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Effect of Aggregation on Phosphate Sorption-Desorption Behaviour of Soils under Various Land Use Patterns of Eastern India

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The present experiment was conducted to study whether aggregation had any influence on phosphorus (P) adsorption-desorption behaviour of soils under four land uses of eastern India. The highest amount of P sorbed at any amount of P addition was recorded in the smallest size aggregate, *i.e*. 0.10-0.05 mm and the least in the largest size aggregate (>2.0 mm). The per cent P sorbed of added P decreased with increase in the level of P addition irrespective of size of aggregates. Sorption isotherms were described by Langmuir and Freundlich adsorption equations. Larger size aggregates had lesser buffering capacity and bonding energy indicating higher solution P concentration for plant absorption than the smaller size aggregates, but would not sustain solution P concentration for longer period of time. The amounts of P desorbed also increased with increase in added P concentration and the proportions of P desorbed of sorbed P increased with increase in the fineness of aggregates. The results thus indicated that weakly aggregated soil would release more P than the well aggregated soil. In a particular size aggregate, the proportion of P release to sorbed P increased up to a limit of P addition (200 mg P kg^{-1}) and thereafter decreased steadily.

Key words: Soil aggregation, phosphate sorption-desorption, land use pattern, adsorption isotherm

Soil aggregate stability is a fundamental property that determines its productivity through influencing a wide range of soil properties, including carbon stabilization, soil porosity, water infiltration, aeration, water retention, hydraulic conductivity, resistance to erosion and degradation (Six *et al*. 2000). Maintaining high stability of soil aggregate is essential for preserving soil productivity, minimising soil erosion and degradation and thus minimising environmental pollution as well.

Soil are known to vary widely in their capacities to supply phosphorus (P) to crop because only a small fraction of the total P in soil is available to crops. Main phosphate-sorbing soil constituents are aluminium (Al) and iron (Fe) oxides, hydroxides, and oxyhydroxides – which are collectively referred to as oxides (Torrent 1997), organic complexes of Al and Fe (Borggard *et al.* 2004), edges of silicate clays, and calcite (Matar *et al.* 1992). Since plant absorption of P depends on desorption of P from soil, understanding P desorption from soils may improve the precision of P diagnosis and fertilizer recommendations. Although land use clearly modifies soil properties, the intensity of the modification depends on the management procedure and also on the soil properties themselves (Troitino *et al*. 2007). Wang *et al.* (2001) observed that soil management that favours soil aggregation may increase availability of applied P. Therefore, perhaps the distribution of soil aggregates should be considered in making P management decisions. The present work was aimed to study the P sorption-desorption behaviour of different size aggregates from soils under four land use pattern of eastern India.

Materials and Methods

Location

The study areas were situated in 26°50′ and 26°56′ N latitude, and 88°7′ and 89°53′ E longitude. Soils under study belonged to soil orders Inceptisol and Entisol developed primarily by the deposition of various types of soil and rock materials brought down from the northern hills of Himalayas (Anonymous 1997-98). The net sown area of this zone under field crops is noted to be nearly 50%, while 14% area is under forest cover, 9% of area under orchards, plantation and miscellaneous trees, and 22% land is

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being utilized for non-agricultural purposes.

Field moist composite surface (0-15 cm) soil samples were collected from each of four land use pattern namely, pine apple orchard, tea garden, fallow and cultivated land with the help of spade. Soils of cultivated land are subjected to regular tillage operation for growing various field crops, like rice, jute, potato and vegetables. Soils of tea garden, pine apple orchard and cultivated land had been receiving on an average 30, 150 and 60 kg P ha^{-1} yr^{-1}. The samples were then allowed to air-dry for 72 h before analysis for aggregate stability. The sieved sample that passed through 5.0 mm sieve but retained on the 2.0 mm sieve was taken for aggregate analysis. Additionally, some air-dried soil samples were hand crushed, passed through 2.0 mm sieve and stored for various physical and chemical analyses.

Soil properties

The processed soil samples (<2 mm) were analyzed for pH, organic carbon (OC), cation exchange capacity (CEC) by standard procedures (Jackson 1973) and particle size distribution by Bouyoucos hydrometer method (Day 1965). Anion exchange capacity (AEC) and citrate buffer extractable hydrous Fe_2O_3 of the soil were determined as per method outlined by Baruah and Barthakur (1997) and Hesse (1971), respectively.

Aggregate analysis was done using Yoder wet sieving apparatus (Kemper and Rosenau 1986). The distribution of soil aggregates obtained from wet sieving method was expressed into following soil aggregate indices:

$$\text{Mean weight diameter (MWD)} = \frac{\sum_{i=1}^{n} W_i X_i}{\sum_{i=1}^{n} W_i}$$

$$\text{Geometric mean diameter (GMD)} = \exp \frac{\sum_{i=1}^{n} W_i \log X_i}{\sum_{i=1}^{n} W_i}$$

where, n is the number of fraction, W_i is the weight (g) of aggregated particle minus sand content in i^{th} sieve, X_i is the mean diameter (mm) of each sieve class.

P adsorption and desorption study

Soil samples (3 g) was equilibrated at 25 °C in centrifuge tube for 6 days with 30 mL of 0.01 *M* $CaCl_2$ solution containing 5, 10, 20, 30, 50 and 100 mg P L^{-1} (*i.e.* 50, 100, 200, 300, 500 and 1000 mg P kg^{-1} soil) as KH_2PO_4 with one drop of toluene to inhibit microbial activity. The soil was shaken for 30 min twice daily using a reciprocal mechanical shaker. At the end of requisite incubation period, the content of the tube was centrifuged at 5000 rpm for 20 min and supernatant liquid was decanted.

Sorbed P was calculated as the difference between added P and equilibrium P concentration. Phosphorus sorbed (mg P kg^{-1}) and equilibrium P concentration (mg L^{-1}) were plotted to the following adsorption isotherm equations:

$$\text{Langmuir equation}: \frac{C}{\frac{x}{m}} = \frac{1}{Kb} + \frac{C}{b}$$

where, C is the equilibrium phosphate concentration (mg L^{-1}), x/m was the amount of phosphate sorbed per unit weight of soil (mg kg^{-1}), b and K were the constants related to P sorption capacity (mg kg^{-1}) and bonding energy (L mg^{-1}), respectively.

$$\text{Freundlich equation}: \frac{x}{m} = K'C^{1/n}\ (n > 1)$$

where, C and x/m were the same as Langmuir equation, K′ and n were two constants. K′ might be taken as a measure of relative P sorption capacity of soil, while n was related to the relative affinity of P for soil solids.

The soil residue of the adsorption study was used for quantifying desorption. The sample was first washed with alcohol to make it free from soluble P and washed soil was shaken with 0.5 *M* $NaHCO_3$ (pH 8.5) for 2 h. The suspensions were centrifuged at 5000 rpm for 20 min and filtered. The samples were subjected to two successive desorption runs. The P concentration in the clear solution was determined by ascorbic acid method (Kuo 1996).

Statistical analysis

To determine the goodness of fit of adsorption data to Langmuir and Freundlich adsorption isotherm and testing the degree of linearity between the amounts of adsorbed P and equilibrium P concentrations the correlation coefficients were determined using Microsoft excel programme.

Results and Discussion

Characteristics of soil used

Some relevant physicochemical properties of soils used in this study are presented in table 1. The soils under tea garden and cultivated land were strongly acidic (5.17-5.46), while the soils of fallow and orchard were moderately acidic (5.69-5.75). The organic carbon (OC) status of soils under all the land

Table 1. Some physicochemical properties of soils under four land uses

Soil Characters	Land uses			
	Cultivated	Tea garden	Orchard	Fallow
pH (1:2)	5.46	5.17	5.75	5.69
Organic carbon (g kg^{-1})	7.7	8.7	7.5	8.4
Bulk density (g cm^{-3})	1.56	1.27	1.34	1.30
CEC [cmol(p^+)kg^{-1}]	7.63	8.37	7.56	7.67
AEC [cmol(e^-)kg^{-1}]	2.53	3.07	2.62	2.75
Hydrous Fe_2O_3 (g kg^{-1})	6.21	7.43	6.12	6.45
Sand (%)	67.3	59.3	67.3	65.9
Silt (%)	20.0	27.0	22.0	23.4
Clay (%)	12.7	13.7	10.7	10.7
Mean weight diameter (mm)	0.82	1.07	0.84	0.94
Geometric mean diameter (mm)	0.77	0.89	0.79	0.82

uses was high (>7.5 g kg^{-1}). Tea garden soil exhibited the highest CEC [8.37 cmol(p^+)kg^{-1}], followed by fallow [7.67 cmol(p^+)kg^{-1}], cultivated land [7.63 cmol(p^+)kg^{-1}] and orchard [7.56 cmol(p^+)kg^{-1}]. The particle size distribution with respect to finer fractions (% clay + % silt) also followed the same pattern as were observed with CEC, *i.e.* tea garden > fallow > orchard > cultivated land. The variation in CEC among the land uses attributed to the variation in organic matter and clay content. The AEC also followed the same trend as was observed with CEC. The trend was well corroborated with organic matter and hydrous Fe_2O_3 content. Among the four land uses, the cultivated soil was the most compact having bulk density of 1.56 g cm^{-3}, followed by orchard (1.34 g cm^{-3}), fallow (1.30 g cm^{-3}) and tea garden (1.27 g cm^{-3}). The highest MWD was recorded in tea garden soil (1.07 mm) followed by fallow (0.94 mm), orchard (0.84 mm) and cultivated land (0.82 mm). The GMD was also followed the same trend as was observed with MWD. Higher organic matter and clay content in tea garden soil were possibly the instrumental behind a better soil aggregation, while intensive tillage in cultivated land destroyed the same.

Sorption of phosphorus

Irrespective of land use pattern the amount of P sorbed at any level of added P increased with decrease in the size of aggregates, but the quantity of P sorbed by any particular size fraction increased with increase in the level of P addition (Table 2-5). Higher proportion of sorption of added P with decrease in aggregate size was possibly due to higher specific surface area of smaller aggregate than the larger one. Again, irrespective of land use and aggregate size fraction the proportion of added P sorbed followed a decreasing trend from the lowest (5 mg L^{-1}) to the highest level (100 mg L^{-1}) of P addition. This might be due to the fact that higher the P saturation of sorption complex lesser would be the number of sites available for further adsorption of P. The results were in agreement with Pal and Mondal (2009). Although

Table 2. Amount of P sorbed (mg kg^{-1}) by different size aggregates soils under fallow and use

P added	Aggregate size (mm)					
(mg kg^{-1})	>2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05
50	46.6	46.9	47.1	47.3	47.5	48.1
	(93.2)*	(93.8)	(94.2)	(94.6)	(95.1)	(96.2)
100	90.1	89.2	92.1	92.8	93.2	94.1
	(90.1)	(89.2)	(92.1)	(92.8)	(93.2)	(94.1)
200	175.6	176.2	181.8	181.8	183.4	185.6
	(87.8)	(88.1)	(90.9)	(90.9)	(91.7)	(92.8)
300	252.9	255.3	265.7	269.4	270.0	271.5
	(84.3)	(85.1)	(88.58)	(89.8)	(90.0)	(90.5)
500	410	416	422	437	444	445
	(82.1)	(83.2)	(84.50)	(87.4)	(88.8)	(89.1)
1000	795	812	828	854	862	878
	(79.5)	(81.2)	(82.8)	(85.4)	(86.2)	(87.8)

Table 3. Amount of P sorbed (mg kg^{-1}) by different size aggregates soils under tea garden land use

P added (mg kg^{-1})	Aggregate size (mm)					
	>2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05
50	47.9	48.1	48.1	48.2	48.3	48.5
	(95.8)*	(96.2)	(96.3)	(96.4)	(96.7)	(97.1)
100	94.2	93.1	94.3	92.5	90.5	93.2
	(94.2)	(93.1)	(94.3)	(92.5)	(90.5)	(93.2)
200	181.6	184.6	180.0	181.8	186.2	190.4
	(90.8)	(92.3)	(90)	(90.9)	(93.1)	(95.2)
300	263.7	270	275.7	282.5	282.2	289.2
	(87.9)	(90.0)	(91.9)	(94.1)	(94.0)	(96.4)
500	422	432	437	440	450	460
	(84.5)	(86.4)	(87.4)	(88.1)	(90.1)	(92.1)
1000	800	825	832	834	849	848
	(80.1)	(82.5)	(83.2)	(83.4)	(84.9)	(84.8)

*Figure in parentheses are the per cent P sorbed of added P

Table 4. Amount of P sorbed (mg kg^{-1}) by different size aggregates soils under orchard land use

P added (mg kg^{-1})	Aggregate size (mm)					
	>2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05
50	45.7	47.1	48.3	48.5	49.1	49.2
	(91.5)*	(94.2)	(96.7)	(97.1)	(98.2)	(98.5)
100	89.5	90.1	93.2	94.3	94.2	96.1
	(89.5)	(90.1)	(93.2)	(94.3)	(94.5)	(96.1)
200	172.8	172.6	181.8	184.6	184.6	185.0
	(86.4)	(86.3)	(90.9)	(92.3)	(92..3)	(92.5)
300	247.8	248.7	265.7	271.5	277.6	281.5
	(82.6)	(82.9)	(88.5)	(90.5)	(89.2)	(93.8)
500	400.5	405.5	422.5	441.5	444.0	449.5
	(80.1)	(81.1)	(84.5)	(88.3)	(88.2)	(89.9)
1000	781	795	828	864	871	875
	(78.1)	(79.5)	(82.8)	(86.4)	(87.1)	(87.5)

*Figure in parentheses are the per cent P sorbed of added P

Table 5. Amount of P sorbed (mg kg^{-1}) by different size aggregates soils under cultivated land use

P added (mg kg^{-1})	Aggregate size (mm)					
	>2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05
50	43.2	44.0	44.1	45.1	45.4	46.7
	(86.4)*	(88.0)	(88.2)	(90.2)	(90.9)	(93.4)
100	82.3	85.8	85.3	88.4	88.1	89.1
	(82.3)	(85.8)	(85.3)	(88.4)	(88.1)	(92.1)
200	161.8	167.6	168.4	169.4	170.6	178.0
	(80.9)	(83.8)	(84.2)	(84.7)	(85.3)	(89.0)
300	236.4	243.0	246.9	245.3	256.7	258.8
	(78.8)	(81.1)	(82.3)	(81.7)	(85.5)	(86.2)
500	385.5	396.0	401.5	400.5	414.5	419.5
	(77.1)	(80.2)	(79.3)	(80.1)	(82.9)	(83.9)
1000	735	778	789	791	811	814
	(73.5)	(77.8)	(78.9)	(79.1)	(81.1)	(81.4)

*Figure in parentheses are the per cent P sorbed of added P

the P adsorption behaviour by any particular size aggregate of various land uses was in close proximity indicating the similarity in the basic nature of soils used for this study. However, among the land uses the least amount of P sorbed at any level of P addition by different size aggregates of soil was observed in cultivated land and the highest in tea garden land use. Variation in the degree of soil aggregation as

Table 6. Goodness of fit of adsorption data to two different adsorption isotherms (R^2)

Land use	Isotherm	Aggregate size (mm)					
		>2.0	2.0-1.0	1.0-0.50	0.50-0.25	0.25-0.10	0.10-0.05
Fallow	Freundlich	0.997	0.992	0.997	0.999	0.996	0.995
	Langmuir	0.799	0.766	0.862	0.878	0.782	0.765
Orchard	Freundlich	0.997	0.989	0.989	0.992	0.965	0.975
	Langmuir	0.791	0.704	0.789	0.786	0.663	0.756
Tea garden	Freundlich	0.999	0.996	0.993	0.993	0.979	0.982
	Langmuir	0.873	0.888	0.746	0.804	0.766	0.701
Cultivated	Freundlich	0.998	0.999	0.998	0.998	0.996	0.996
	Langmuir	0.847	0.777	0.789	0.912	0.713	0.772

manifested by their MWD and GMD values was possibly behind the phenomenon. The more the surface area exposed with given type of soil, the greater would be the capacity to adsorb P (Havlin *et al*. 2007).

Sorption parameters

The adsorption data of each aggregate size under each land use pattern were fitted to Langmuir and Freundlich adsorption equations (Table 6). The results revealed that adsorption data were fitted better in Freundlich adsorption equation than Langmuir equation in all the aggregate sizes irrespective of land use pattern. The R^2 values of Freundlich adsorption equation for various aggregate sizes of fallow land varied from 0.992 to 0.999, while those for orchard ranged from 0.965 to 0.997, for tea garden from 0.979 to 0.999 and for cultivated land from 0.996 to 0.999. The corresponding values for Langmuir adsorption equations varied from 0.765 to 0.878, 0.663 to 0.791, 0.701 to 0.888, and 0713 to 0.912, respectively.

Sorption maxima (b), *i.e*. monolayer adsorption capacity of different size aggregates varied between 1471 and 2174 mg P kg^{-1} in fallow, between 1274 and 1751 mg P kg^{-1} in cultivated land, between 1087 and 1250 mg P kg^{-1} in orchard, and between 909 and 1250 mg P kg^{-1} in tea garden soil. Sorption maxima did not follow any definite trend with the size of aggregates in any land use soil. On the other hand, barring few exceptions, the coefficient or constant relating to bonding energy (K) or the affinity of the aggregates for phosphate increased with decrease in the size of aggregates possibly due to increase in specific surface area. Among the four land uses, the bonding energy was the highest in tea garden soil (0.097 to 0.150 L mg^{-1}) followed by orchard (0.063 to 0.178 L mg^{-1}), fallow (0.058 to 0.083 L mg^{-1}) and cultivated land (0.034 to 0.079 L mg^{-1}). Relatively higher bonding energy in tea garden was attributed to higher content of finer soil particles and organic matter which was further reflected in the values of MWD and GMW, the indices for degree of soil aggregation.

The buffering capacity (Kb) of the aggregates of various land uses followed almost same trend as was observed with the phosphate bonding energy coefficients (Table 7). Usually smaller aggregates exhibited higher buffering capacity than larger aggregates. Since solution P concentration was inversely related to buffering capacity, poorly (smaller size) aggregated soils though would have less solution P concentration at a given level of available P for plant utilization but would maintain the P concentration for longer period of time. Since smaller size aggregates always associated with higher specific surface area exhibited higher buffering capacity.

Except in tea garden soil, Freundlich constant K′ (measure of adsorbability) increased with decrease in the size of aggregates (Table 7). Among land uses the higher adsorption capacity was observed in orchard and tea garden soil land uses which contained higher amount of clay, Fe_2O_3 and organic matter, the adsorbent for phosphate. Freundlich constant K′ followed more or less similar trend as was observed with Langmuir buffering capacity, while Freundlich other constant, n (measure of bonding energy) followed the same sequence as of Langmuir bonding energy coefficient. The highest bonding energy of phosphate for tea garden soil was attributed to the highest amount of clay, Fe_2O_3 and organic matter. Since bonding energy is a surface property, it increases with increasing surface area but decrease exponentially with increasing saturation of exchange sites with phosphate. Pal (2011) reported that the magnitude of P adsorption was greater in soil having less P saturation (less amount of P already adsorbed to the sorption complexes), since higher number of adsorption sites are still available for further P adsorption.

Table 7. Soil P sorption parameters of various aggregate sizes under four land uses

Land use pattern		Aggregate size(mm)					
		>2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05
Fallow	Adsorption maxima (b)	1562	1471	1515	1961	2174	1961
	Bonding energy (K)	0.058	0.062	0.083	0.067	0.061	0.082
	Buffering capacity (Kb)	90.9	90.9	125.0	131.6	131.6	161.3
	K′	93.8	95.5	111.9	121.3	122.5	144.2
		0.685	0.698	0.690	0.729	0.714	0.683
Orchard	Adsorption maxima (b)	1250	1190	1087	1220	1235	1124
	Bonding energy (K)	0.063	0.072	0.126	0.134	0.131	0.178
	Buffering capacity (Kb)	78.1	86.2	137.0	163.9	161.3	200.0
	K′	83.8	95.5	132.7	147.9	158.5	177.4
		0.701	0.653	0.595	0.634	0.572	0.535
Tea garden	Adsorption maxima (b)	1031	1111	1250	1190	1205	909
	Bonding energy (K)	0.131	0.134	0.112	0.110	0.097	0.150
	Buffering capacity (Kb)	135.1	148.4	139.7	131.1	117.0	136.2
	K′	126.8	133.4	134.0	127.4	124.5	129.7
		0.601	0.628	0.643	0.636	0.601	0.565
Cultivated	Adsorption maxima (b)	1488	1751	1592	1481	1397	1274
	Bonding energy (K)	0.034	0.035	0.038	0.054	0.050	0.079
	Buffering capacity (Kb)	50.3	60.6	60.2	79.6	69.5	101.0
	K′	56.2	65.2	65.3	80.5	76.9	102.1
		0.782	0.804	0.786	0.775	0.730	0.695

Table 8. Amount of P desorbed (mg kg^{-1}) by soil aggregates of fallow land use

P added	Aggregate size (mm)						Mean recovery
(mg kg^{-1})	>2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05	(%)
50	17.2	17.9	18.9	19.2	20.1	21.3	40.4
	(36.9)*	(38.2)	(40.1)	(40.5)	(42.3)	(44.2)	
100	46.0	47.7	49.3	51.2	53.3	56.0	55.0
	(51.0)	(53.5)	(53.5)	(55.2)	(57.2)	(59.5)	
200	94.0	100.1	110.4	120.9	122.9	127.4	62.4
	(53.6)	(57.0)	(60.7)	(66.5)	(68.1)	(68.7)	
300	114.9	121.1	128.8	132.0	134.0	137.4	48.4
	(45.4)	(47.5)	(48.5)	(49.0)	(49.7)	(50.6)	
500	133.7	136.1	139.7	150.1	153.8	165.1	34.1
	(32.6)	(32.7)	(33.0)	(33.8)	(35.2)	(37.1)	
1000	202.5	209.0	213.7	230.4	234.4	237.3	26.4
	(25.5)	(25.7)	(25.8)	(27.0)	(27.2)	(27.0)	
Mean recovery (%)	40.7	42.4	43.6	45.3	46.6	47.8	44.4

*Figures in parentheses are the per cent P desorbed of sorbed P

Desorption of phosphorus

The results revealed that like sorbed P, the amount of P desorbed was also increased with decrease in the added P concentration in all aggregate size fractions (Table 8-11). Barring few exceptions, the proportions of P desorbed of sorbed increased with increase in the fineness of aggregate size. This might be due to the fact that desorption of P from sorption complex was greater from soils having higher P saturation as phosphate ions were less tightly held due to increasing surface coverage by phosphate ions. The result was in conformity with the findings of Wang *et al.* (2001) and Pal (2011). The results further revealed that desorption of P was higher in poorly aggregated soils than in well aggregated soil. The observation was in agreement with the findings of Mendoza and Barrow (1987) and Dolui and Dasgupta (1998). Again, in a particular aggregate size, though the total amount of P desorbed to sorbed P increased with increase in P addition during sorption, but the proportion of P release to sorbed P increased up to addition of 20 mg P L^{-1} (*i.e.* 200 mg P kg^{-1} soil) and thereafter decreased steadily. The mean attainable recoveries, *i.e.* the proportions of desorbed P to sorbed P varied from 40.7 to 47.8 per cent for aggregate

Table 9. Amount of P desorbed (mg kg^{-1}) by soil aggregates of orchard land use

P added (mg kg^{-1})	Aggregate size (mm) >2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05	Mean recovery (%)
50	15.2 (33.2)*	16.1 (34.2)	17.4 (36.0)	18.5 (38.2)	20.0 (40.8)	22.1 (44.9)	37.9
100	44.1 (49.3)	47.6 (52.8)	51.7 (55.5)	62.0 (65.7)	63.5 (67.4)	67.1 (69.9)	60.1
200	100.5 (58.1)	116.1 (67.3)	122.0 (67.1)	130.1 (70.5)	132.3 (71.7)	134.3 (72.6)	67.9
300	110.3 (44.5)	118.3 (47.6)	126.9 (47.8)	130.5 (48.1)	135.2 (48.7)	137.4 (48.8)	47.6
500	123.4 (30.8)	128.7 (31.7)	143.7 (34.0)	173.1 (39.2)	179.5 (40.4)	190.7 (42.4)	36.4
1000	173.1 (22.2)	199.6 (25.1)	221.0 (26.7)	230.7 (26.7)	232.7 (26.7)	235.4 (26.9)	25.7
Mean recovery (%)	39.7	43.1	44.5	48.1	49.3	50.9	45.9

*Figures in parentheses are the per cent P desorbed of sorbed P

Table 10. Amount of P desorbed (mg kg^{-1}) by soil aggregates of tea garden land use

P added (mg kg^{-1})	Aggregate size (mm) >2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05	Mean recovery (%)
50	14.7 (30.8)*	17.3 (35.9)	18.5 (38.4)	19.7 (40.9)	20.0 (41.3)	20.7 (42.6)	38.3
100	36.0 (38.2)	41.2 (44.3)	43.0 (45.6)	44.2 (47.8)	45.2 (49.9)	46.0 (49.3)	45.9
200	108.2 (59.6)	112.3 (60.8)	114.9 (63.8)	117.9 (64.8)	121.1 (65.0)	127.0 (66.7)	63.5
300	122.5 (46.5)	132.8 (49.2)	137.3 (49.8)	141.7 (50.1)	150.7 (53.4)	155.5 (53.8)	50.5
500	164.9 (39.0)	200.1 (46.3)	206.3 (47.2)	209.2 (47.5)	224.5 (49.8)	235.0 (51.0)	46.8
1000	189.9 (23.7)	226.9 (27.5)	231.9 (27.9)	233.4 (28.0)	250.6 (29.5)	255.5 (30.1)	27.8
Mean recovery (%)	39.6	44.0	45.5	46.5	48.2	48.9	45.5

*Figures in parentheses are the per cent P desorbed of sorbed P

Table 11. Amount of P desorbed (mg kg^{-1}) by soil aggregates of cultivated land use

P added (mg kg^{-1})	Aggregate size (mm) >2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.05	Mean recovery (%)
50	18.3 (42.3)*	19.0 (43.1)	19.3 (43.8)	20.2 (44.9)	21.2 (46.6)	22.6 (48.5)	44.9
100	45.5 (55.3)	49.1 (57.2)	52.2 (61.2)	53.8 (60.8)	57.3 (65.0)	58.5 (65.6)	60.9
200	95.2 (58.9)	103.4 (61.5)	111.4 (66.1)	119.9 (70.8)	121.3 (71.1)	128.2 (72.0)	66.7
300	103.5 (43.8)	109.5 (45.0)	117.4 (47.5)	121.1 (49.4)	127.0 (49.5)	133.7 (51.7)	47.8
500	113.5 (29.4)	116.3 (29.4)	118.1 (29.4)	127.0 (31.7)	132.0 (31.8)	135.2 (32.2)	30.7
1000	121.1 (16.5)	127.8 (16.4)	132.0 (16.7)	150.5 (19.0)	165.5 (20.4)	180.2 (22.1)	18.5
Mean recovery (%)	41.0	42.1	44.1	46.1	47.4	48.7	44.9

*Figures in parentheses are the per cent P desorbed of sorbed P fractions under fallow land. The corresponding values for tea garden soil varied from 39.6 to 48.9 per cent, from 39.7 to 50.9 per cent for orchard and from 41.0 to 48.7 per cent for cultivated land soil. The result showing little variation in mean attainable recovery of P in different size aggregates under various land use patterns thus indicated that soils of different land uses under the study area had little variation in their basic nature

Conclusions

The results of the study revealed that soil aggregation as well as land use pattern had a definite influence both on P-adsorption and desorption behaviour of soil. Variation in different adsorption parameters among the land uses was attributed to the variation in soil properties like, the amount of organic matter, clay and Fe_2O_3 content. Larger size aggregates had lesser buffering capacity and bonding energy coefficient indicating higher solution P concentration for plant absorption at a given level of sorbed P, but would not be able to maintain solution P concentration for a longer period of time. Thus, well aggregated soils required P fertilization earlier than the poorly aggregated soils.

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