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## Phosphorus Fractions in Soils of Transect of Kohora Watershed of Assam, India

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The forms of phosphorus in some surface soils representing various land forms *viz.* hillock top (crest 0-5 % slope), upper slope (30-35 % slope), middle slope (15-30 % slope), lower slope (10-15 % slope), flatter land (moderately sloping, 5-10 % slope), upland (gently sloping, 2-5 % slope), medium land (very gently sloping, 1-3 % slope) and low land (level to nearly level, 0-1 % slope) in a transect of Kohora watershed of Karbi Anglong district of Assam, India were studied. All the soils were acidic in reaction having variation in soil texture from skeletal sandy clay to sandy clay. Total free  $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$ ,  $\text{Al}_d$  and  $\text{Fe}_d$  of these soils were quite high and showed an increasing trend downward the transect along with clay. The study revealed that the sequential occurrence of various inorganic phosphorus fractions followed the order:  $\text{Fe-P} > \text{Al-P} > \text{Organic-P} > \text{Res-P} > \text{Ca-P}$ . Average inorganic phosphorus fractions as a constituent of total phosphorus in these soils was in the following order:  $\text{Fe-P} (29\%) > \text{Al-P} (27\%) > \text{Organic-P} (23\%) > \text{Res-P} (12\%) > \text{Ca-P} (3\%)$ . Both Al-P and Fe-P were significantly correlated with  $\text{Fe}_d$ ,  $\text{Al}_d$  and  $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$  and negatively with pH, Bray's I-P, Bray's II-P and Olsen's-P. Olsen's reagent extracted the highest amount of available phosphorus (15.38 to 24.21  $\text{mg Kg}^{-1}$ ) followed by Bray's-II (13.29 to 23.35  $\text{mg Kg}^{-1}$ ) and Bray's-I (12.39 to 21.35  $\text{mg Kg}^{-1}$ ). Both Al-P and Fe-P were the major contributing phosphorus fractions to the total and available phosphorus pool and phosphate nutrition to crop plants. Distribution of various fractions of phosphorus in soils of the watershed was the functions of local (micro) variations in land forms rather than interrelationship of phosphorus fractions.

**Keywords:** Phosphorus fractions, Watershed transect.

### INTRODUCTION

Evaluation of phosphorus fertility status of soil is necessary to make a sound phosphorus fertilizer recommendation for optimizing crop yield. Phosphorus is one of the major limiting factors of plant growth in many soils. Plant availability of inorganic phosphorus can be limited by formation of inorganic phosphorus such as Al-P, Fe-P, Ca-P, occluded and organic phosphorus. The proportion of each of these fractions governs the response of applied phosphorus. The transformations of phosphorus in soils involve complex microbiological, chemical and biological processes. However, adsorption of applied or native phosphorus to Fe- and Al-oxides [1,2], 1:1 type of silicate clays [3-5] and formation of Fe- and Al-P complexes with humic acids [6] in acid soils are considered as the dominant mechanisms of phosphorus fixation affecting concentration of available phosphorus in soil solution at any point of time.

The soils of north-east region are the product of slow diagenetic changes of acidic parent materials causing inherent soil acidity and high precipitation further aggravates this problem due to leaching of basic cations [7,8]. Higher phosphorus fixation due to presence of large amounts of Fe and

Al-oxides and hydroxides in these soils results phosphorus deficiency [9]. Variations in land forms and land use patterns also have profound influence on the chemical nature of soils which in turn governs the dominance of different phosphorus fractions in soils. Information about different fractions of soil phosphorus compound in a watershed context in Assam has not been generated earlier. Hence, an attempt was made to characterize the soils and to quantify different fractions of phosphorus and their contributions to the total and available phosphorus pool relating physical and chemical properties in soils of a transect of Kohora watershed of Assam, India.

### EXPERIMENTAL

The Kohora watershed of Assam (India) lies between  $93^{\circ}20'E$  to  $94^{\circ}25'E$  longitude and  $26^{\circ}30'N$  to  $25^{\circ}45'N$  latitude covering a part of Karbi Anglong and Golaghat districts of Assam and includes a part of Kaziranga National Park. The study area covers a part of Kohora watershed under Karbi Anglong district with a geographical area of 295 hectares having humid sub-tropical climate with mean annual rainfall of 2246 mm. Based on contour information available in the toposheet following FAO guidelines (2006) and local modifications, eight land forms *viz.* hillock top (crest 0-5 % slope),

upper slope (30-35 % slope), middle slope (15-30 % slope), lower slope (10-15 % slope), flatter land (moderately sloping, 5-10 % slope), upland (gently sloping, 2-5 % slope), medium land (very gently sloping, 1-3 % slope) and low land (level to nearly level, 0-1 % slope) were identified in the transect in relation to vertical height in the toposheet to the distance on the ground. Altogether eight surface soil samples (0-15 cm) were collected from the above land forms of the watershed (Fig. 1). The soils were processed and analyzed for physico-chemical properties using standard procedures [10].

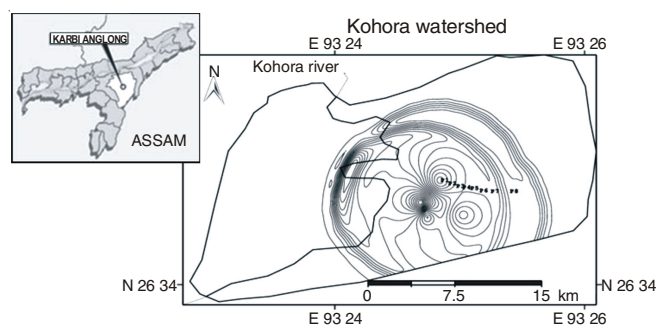


Fig. 1. Kohora watershed, Assam, India

Phosphorus fractionation was done by the modified procedure of Chang and Jackson [11] as modified by Peterson and Corey [12] and reported by Page *et al.* [13]. Total and organic phosphorus was determined by the NaOH digestion method [14]. The available phosphorus in the soils was estimated by using three extractants *viz.* Bray's-I (0.03 N  $\text{NH}_4\text{F}$  + 0.025 N HCl), Bray's-II (0.03 N  $\text{NH}_4\text{F}$  + 0.1 N HCl) [15] and Olsen's reagent (0.5 M  $\text{NaHCO}_3$ ) [16]. Phosphorus in the extracts was determined colorimetrically by the Ascorbic acid method of Murphy and Riley, [17] as modified by Watanabe and Olsen

[18] and reported by Page *et al.* [13]. Free Fe and Al oxides (total oxides) were extracted by the citrate dithionate-bicarbonate method, Mehra and Jackson [19]. Extractable Fe and Al in the extracts were determined with an atomic absorption spectrophotometer.

## RESULTS AND DISCUSSION

**Soil properties:** The texture of the soils of Kohora watershed was skeletal sandy loam to sandy clay with clay content varying from 19.4 to 40.23 % (Table-1). The clay content was found to increase towards lower slope and the highest being observed in low land soil. This was because of washing off of finer particles by rain water from the hill top and subsequent deposition in the lower position of the transect.

The soils were strongly acidic in reaction (pH 4.7 to 5.3). However, pH did not show any specific distribution pattern along the watershed transect. A significant negative correlation (Table-2) of pH with dithionite extractable Al ( $\text{Al}_d$ ) and free  $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$  revealed that soil reaction was basically governed by these oxides. Seats and Peterson [20] reported that in acidic environment, Fe and Al hydrous oxides undergo hydrolysis with release of  $\text{H}^+$  ions which results in drop of soil pH. Organic carbon (OC) content of all the soils was high (0.85 to 1.35 %). The distribution pattern (Table-1) of organic carbon in the transect showed an accumulation on the hill top soil might be due to rich vegetation cover and gentle slope (0-5 %). However, increase in slope (35 %) downward enhanced horizontal movement of organic carbon along with runoff water which was accumulated in the soils of lower slope to flat land. The lesser content of organic carbon in medium and low land soils may be attributed to paddy cultivation under which alternate oxidation-reduction conditions promoted oxidation of organic matter and their subsequent decomposition in soil.

TABLE-1  
PHYSICO-CHEMICAL PROPERTIES OF THE SOIL

Soils	Mechanical separates (%)			Texture	pH	OC (%)	Exch-Al [ $\text{cmol}(\text{p}^+)$ $\text{kg}^{-1}$ ]	CEC [ $\text{cmol}(\text{p}^+)$ $\text{kg}^{-1}$ ]	CBD* extractable (%)		$\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$ (%)
	Sand	Silt	Clay						$\text{Al}_d$	$\text{Fe}_d$	
Hillock top (Crest)	61.2	18.3	20.5	Skeletal scl	4.7	1.35	0.85	6.5	1.01	1.05	3.41
Upper slope	63.6	17.1	19.4	Skeletal sl	4.8	0.98	1.42	5.6	0.95	0.99	3.32
Middle slope	55.0	22.4	22.6	Skeletal scl	5.2	0.95	1.69	8.4	0.63	0.85	2.41
Lower slope	51.9	23.5	24.5	Skeletal scl	5.0	1.20	0.75	9.5	0.79	0.82	2.67
Flatter land (moderately sloping)	49.1	21.3	29.6	scl	4.8	1.10	1.53	9.4	1.11	1.15	3.74
Upland (gently sloping)	47.9	16.6	34.5	sc	5.1	1.20	0.83	10.2	0.75	0.94	2.76
Medium land (very gently sloping)	43.2	19.6	37.2	sc	4.9	0.83	1.55	10.9	1.28	1.30	4.28
Low land (level to nearly level)	40.4	19.3	40.2	sc	5.3	0.85	0.85	11.2	0.73	0.75	2.45

\*Citrate-Bicarbonate-Dithionite; OC = organic carbon; CEC = cation exchange capacity

TABLE-2  
CORRELATION CO-EFFICIENT (r) AMONGST SOIL PROPERTIES

Properties	pH	OC	CEC	$\text{Al}_d$	$\text{Fe}_d$	$\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$
Clay	0.514	-0.491	0.909**	0.107	0.076	0.068
pH	1	-0.463	0.605	-0.740*	-0.693*	-0.075
OC		1	-0.395	-0.077	-0.054	-0.079
CEC			1	-0.027	-0.034	-0.069
$\text{Al}_d$				1	0.936**	0.990**
$\text{Fe}_d$					1	0.972**

\* $P < 0.05$ , \*\* $P < 0.01$ ; OC = organic carbon; CEC = cation exchange capacity

The total free  $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$  of these soils was quite high (2.41-4.28 %) and this is due to Fe and Al rich parent material of the soil. Distribution of  $\text{Fe}_d$  and  $\text{Al}_d$  showed an increasing trend towards the down slope of the transect. The pH of the soils was significantly and negatively correlated with exchangeable Al, dithionite extractable Al and Fe and free  $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$  ( $r = -0.730$ ,  $P = 5\%$ ). This was due to increasing solubility of Fe and Al under condition of low pH [21]. The exchangeable Al exhibited significant negative correlation with organic carbon indicating that organic matter either forms insoluble complexes with  $\text{Al}^{3+}$  or blocks the exchange sites. The negative correlation of organic carbon with  $\text{Fe}_d$ ,  $\text{Al}_d$  and  $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$  (Table-2) also indicated that organic matter inhibited crystallization of amorphous oxides of Fe and Al in these soils. These observations are consistent with those of Schwartmann [22]. The cation exchange capacity of the soils varied from 5.6 to 11.2 ( $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ ) and increased from the hill top to lowland soil (Table-1) which is attributed to increase in the clay content of the soil. This observation was evidenced by a highly significant positive correlation between cation exchange capacity and clay content of the soil ( $r = 0.906$ ,  $P = 1\%$ ). The amount of exchangeable cations in these soils was very low because of their inherent acidic reaction (Table-3). The exchange complex of the soils was found to be dominated by exchangeable  $\text{Mg}^{2+}$  and was indicative of high degree of pedogenic evolution of the soils.

**Phosphorus fractions:** Results showed that the total phosphorus in the soils ranged from 478.4 to 542.8  $\text{mg Kg}^{-1}$

with a mean of 523.7  $\text{mg Kg}^{-1}$  (Table-4). The hill top soil contained the highest amount of total phosphorus which decreased to the lowest value in the lower slope. It tended to increase towards the lower position of transect. Amongst the different inorganic fractions of phosphate, Fe-P was the dominant fraction of phosphate, followed by Al-P and the Ca-P was the lowest (Table-4). These three fractions ranged from 150.5 to 175  $\text{mg Kg}^{-1}$ , 125.4 to 148.5  $\text{mg Kg}^{-1}$  and 14.3 to 24.5  $\text{mg Kg}^{-1}$ , respectively. The soils under lowland condition contained the lowest amount of Fe-P while under medium land situation its quantity was the highest. Fe-P constituted the highest percentage (29.1 %) of total phosphorus while Al-P contributed about 26.5 % to total phosphorus. The inorganic phosphorus ranged from 289.4 to 413.9  $\text{mg Kg}^{-1}$  with a mean of 388.4  $\text{mg Kg}^{-1}$  and constituted 74.2 % of total P, whereas the organic phosphorus varied from 109.9 to 127.8  $\text{mg Kg}^{-1}$  (mean of 119.9  $\text{mg Kg}^{-1}$ ) and contributed only 22.9 % to total phosphorus pool. The Fe-P, Al-P and occluded phosphorus fractions (residual-P) contributed mostly to the total phosphorus. These results are in accordance with the findings of Singh and Datta [23], Lacerda *et al.* [1] and Ojo *et al.* [2]. Distribution of various inorganic phosphorus fractions as a constituent of total phosphorus in these soils followed the order: Fe-P (29 %) > Al-P (27 %) > organic-P (23 %) > res-P (12 %) > Ca-P (3 %).

Organic-P of the soils ranged from 109.9 to 127.8  $\text{mg Kg}^{-1}$  and did not show any definite trend of distribution within transect. As expected, the organic-P was positively and significantly correlated with organic carbon (Table-5). Available phosphorus in the soil was extracted by three extractants *viz.* Bray's I (Bray's I-P), Bray's II (Bray's II-P) and Olsen's (Olsen's-P) reagents. The Bray's I-P, Bray's II-P and Olsen's-P in the soil ranged from 12.39 to 21.35  $\text{mg Kg}^{-1}$ , 13.29 to 23.35 and 15.38 to 24.21  $\text{mg Kg}^{-1}$ , respectively (Table-4). The amount of available phosphorus in soil extracted by these three extractants followed the order: Bray's I-P < Bray's II-P < Olsen's-P. The amount of available phosphorus extracted by Bray's-I method (recommended for acid soils) in these soils was found to be within medium range. The latter two reagents extracted relatively more amount of available phosphorus which might be due to strong acids involved in Bray's-II

TABLE-3  
EXCHANGEABLE CATIONS OF THE SOILS

Soils	Exchangeable cations of the soils [ $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ ]			
	$\text{Ca}^{2+}$	$\text{Mg}^{2+}$	$\text{K}^+$	$\text{Na}^+$
Hillock top (Crest)	0.6	2.0	0.80	0.07
Upper slope	0.4	1.2	0.48	0.04
Middle slope	0.5	0.8	1.22	0.05
Lower slope	0.6	1.8	0.88	0.06
Flatter land (moderately sloping)	0.5	1.1	1.10	0.05
Upland (gently sloping)	0.8	1.0	1.22	0.08
Medium land (very gently sloping)	0.5	1.6	1.35	0.09
Low land (level to nearly level)	1.0	1.4	1.38	0.10

TABLE-4  
P-FRACTIONS IN THE SOIL ( $\text{mg Kg}^{-1}$ )

Soils	Total-P	Org-P	Fe-P	Al-P	Ca-P	Residual P	Bray's-I P	Bray's- II P	Olsen's P
Hillock top (Crest)	542.8	125.5 (23.1)	174.5 (32.1)	148.5 (27.3)	14.3 (2.6)	57.6 (10.6)	12.4 (2.3)	13.4 (2.4)	15.4 (2.8)
Upper slope	529.4	115.4 (21.8)	172 (32.5)	144.0 (27.2)	15.5 (2.9)	58.9 (11.1)	14.6 (2.7)	14.9 (2.8)	17.8 (3.4)
Middle slope	507	109.9 (21.7)	154.0 (30.4)	132.2 (26.1)	18.5 (3.6)	61.8 (12.2)	19.6 (3.9)	21.8 (4.3)	24.2 (4.8)
Lower slope	478.4	127.8 (26.7)	156.7 (32.7)	135.4 (28.3)	19.5 (4.1)	61.0 (12.7)	18.9 (4.0)	19.6 (4.1)	21.6 (4.5)
Flatter land (moderately sloping)	535.3	119.3 (22.3)	174.3 (32.6)	142.15 (26.6)	18.1 (3.4)	60.8 (11.4)	13.6 (2.5)	15.6 (2.9)	18.3 (3.4)
Upland (gently sloping)	539	125.4 (23.3)	163 (30.2)	136.8 (25.4)	20.4 (3.8)	63.1 (11.7)	21.3 (3.9)	23.3 (4.3)	24.2 (4.5)
Medium land (very gently sloping)	536.2	113.7 (21.2)	175.0 (32.6)	145.5 (27.1)	19.2 (3.6)	59.2 (11.0)	15.0 (2.8)	16.6 (3.1)	18.1 (3.4)
Low land (level to nearly level)	521.4	122.5 (23.5)	50.5 (9.7)	125.4 (24.0)	24.5 (4.7)	68.7 (13.2)	20.3 (3.9)	21.6 (4.1)	22.3 (4.3)

\*Figures in parentheses indicate per cent contribution to total-P

TABLE-5  
CORRELATION (r) BETWEEN PHYSICO-CHEMICAL PROPERTIES AND P-FRACTIONS OF THE SOILS

Properties	Total-P	Org-P	Fe-P	Al-P	Ca-P	Residual P	Bray's- I P	Bray's- II P	Olsen's-P
Clay (%)	0.213	0.09	-0.55	-0.418	0.830**	0.669*	0.413	0.459	0.327
pH	-0.404	-0.074	-0.742*	-0.947**	0.848**	0.866**	0.916**	0.921**	0.894**
OC	0.028	0.697*	0.437	0.379	-0.506	-0.406	-0.205	-0.225	-0.221
CEC	-0.125	0.127	-0.473	-0.528	0.866**	0.646	0.544	0.598	0.501
Al <sub>d</sub>	0.516	-0.157	0.485	0.748**	-0.388	-0.579	-0.797*	-0.759*	-0.798**
Fe <sub>d</sub>	0.606	-0.307	0.648	0.813**	-0.415	-0.645	-0.716*	-0.634	-0.654
Fe <sub>2</sub> O <sub>3</sub> + Al <sub>2</sub> O <sub>3</sub>	0.56	-0.233	0.566	0.820**	-0.441	-0.629	-0.790*	-0.739*	-0.767*

\*P < 0.05, \*\*P < 0.01

reagent to solubilize Ca-P fraction and their influence on dissolution of Fe-P and Al-P [24]. On the other hand, high pH in the Olsen's reagent extracted large amount of phosphorus by dissolution of inorganic phosphorus. Available phosphorus extracted by all the reagents distributed almost similarly in the watershed transects. It was observed that available phosphorus in the soil as extracted by Bray's I, Bray's II and Olsen's reagents was highly and significantly correlated with pH ( $r = 0.916^{**}$ ,  $0.9218^{**}$  and  $0.894^{**}$ ) indicating that available-P increased with increase in soil pH. On the other hand, they had significant but negative relationships with Fe<sub>d</sub>, Al<sub>d</sub> and Fe<sub>2</sub>O<sub>3</sub> + Al<sub>2</sub>O<sub>3</sub> (Table-5). This suggests that available phosphate fractions in soil were largely influenced by different forms of Fe and Al and pH. The content and reactivity of oxides, hydroxides and oxyhydroxides of Fe and Al in many acid soils are the components that predominantly influence phosphorus adsorption because these oxides serve as the most effective phosphorus sorbents [25-27]. The oxides of Fe and Al are the residual products formed during silicate weathering and their amounts increase as weathering proceeds. Strongly weathered acid soils are, therefore, rich in Fe and Al oxides which are expected to cause decreased availability of phosphorus in acid soils. Similar observations were also made by Das [28] in 14 acid soils of Assam.

Both Al-P and Fe-P were significantly correlated with Fe<sub>d</sub>, Al<sub>d</sub> and Fe<sub>2</sub>O<sub>3</sub> + Al<sub>2</sub>O<sub>3</sub> and negatively with pH, Bray's I-P, Bray's II-P and Olsen's-P (Table-5). Calcium phosphate exhibited significant positive correlations with pH and clay while negative with Fe<sub>2</sub>O<sub>3</sub> + Al<sub>2</sub>O<sub>3</sub> and Fe<sub>d</sub>. Both Fe-P and Al-P increased with increase in different forms of Fe and Al and decreased significantly with soil pH. These observations conform to the findings of Das [28]. Of all the inorganic phosphorus fractions, Al-P exhibited high degree relationship (Table-5) with total-P ( $r = 0.517$ ), indicating that this is the most dominant fraction that effect the total-P throughout the transect. Insignificant and negative correlation of other phosphorus fractions with total-P suggests that variations in land forms in the watershed transect greatly influence phosphorus distribution rather interrelationship amongst various phosphorus fractions. It was observed that large portion of Al-P and Fe-P remained occluded [29] and could not be extracted through sequential extraction. The highly significant negative correlation of Al-P and Fe-P with residual phosphorus (Table-5) further support this observation.

In conclusion, both Al-P and Fe-P were the major contributing phosphorus fractions to the total and available phosphorus pool and phosphate nutrition to crop plants. Distribution of

various fractions of phosphorus in soils of the watershed was largely affected by local (micro) variations in land forms rather than a broad transect and inter-relationship of phosphorus fractions.

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