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Phosphorus Fractionations in Ganges Tidal Floodplain Soil of Bangladesh

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ABSTRACT

The present investigation aimed to evaluate different fractions of P of Ganges tidal floodplain soils of Bangladesh in terms of plant availability in the selected soil. The samples were analyzed for solution P, labile pool, alkali-extracted inorganic pool, organic pool, acidic pool and residual P. The soil solution P in the tested soils ranged from 0.03 to 0.11 mg L^{-1}. The concentration of 0.5M $NaHCO_3$ extracted P had a range of 8-34 mg kg^{-1}. Dilute NaOH extracted inorganic P had a range of 25-59 mg kg^{-1}. NaOH extracted organic P ranged from 334 to 542 mg kg^{-1} and acid extracted P represented from 140 to 443 mg kg^{-1}, respectively. Residual P of the tested soils showed a concentration of 104-262 mg kg^{-1}. On average of the 12 soils, the relative concentration of solution P was 0.01%, $NaHCO_3$ P was 3.2%, NaOH-Pi was 6.8%, NaOH-Po was 44.6%, acid pool was 27.3% and residual fraction was 18.1%. Different P pools showed strong correlation either with sand, silt, clay, electrical conductivity, pH(H_2O), ΔpH, organic carbon or extractable Fe content. The tested Ganges tidal floodplain soils demonstrated wide variation in the relative proportion of different P pools.

Key words: Tidal floodplain, solution P, inorganic P, organic P, acid P, labile P, stable P, residual P.

INTRODUCTION

Ganges tidal floodplain soils spread widely in Bangladesh and India. The Ganges tidal floodplain soils below 24°30" north latitude covering about 7,115 square miles, which is about 85 percent of the total area of the three coastal districts (greater Khulna, Barisal and Patuakhali) of Bangladesh. Regular tidal inundation throughout the April-October in each year makes the coastal zone different from that of the inland. Single rice, rice-lathyrus and rice-rice are the dominant cropping systems in the zone. The soils in the tidal flooded ecosystems receive no or little P fertilizer application for long time, because the rice showed little response to applied P fertilizer even during the period of green revolution. The tidal flooded soils received little attention for its soil fertility evaluation (Saleque *et al.*, 2004), particularly for P. Because of great diversity in tidal deposits and cropping history, tidal flooded soils may have wider variation in soil P availability and fractions of P. Hedley *et al.* (1982) proposed a modified P fraction scheme, which sequentially extracts most available P first and progressively less available P with each subsequent extraction. The P pools of Hedley's method are resin-P, NaOH-Pi (NaOH extracted inorganic P), NaOH-Po (NaOH extracted organic P), acid-P and residual P. Saleque and Kirk (1995) applied Hedley's method of P fraction for lowland rice soil and found it successful by recovering about 98% of the applied P. Sui *et al*. (1999) modified Hedley's method of P fraction by avoiding resin strip. The fractions of P in this method are: water soluble P, labile P (extracted by $NaHCO_3$), NaOH-Pi, NaOH-Po, acid-P and residual P. Saleque *et al*. (2004) applied Sui's method for P fractionation scheme of a rice soil from a long-term experiment in rice-rice cropping system. Phosphorus fractionation studies in Bangladesh are not much reported, however, Shil (2002) observed P fraction in soils Sreepur, Gazipur and Satkhira and Islam *et al*. (2010) studied P fraction in Acid Piedmont soils in north-east of Bangladesh.

Phosphorus fractionation of tidal flooded soils and the distribution of different P pools in soils need to be understood for designing P fertility management. Therefore, the present research work was carried out to determine the distribution of soil P fractions in selected rice growing Ganges tidal floodplain soils.

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MATERIALS AND METHODS

Twelve surface (0-15 cm) soil samples used for the fractionation study were collected from cultivated rice fields in January to March 2008 after T. Aman harvest. The selected soil sampling sites were of different upazilas (Dumki, Kalapara, Amtali, Wuzirpur, Gouranadi, Borhanuddin, Lalmohan) of Patuakhali, Borguna, Barisal and Bhola districts. According to USDA soil taxonomy, these have been classified as Typic Edoaquept, Typic Haplaquept, Aeric Haplaquept, Thapto-Histic Haplaquept, Aquic Eutrochrept and Histosols. For the convenience of discussion, the 12 soils are referred to as soil 1 through soil 12 (Table 1). The collected soil samples were air-dried and ground to pass a 2-mm sieve and then mixed to form a composite sample.

Table 1. Some selected properties of the studied soils.

Soil no.	Sand (%)	Silt (%)	Clay (%)	EC (dS/m)	pH (H_2O)	pH (KCl)	ΔpH	CEC (meq/100 g soil)	O.C (%)	Avail. P (ppm)	Avail Fe(μg/g soil)
Soil 1 (Barisal clay, pH 6.2)	3.30	28.16	68.54	1.45	6.20	4.58	-1.62	16.5	2.28	4.1	158.95
Soil 2 (Jhalokathi clay, pH 5.9)	3.33	38.17	58.50	2.50	5.90	4.71	-1.19	14.0	2.69	5.2	118.75
Soil 3 (Bholasilty clay)	4.26	54.27	41.47	6.15	5.80	4.94	-0.86	12.4	2.45	10.7	131.96
Soil 4 (Nilkamalsilty clay loam)	4.32	70.95	24.73	7.60	7.00	7.75	0.75	9.4	0.71	22.6	16.33
Soil 5 (Ramgatisilty clay loam)	8.48	54.67	36.85	1.16	7.36	6.25	-1.11	12.1	1.40	5.3	98.44
Soil 6 (Katra silt loam)	8.00	68.72	23.28	1.23	7.49	5.97	-1.52	10.0	1.43	16.5	79.21
Soil 7 (Barisal clay, pH 6.0)	7.13	40.02	52.85	1.26	5.99	3.76	-2.23	13.4	0.74	4.3	253.10
Soil 8 (Jhalokathi clay, pH 5.7)	7.81	37.27	54.92	1.23	5.70	7.04	1.34	15.5	2.49	6.1	248.43
Soil 9 (Hartasilty clay loam)	16.87	55.67	27.46	2.11	6.30	5.27	-1.03	15.6	5.14	8.5	157.73
Soil 10 (Satlasilty clay)	19.50	48.32	32.18	4.18	5.90	4.82	-1.08	15.4	10.86	6.0	494.74
11. Sara silty clay	10.81	45.29	43.90	0.98	6.10	4.68	-1.42	14.9	2.07	8.3	258.76
12. Barisal clay (pH 6.6)	3.02	41.47	55.51	1.05	6.60	5.38	-1.22	16.3	2.91	19.9	185.42

Soils were analyzed in Soil Science laboratory and Central laboratory of Patuakhali Science and Technology University during January 2008 to April 2008. The sand, silt and clay content of soils were determined using the hydrometer method (Black *et al*., 1965). Soil pH_{H2O} was measured in a 1:2.5 soil water ratio, using glass electrode pH meter method (Jackson, 1958), and the pH_{KCl} was also measured by using a 1.0 M KCl in a similar manner as in pH_{H2O} determination. Organic carbon of soil was determined by Walkley and Black wet digestion method as outlined by Nelson and Sommers (1982). Mehlich-3 (M3) extractable P was determined by using the Mehlich-3 extraction method (Mehlich, 1984). Available Fe was determined by sodium dithionate-citrate system buffered with sodium bicarbonate (Mehra and Jackson, 1960). Table 1 presents the physical and chemical characteristics of the tested initial soils.

Phosphorus fractionation

The experiment was conducted in a complete randomized block design with three replications. One g air-dried soil was taken in 50 ml centrifuge tube for P fractionation study. One run of the analysis was considered as one replication.

Fractionation of inorganic P was performed on each soil following Saleque *et al*. (2004) method modified from P fractionation scheme of Sui *et al*. (1999).

The following soil P fractions were measured in sequence:

i) Solution P, by shaking 1 g soil in 30 ml of 0.05M $CaCl_2$ for 16 hours, centrifuging, filtering and measuring P in the filtrate.
ii) $NaHCO_3$-P, by shaking the residue from (i) in 30 ml 0.5M $NaHCO_3$ for 16 hours, centrifuging, filtering and measuring P in the filtrate.
iii) NaOH-Pi, by shaking the residue from (ii) in 30 ml 0.1M NaOH for 16 hours, centrifuging, filtering and measuring P in the filtrate after acidifying with 5 ml concentrate HCl.
iv) NaOH-Po, by digesting 5 ml of the filtrate from (iii) in 6 ml of concentrate H_2SO_4 for 1 hour, cooling, adding 5 ml of H_2O_2 and reheating until the residue becomes white, determining P in the digest and subtracting the NaOH-Pi from it.
v) Acid-P, by shaking the residue from (iii) in 30 ml 1:1 mixture of 1M HCl/1M H_2SO_4, centrifuging, filtering and measuring P in the filtrate.
vi) Residual-P, by fluxing the soil residue from (v) in 6 ml of a 5:2 mixture of concentrated HNO_3 and $HClO_4$ and determining P from the digest.

All P was determined colorimetrically (Murphy and Riley, 1962) after neutralization when necessary with dilute HCl and NaOH and the neutral pH indicated by the slight yellowish colour of the solution in the presence of p-nitrophenol indicator. Absorbance of P was determined at a wavelength 712 nm by spectrophotometer. All measurements of P were done in duplicate and the data were analyzed by Excel software.

RESULTS AND DISCUSSION

Soil solution phosphorus

Soil solution P in the tested soils ranged from 0.03 mg L^{-1} to 0.11 mg L^{-1} (Table 2). Nilkamal silty clay loam had the highest solution P followed by Bhola silty clay (0.10 mg L^{-1}), Katra silt loam (0.07 mg L^{-1}). Ramgati silty clay loam, Jhalakhathi clay of pH 5.7, Harta silty clay loam and Sara silty clay had the lowest solution P (0.03 mg L^{-1}). Islam *et al*. (2010) observed 0.2 to 0.6 mg kg^{-1} solution from different Piedmont soils of Bangladesh. Vig *et al.* (2000) also found 0.01M $CaCl_2$ extractable P ranged from 0.05 mg P kg^{-1} to 0.37 mg P kg^{-1} in Habibowal sandy loam soil. Critical level of solution P associated with near maximum rice yield (flooded pots) is 0.02 mg L^{-1} (Hue and Fox, 2010). The tested soils had solution P above the critical level (0.02 mg PL^{-1}).

$NaHCO_3$-P

The range of $NaHCO_3$-P varied from 8 to 34 mg kg^{-1} (Table 2). The highest $NaHCO_3$-P was found in Barisal clay of pH 6.6. Katra silt loam had the second highest (26 mg kg^{-1}) $NaHCO_3$-P followed by 20 mg kg^{-1} in Nilkama lsilty clay loam, 19 mg kg^{-1} in Sara silty clay, 17 mg kg^{-1} in Bhola silty clay, 15 mg kg^{-1} in Jhalokathai clay of pH 5.9 and the lowest (8 mg kg^{-1}) in Barisal clay of pH 6.0. The labile P is strongly related to P uptake by plants (Fixen and Grove, 1990) and it quantitatively measures organic P associated with rapid inorganic P mineralization (Bowman and Cole, 1978). The $NaHCO_3$-P pool is readily available to plants (Bowman and Cole, 1978). Islam *et al*. (2010) reported 5-50 mg kg^{-1} $NaHCO_3$-P in acid Piedmont soils of Bangladesh.

Table 2. Soil P fractions and total P in some Ganges tidal floodplain soils.

Soil	Solution P (mg L^{-1})	$NaHCO_3$-P (mg kg^{-1})	NaOH-Pi (mg kg^{-1})	NaOH-Po (mg kg^{-1})	Acid P (mg kg^{-1})	Residual P (mg kg^{-1})
Barisal clay (pH 6.2)	0.05	14	52	443	174	114
Jhalokathi clay (pH 5.9)	0.05	15	31	431	141	128
Bholasilty clay	0.10	17	43	541	299	149
Nilkamalsilty clay loam	0.11	20	29	498	365	142
Ramgatisilty clay loam	0.03	13	25	490	286	153
Katra silt loam	0.07	26	31	425	443	152
Barisal clay (pH 6.0)	0.05	8	37	419	177	121
Jhalokathi clay (pH 5.7)	0.03	9	33	345	161	104
Hartasilty clay loam	0.03	12	38	334	230	227
Satlasilty clay	0.04	9	58	355	184	232
Sara silty clay	0.03	19	59	339	207	237
Barisal clay (pH 6.6)	0.05	34	44	354	298	262
Minimum	0.03	8	25	334	141	104
Maximum	0.11	34	59	541	443	262
Mean	0.05	16	40	415	247	168
CV(%)	51	47	28	17	37	33

NaOH-Pi

The NaOH Pi ranged from 25 to 59 mg kg^{-1} (Table 2). Sara silty clay soil had the highest (59 mg kg^{-1}) NaOH Pi followed by 58 mg kg^{-1} of NaOH Pi was found in Satla silty. Barisal clay (pH 6.2) had NaOH-Pi of 52 mg kg^{-1} compared to 44 mg kg^{-1} in Barisal clay (pH 6.6), 43 mg kg^{-1} in Bhola silty clay and 37 mg kg^{-1} in Barisal clay (pH 6.0), 33 mg kg^{-1} in Jhalokathi clay (pH 5.7) and, 31 mg kg^{-1} in Jhalokathi clay (pH 5.9 (soil no. 2). Ramgati silty clay soil had the lowest NaOH-Pi. Islam *et al.* (2010) reported 12-108 mg kg $^{-1}$ of NaOH Pi in thirteen acid Piedmont soils of Bangladesh. Hoque *et al.* (2011) reported 22 to 35 mg kg^{-1} of NaOH Pi in tidal floodplain soils of Bangladesh. The fraction of NaOH extracted inorganic P is associated with amorphous and crystalline Al and Fe phosphate. This fraction of P is less related to plant uptake than $NaHCO_3$-P and contribute about only 10% of the total P depletion by rice plants (Saleque *et al.*, 2004).

NaOH-Po

The concentration of NaOH Po ranged from 334 mg kg^{-1} to 541 mg kg^{-1} (Table 2). Bhola silty clay had the highest NaOH-Po and the lowest was in Harta silty clay loam. Hydroxide extractable Po is generally considered as stable form of organic P involved in long-term transformation in soil and it could be an important source for soil microorganisms, especially when labile P ($NaHCO_3$-Pi) is low (Tiessen *et al.*, 1984). Labile organic P is mineralized rapidly and NaOH Po replenishes P in the labile inorganic P pools in response to P uptake by plants (Sharply, 1985). Organic P pool theoretically should be correlated to the soil organic matter, but our results contradicted to the hypothesis.

Acid phosphorus

Acid-P fraction varied from 141 mg kg^{-1} to 443 mg kg^{-1} among the tested soils (Table 2). The highest (443 mg kg^{-1}) acid-P was observed in Katra silt loam and the lowest (141 mg kg^{-1}) was in Jhalakhathi clay of pH 5.9. The acid-P fraction is associated with insoluble Ca-P compounds such as hydroxyapatite (Williams *et al.*, 1980); so it would unlikely contribute to the eutrophication of water sources. The acid-P fraction is being considered less labile fractions and hence sparingly available for plant uptake (Syers *et al.*, 2008). However, it would be mobilized to labile fraction when the later is depleted. Saleque and Kirk (1995) reported that the acid-P contributed about 25% of the total uptake by rice under green house conditions. They also reported that exerting proton exudation under lowland situation, rice plant can uptake P from acid-P fraction.

Residual phosphorus

The concentration of residual P ranged from 104 mg kg^{-1} to 262 mg kg^{-1}. The highest concentration of residual of 262 mg kg^{-1} P was found in Barisal clay of pH 6.6 followed by 237 mg kg^{-1} in Sara silty clay and 232 mg kg^{-1} in Satla silty clay, respectively. Harta silty clay loam had residual P of 227 mg kg^{-1}. Nilkamal silty clay loam, Bhola silty clay, Katra silt loam and Ramgati silty clay loam had residual P in the range of 142-153 mg kg^{-1}. Jhalakathi clay (pH 5.7), Jhalakathi clay (pH 5.9), Barisal clay (pH 6.0), Barisal clay (pH 6.2) had residual P in the range of 104-128 mg kg^{-1}. Residual P fraction is likely in the stable humus fraction and very insoluble forms (Islam *et al.*, 2010). The variation in residual P pool among the soils is attributed to parent materials and long-term genesis of the soil (Iyamuremye *et al.*, 1996a). Ball-Coelho *et al*. (1993) reported that depletion of the residual P fraction occurred with time.

Relative concentration (%) of P fraction in different soils

The relative concentration of a soil is the proportion of that fraction in the total amount of P. On average in the tested soils, solution P fraction constituted about 0.01%, $NaHCO_3$-P fraction contributed about 1.8%, NaOH-Pi fraction comprised 4.3%, NaOH-Po fraction represents 46.7%, acid P 28.2% and the rest was by residual P (Table 3). The variations in relative contribution of different P fractions to the total soil P were enormous except solution P. Of the total P in soil, the solution P constituted about 0.02% in Nilkama lsilty clay loam (soil no. 4) and about 0.01% in rest of the soils.

Table 3. Relative concentration (%) of P fraction in different Ganges tidal floodplain soils.

Soil	Solution P (%)	$NaHCO_3$-P (%)	NaOH-Pi (%)	NaOH-Po (%)	Acid P (%)	Residual P (%)
Barisal clay (pH 6.2)	0.01	2.7	9.5	52.3	22.1	13.4
Jhalokathi clay (pH 5.9)	0.01	3.2	7.5	53.3	20.3	15.8
Bholasilty clay	0.01	3.2	6.3	48.9	28.0	13.5
Nilkamalsilty clay loam	0.02	3.8	4.8	44.6	34.0	12.8
Ramgatisilty clay loam	0.01	2.3	4.7	48.2	29.7	15.2
Katra silt loam	0.01	4.0	4.8	37.6	40.1	13.6
Barisal clay (pH 6.0)	0.01	2.3	7.4	51.6	23.6	15.0
Jhalokathi clay (pH 5.7)	0.01	3.0	7.2	49.1	25.8	14.9
Hartasilty clay loam	0.01	2.4	6.3	37.6	28.2	25.6
Satlasilty clay	0.01	2.8	6.1	41.0	23.1	27.0
Sara silty clay	0.01	3.4	9.6	36.8	23.9	26.3
Barisal clay (pH 6.6)	0.01	4.7	7.7	33.9	28.8	25.0
Minimum	0.01	2.3	4.7	33.9	20.3	12.8
Maximum	0.02	4.7	9.6	53.3	40.1	27.0
Mean	0.01	3.2	6.8	44.6	27.3	18.2
CV (%)	27	23	24	15	20	32

The contribution of $NaHCO_3$-P fraction to the total soil P was 2.3-3.4% for most of the tested soils. The $NaHCO_3$-P fraction of Nilkamal silty clay loam, Katra silt loam and Barisal clay contributed about 3.4-4.7% of the total P. The relative contribution of the NaOH-Pi fraction to the total soil P varied from 4.7% in Ramgati silty clay loam to 9.6% in Sara silty clay. The NaOH-Po fraction constituted about 33.9% of total P in Barisal clay (pH 6.6) to 53.3% in Jhalokathi clay (pH5.9). The relative concentration of the acid P was slightly lower than NaOH-Po pool of soil P. The relative concentration of acid P in most of the soils varied from 20-30%. Acid P in Nilkamal silty clay loam soil constituted about 34% of the total P compared to 40.1% in Katra silt loam. The residual P comprised about 12.8-15.8% of the total P in most of the tested soils. Four, out of 12 soils, showed about 25.0-27.0% contribution of the residual P to the total P. Hoque *et al.* (2011) reported that organic and residual P fraction in the Ganges tidal floodplain soil might have been dwindled over decades of rice production without proper P management. They also reported that the labile and non-labile fractions of the soil P was exhausted due to long-term crop production, the resistant P pools would not be a source, which support to mobilize P for long time.

Correlation of different P fractions with soil properties

Table 4 presents the relationship between the soil characteristics and different fractions of soil P. Significant relationship was observed between the soil characteristics and different P fractions of soils. Solution P was positively correlated (r = 0.55, P < 0.05) with silt and (r = 0.71, P < 0.01) with ΔpH but negatively correlated with EC, (r = -0.58, P < 0.05) and with pH (H_2O) and (r = 0.71, P < 0.01). $NaHCO_3$-P showed poor relationship with the soil properties. NaOH-Pi showed significantly positive relationship with clay (r = 0.77, P < 0.01) and pH (H_2O) (r = 0.73, P < 0.01) negatively correlated with silt (r = -0.82, P < 0.01) and with pH (KCl) (r = -0.59, P < 0.05). Positive and significant relationship of acid P was observed with silt (r = 0.84, P < 0.01) and $pH_{(HCl)}$(r = 0.82, P < 0.01) but negative correlation was found (r = -0.71, P < 0.01) with clay, (-0.72, P < 0.01) with pH(H_2O), (-0.54, P < 0.05) with Fe and (r = -0.54, P < .05) with Cu. Residual P had also a positive and significant correlation (r = 0.66, P < 0.01) with sand, (r = 0.58, P < 0.05) with pH (H_2O), (r = 0.66, P < 0.01) with organic carbon, (r = 0.62, P < 0.05) and with Fe, (r = 0.64, P < 0.05).

Table 4. Correlation of different P fractions with soil properties

Soil property	Solution P	$NaHCO_3$-P	NaOH-Pi	NaOH-Po	Acid P	Residual P
Sand	-0.22	-0.42	-0.18	-0.42	-0.07	0.66**
Silt	0.55*	0.27	-0.82**	-0.41	0.84**	-0.12
Clay	-0.40	-0.08	0.77**	0.51	-0.71**	-0.14
EC	0.71**	0.15	-0.42	0.13	0.18	-0.22
pH (H_2O)	-0.58*	-0.19	0.73**	-0.07	-0.72**	0.58*
pH (KCl)	0.33	0.30	-0.59*	-0.31	0.82**	-0.28
ΔpH	0.71**	0.30	-0.17	-0.04	0.16	-0.10
Org. C	-0.25	-0.17	-0.03	-0.28	-0.32	0.66**
Fe	-0.43	-0.26	0.32	-0.14	-0.54*	0.62*

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

Link between P fractions in soil

Solution P was poorly linked with the other fractions of P (Table 5). $NaHCO_3$-P was negatively correlated (r = -0.54, P < 0.05) with NaOH Po. There was significant negative (r = -0.71, P < 0.01) correlation between NaOH Pi and acid P. Similarly, significant negative relationship (r = -0.71, P < 0.05) was observed between NaOH-Po and residual P.

Table 5. Correlation coefficient values of the relationship between P fractions of the experimental soils

	Solution P	$NaHCO_3$-P	NaOH-Pi	NaOH-Po	Acid P	Residual P
Solution P	1	0.28	-0.38	0.00	0.38	-0.29
$NaHCO_3$-P		1	-0.03	-0.54*	0.47	0.08
NaOH-Pi			1	0.09	-0.71**	0.28
NaOH-Po				1	-0.46	-0.71**
Acid P					1	-0.27
Residual P						1

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

CONCLUSIONS

Soil P is distributed in solution, $NaHCO_3$-P, NaOH-Pi, NaOH-Po, acid and residual P fractions. On average of the 12 soils, the relative concentration of native soil P was 0.01% in solution P, 3.2% in $NaHCO_3$ P, 6.8% in NaOH-Pi, 44.6% in NaOH-Po, 27.3% in acid pool and 18.2% in residual fraction. However, there was large variation in the distribution of different P fractions of tidal floodplain soils of Bangladesh. This information would be helpful for recommendation of phosphorus in the respective areas.

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