	541.33 (74.68)	183.5 (25.32)	45.94 (6.34)
24	Panigram	1243.85	1004.75 (80.78)	239.1 (19.22)	45.94 (3.69)
25	Nayarhat	1463.09	1239.98 (84.75)	223.11 (15.25)	52.67 (3.60)
Range		241.61-1463.09	121.87-1239.98	65.77-239.10	5.34-52.67
Mean		612.79	480.84 (78.47)	131.96 (21.53)	22.25 (3.63)
SD		13.30	51.91	276.50	308.12

Figures in parentheses represent the percent contribution to Total P

Table 3. Correlation matrix between physicochemical properties⁺ and different forms of P⁺⁺ in soils of Cooch Behar district

	pH	OC	Sand	Silt	Clay	ECEC	EA	EB	AP	OP	TIP	TP
pH	-											
OC	0.047	-										
Sand	0.183	0.302	-									
Silt	-0.213	-0.329	-0.955**	-								
Clay	0.071	0.039	-0.300	0.002	-							
ECEC	0.324	0.188	-0.195	0.068	0.437*	-						
EA	-0.386	-0.084	-0.029	-0.052	0.264	-0.236	-					
EB	0.416*	0.190	-0.155	0.076	0.275	0.935**	-0.566**	-				
AP	0.036	0.509**	0.609**	-0.530**	-0.346	-0.056	-0.213	0.030	-			
OP	-0.150	0.538**	0.287	-0.272	-0.096	0.003	0.170	-0.060	0.508**	-		
TIP	-0.116	0.295	0.361	-0.252	-0.405*	-0.125	-0.197	-0.034	0.756**	0.550**	-	
TP	-0.129	0.355	0.372	-0.272	-0.379	-0.112	-0.148	-0.041	0.764**	0.662**	0.990**	-

+ OC - Organic carbon, ECEC - Effective cation exchange capacity, EA - Exchangeable acidity, EB - Exchangeable bases;

++ AP - Available P, OP - Organic P, TIP - Total inorganic P, TP - Total P;

* Significant at 5% level, ** Significant at 1% level

3.3 Total Inorganic Phosphorus

The total inorganic P (TIP) content estimated by the difference between the total P and organic P varied widely among the soils from 121.87 to 1239.98 mg kg⁻¹ with a mean of 480.84 mg kg⁻¹, and it constituted 49.08 to 89.08% with an average of 78.47% of the total P (Table 2), indicating thereby the occurrence of major portion of P as inorganic form in these soils. The wide range of variation in TIP observed in the soils might be due to the variability in the composition of parent materials and weathering coupled with fertilizer application [29]. Similar results showing TIP as the predominant P form comprising 63 to 73% of total P in rice growing acidic soils of Chotanagpur Plateau, West Bengal and 75% of the total P on average in acid soils of Mizoram state in eastern India have been reported by Sarkar et al. [30] and Laxminarayana [31], respectively. Among the soil properties, clay content was negatively and significantly correlated with the total inorganic P ($r=-0.405^*$) (Table 3). P present in different forms is closely associated with soil fractions and texture determines P reserves and equilibrium of its different forms in soils [12]. Transformation of P from Ca-P to Al-P and Fe-P as weathering proceeds from younger (Entisols, Inceptisols) to older stage (Oxisols) was reported by Tiessen et al. [32]. Further that relative dominance of Al- and Fe- bound inorganic P fractions over Ca-bound phosphates in the acidic soil at the active stage of its weathering was observed by Mishra [29]. It is imperative that presence of hydrated Al and Fe compounds in soil finer fractions (clay, silt) are apt to provide more active sites for irreversible P fixation rendering its less extractability in soil. Moreover, separate studies with fifty soil (0-0.15 m) samples from different identified series in acidic alluvial (Entisols) soils of West Bengal also indicated relative dominance of both amorphous and crystalline Al and Fe compounds (oxalate- and CBD-extractable) with low content of Ca-bound phosphates [33]. Considering all these above, significant negative correlation observed between clay separate and total inorganic P for soils in our study is ascribed to the influence of amorphous and/or crystalline Al and Fe oxide and hydroxide group of minerals in finer fractions of soil separates on the distribution of inorganic phosphates.

3.4 Organic Phosphorus

The organic P (OP) content in soils ranged between 65.77 and 239.0 mg kg⁻¹ with a mean of

131.96 mg kg⁻¹ (Table 2). The share of OP to total P varied from 10.92 to 50.92% with an average of 21.53%. The percent contribution of OP to TP is well corroborated with that obtained for acid soils of West Bengal by Adhikari and Si [34] and Lungmuana et al. [7]. Organic P was significantly and positively correlated with OC ($r=0.538^{**}$) status (Table 3) indicating that organic matter is the potent source of organic P fraction in soils used in this study.

3.5 Available Phosphorus

The available P (AP) status ranged from 5.34 to 52.67 mg kg⁻¹ with its average value of 22.25 mg kg⁻¹ soil (Table 2). The percent contribution of AP to TP appeared as only 3.63% on average and varied within the limit between 1.47 and 5.82%. Out of twenty five soil samples tested, almost 50 percent had the AP status below the critical crop response limit (< 20 mg kg⁻¹ soil) [35], and fell in the probable response class with respect to P status, and the rest 50 percent of samples in the category of non-responsive to P fertilizer application. Similar results of wide variability of AP (Bray-1 extractable) in acidic Inceptisols have been reported by Patiram et al. [6]. Data presented in Table 3 reveal strong interrelations among different forms of P themselves: AP with TP ($r=0.764^{**}$), TIP ($r=0.756^{**}$) and OP ($r=0.508^{**}$) suggesting that all forms are in equilibrium with each other and further that soils having higher TIP maintain higher AP content. The significant positive correlations of AP with OP and OC ($r=0.509^{**}$) clearly indicate that P availability in these soils is largely influenced by organic matter content. Tomar [36] reported in his studies on organic matter decomposition with P release that during decay process, a large part of inorganic P gets converted into organic P compounds at the initial stage of decomposition but later on with the exhaustion of energy source, mineralization of organic P occurs.

4. CONCLUSION

The results showed that total inorganic P (TIP) was the predominant P form, comprising 49.08 to 89.08% of the total soil P. Strong interrelations among different P forms suggest equilibrium is maintained with each other, and P release into various forms is dependent upon total P content in soils. Significant and positive correlation of available P (AP) with organic carbon (OC) and organic P (OP) indicates reversible association between phosphorus and organic matter, and non-stabilization of phosphorus-organic matter complexation in soils under study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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