

## **Chapter – IV**

*Results and Discussion*

## 4. RESULTS AND DISCUSSION

### Characteristics of Soils Used

Some relevant physical and chemical characteristics of soils used in these studies were presented in Table 7 and 8. Soils of tea garden and orchard were strongly to moderately acidic, while soils of cultivated land and forest were strongly acidic to neutral in reaction. Electrical conductivity of *terai* soils were low ( $<1 \text{ dSm}^{-1}$ ) ranging from 0.003 to  $0.074 \text{ dSm}^{-1}$ . The average organic carbon content of these soils were high ( $>7.5 \text{ gkg}^{-1}$ ) which probably highly influenced the cation exchange capacity as indicated by having the same trend. Organic carbon and cation exchange capacity of the soils under various land uses was in the order: cultivated land  $<$  orchard  $<$  tea garden  $<$  forest. Soils of tea garden and orchard were loamy sand to loam while soils of cultivated land and forest were sandy loam to loam in texture. Cultivated land soils recorded the highest average base saturation (48.4%) followed by the soils of forest (28.4%), orchard (12.6%) and the least in tea garden (9.0%) while reverse was the trend with respect to Al saturation percent of ECEC. Average exchangeable  $\text{Al}^{3+}$  content was maximum in orchard soil followed by tea garden, forest and cultivated land; reverse was the sequence of pH of these land use soils indicating the former's contribution to the latter.

Range and mean values of different types of acidities under various land uses were also presented in Table 8. The soils under tea garden exhibited maximum total potential acidity, pH-dependent acidity, hydrolytic acidity, extractable  $\text{Al}^{3+}$  and non-exchangeable  $\text{Al}^{3+}$  followed by orchard, forest and cultivated land whereas exchange acidity and total acidity followed the order: orchard soil  $>$  tea garden soil  $>$  forest soil  $>$  cultivated land soil. The electrostatically bound  $\text{H}^+$  constituted 17.2 to 20.5 per cent of exchange acidity while pH-dependent acidity contributed 86.4 to 93.4 per cent of total potential acidity. Lower values of acidity in cultivated land was probably because of less amount of exchangeable  $\text{Al}^{3+}$  and organic matter, and organic matter might have contributed to some forms of acidity through their functional group like  $-\text{COOH}$

**Table 7. Some Physico-Chemical Properties of soils *terai* Zone of West Bengal**

Soil Characters	Range	Mean	CV %
pH(1:2.5)	3.7-7.13	5.12	15
EC $\times 10^2$ (dSm $^{-1}$ )	0.33-7.40	1.46	93
Organic C(gkg $^{-1}$ )	4.5-26.2	13.4	36
Clay(gkg $^{-1}$ )	92-254	151	23
Silt (gkg $^{-1}$ )	174 -491	285	26
CEC[cmol(p+)kg $^{-1}$ ]	4.67 - 28.8	16.29	34
AEC[cmol(p+)kg $^{-1}$ ]	1.68 - 5.66	3.92	20
Exchangeable(Ca+Mg)[ $^m$ ]	0.50- 9.80	3.17	82
Exchangeable K[ $^m$ ]	0.02- 0.82	0.15	96
Total Acidity [ $^m$ ]	0.25 - 8.36	3.15	73
Exchange Acidity [ $^m$ ]	0.22 - 5.47	1.83	77
Hydrolytic Acidity [ $^m$ ]	0.01- 4.98	1.34	87
Total Potential acidity [ $^m$ ]	3.29 - 32.90	17.66	46
pH dependent acidity [ $^m$ ]	4.50 - 29.51	15.83	45
Exchangeable Al $^{3+}$ [ $^m$ ]	0.34 - 8.11	4.98	39
Extractable Al $^{3+}$ [ $^m$ ]	0.12 - 6.42	3.14	47
Non-exchangeable Al $^{3+}$ [ $^m$ ]	0.17 - 4.77	1.50	79
Free Fe $_2$ O $_3$ (gkg $^{-1}$ )	3.19 - 14.56	8.64	25
Bulk density(gcm $^{-3}$ )	0.92 - 1.37	1.12	09
Particle Density (gcm $^{-3}$ )	1.79 - 2.67	2.27	08
Base saturation (%)	3.0 - 72.9	24.6	81.4
ECEC [ cmol (P $^+$ ) kg $^{-1}$ ]	2.27 - 14.62	4.84	41.2
Al saturation of ECEC (%)	1.2 - 82.9	36.6	74.6
Available N (mgkg $^{-1}$ )	72 - 319	146	37

Table 8. Some Physico-chemical properties of soils under different land use patterns

Land use patterns Soil characters	Tea Garden			Orchard			Cultivated Lnad			Forest		
	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)
pH (1:2.5)	3.7-5.54	4.78	10	3.84-5.85	4.86	16	4.80-7.13	5.67	12	4.64-6.90	5.34	14
EC $\times 10^2$ ( $\text{dsm}^{-1}$ )	0.33-5.94	1.33	105	0.34-7.40	1.63	115	0.48-4.41	1.44	80	0.57-4.07	1.46	68
Organic C ( $\text{gkg}^{-1}$ )	4.5-25.4	14.2	32	7.0-18.3	13.9	27	7.0-12.4	8.9	16	9.3-26.2	16.5	34
Clay ( $\text{gkg}^{-1}$ )	112-172	139	16	102-174	143	15	154-254	192	15	92-182	130	21
Silt ( $\text{gkg}^{-1}$ )	180-331	273	17	174-425	275	30	200-323	262	22	234-491	328	26
CEC [ $\text{cmol (p+) kg}^{-1}$ ]	9.75-28.80	18.22	26	9.75-24.14	18.16	23	4.67-13.56	10.44	23	9.33-26.68	18.36	32
AEC [ $\text{cmol (p+) kg}^{-1}$ ]	2.04-5.66	4.17	18	2.45-4.65	4.06	59	1.68-4.45	3.40	30	2.85-5.38	4.05	12
Exchangeble (Ca+Mg) [ $\text{cmol (p+) kg}^{-1}$ ]	0.50-2.80	1.28	43	0.85-4.20	1.77	63	2.85-9.80	4.68	37	2.10-9.35	4.75	74
Exchangeable K [ $\text{cmol (p+) kg}^{-1}$ ]	0.30-0.80	0.23	84	0.02-0.82	0.16	128	0.02-0.19	0.10	56	0.03-0.23	0.14	42
Total acidity [ " ]	1.23-8.36	4.37	50	1.23-7.74	4.67	49	0.25-1.97	0.99	40	0.25-5.66	2.58	65
Exchange acidity [ " ]	1.09-3.94	2.26	38	0.44-5.47	3.00	60	0.22-1.53	0.61	69	0.22-2.63	1.46	62
Hydrolytic acidity [ " ]	0.01-4.98	2.14	74	0.79-3.06	1.68	45	0.01-0.79	0.38	61	0.03-3.03	1.15	91
Total Potential acidity [ " ]	18.10-32.90	25.56	16	4.94-29.61	20.18	38	4.94-13.16	9.54	23	3.29-24.68	15.36	47

Land use patterns Soil characters	Tea Garden			Orchard			Cultivated Lnad			Forest		
	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)
pH- dependent acidity [cmol (p+) kg <sup>-1</sup> ]	16.79-29.51	23.29	16	4.50-25.78	17.18	37	4.50-12.83	8.93	24	5.71-22.82	13.90	47
Extractable Al <sup>3+</sup> [ " ]	5.52-8.11	6.42	11	2.93-8.11	5.90	24	0.34-6.04	3.00	51	0.34-8.11	4.59	43
Non- exchangeable Al <sup>3+</sup> [ " ]	1.58-6.03	4.16	26	0.14-6.42	2.89	54	0.12-4.94	2.39	53	0.12-6.25	3.13	46
Exchangeable Al <sup>3+</sup> [ " ]	0.91-3.18	1.85	35	0.23-4.77	2.47	62	0.17-1.14	0.47	64	0.17-2.39	1.21	65
Free Fe <sub>2</sub> O <sub>3</sub> (gkg <sup>-1</sup> )	6.98-14.56	9.02	27	6.71-12.66	9.76	17	3.19-10.29	7.18	26	5.63-11.58	8.60	20
Bulk density (gcm <sup>-3</sup> )	1.02-1.25	1.15	06	1.05-1.37	1.15	07	0.93-1.19	1.06	07	0.92-1.31	1.11	12
Particle density (gcm <sup>-3</sup> )	2.04-2.62	2.27	07	1.87-2.67	2.24	08	1.79-2.38	2.22	09	1.82-2.48	2.33	09
Base saturation (%)	3.0-19.7	9.0	49.8	4.1-31.4	12.06	80.6	31.8-72.9	48.4	26.9	10.5-72-6	28.4	66.5
ECEC [cmol (p <sup>+</sup> )Kg <sup>-1</sup> ]	2.27-4.51	3.36	18.2	3.28-5.67	4.47	16.7	3.68-10.07	5.45	28.7	3.83-14.62	6.09	48.7
Al sataration of ECEC (%)	23.2-74.9	56.1	28.6	5.5-82.9	54.0	53.8	1.8-26.6	9.8	78.3	1.2-55.1	26.3	71.9
Available N (mgkg <sup>-1</sup> )	98-187	141	21	72-285	147	47	98-319	129	43	94-238	167	31

and phenolic- OH. Free  $\text{Fe}_2\text{O}_3$  content in the soils of different land use patterns followed the sequence of orchard > tea garden > forest > cultivated land. Exchangeable  $\text{Al}^{3+}$  alone could explain 99% variation in exchange acidity. Exchangeable  $\text{Al}^{3+}$  and cation exchange capacity collectively could explain 91% and 76% variation in total acidity and total potential acidity, respectively. While 76% variability in pH-dependent acidity could be explained by cation exchange capacity and extractable  $\text{Al}^{3+}$  (Table 9).

## 4.1 Distribution of soil Phosphorus in Organic and Inorganic Fractions

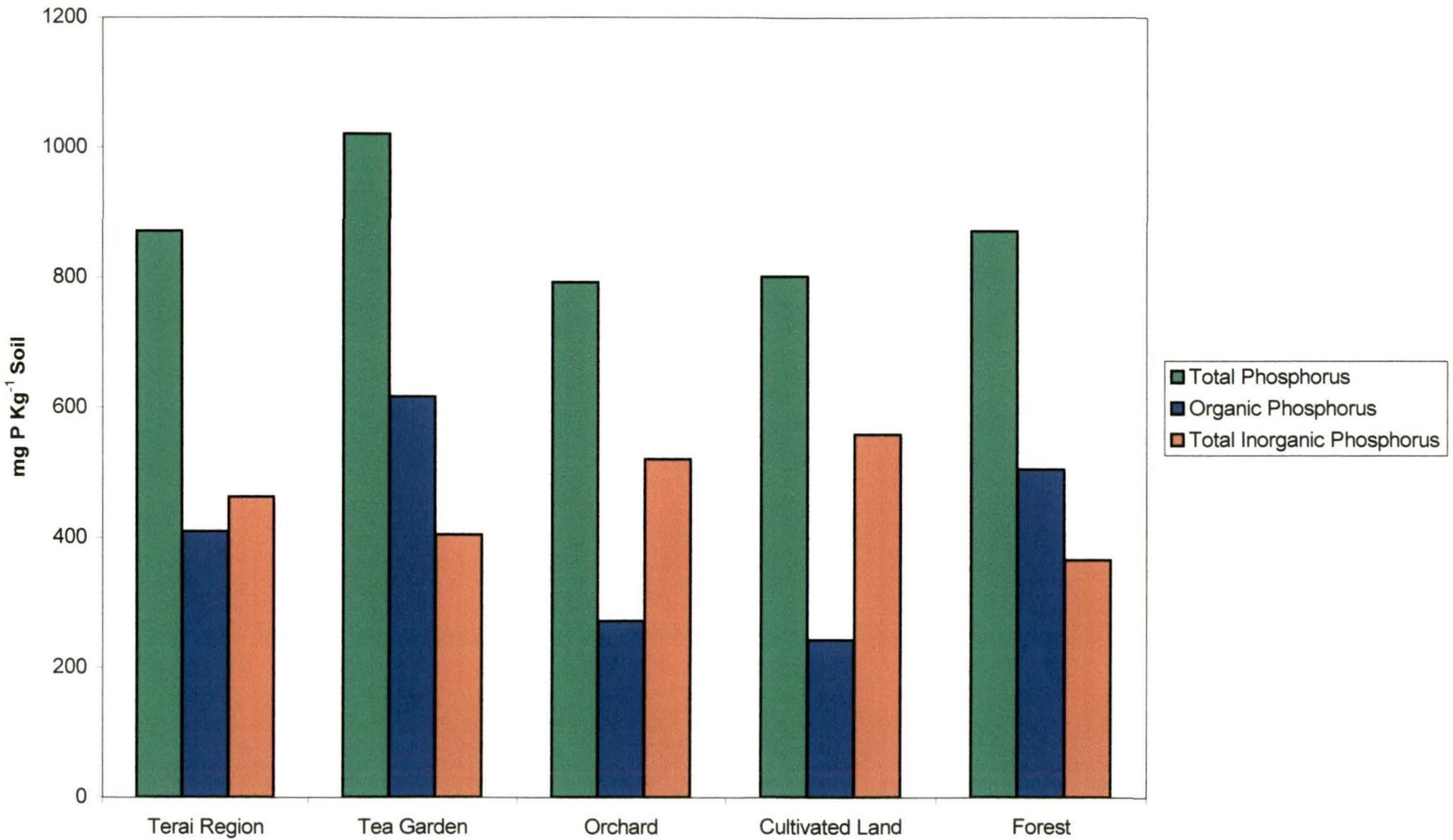
### 4.1.1 Total P

The total P content in *terai* soils of West Bengal ranged from 293 to 1868  $\text{mgkg}^{-1}$  with an average of 871  $\text{mgkg}^{-1}$  which was recorded somewhat higher than P content in *terai* soil of U.P. (350  $\text{mgkg}^{-1}$ ) (Bhar and Tripathi, 1973). Among the different land use patterns, soils of tea garden contained the highest amount of total P ranging from 293 to 1737  $\text{mgkg}^{-1}$  with an average of 1020  $\text{mgkg}^{-1}$  followed by 293 to 1868  $\text{mgkg}^{-1}$  with an average of 871  $\text{mgkg}^{-1}$  in forest, 425 to 1212  $\text{mgkg}^{-1}$  with an average of 801  $\text{mgkg}^{-1}$  in orchard soils (Table- 10, 11 and Fig.3 ). Substantially higher amount of total P in tea garden soils than the others may be due to higher amount of P fertilizer application for tea production, Total P in *terai* soils showed a significant positive relationship with CEC ( $r=0.426^{**}$ ), organic C ( $r=0.337^{**}$ ) AEC ( $r=0.372^{**}$ ) while a negative relationship with exchangeable Ca and Mg ( $r= -0.464^{**}$ ) (Table-13).

### 4.1.2 Organic P

Organic P content of *terai* soils varied from 16 to 1574  $\text{mgkg}^{-1}$  with a mean of 409  $\text{mgkg}^{-1}$ . Organic P content constituted roughly 47 per cent of total P. The coefficient of variation of organic P was found to be 86.1%. The proportion of this form of P to total P varied directly with the organic matter content of the soil which

**Fig. 3** Distribution of Soil Phosphorus in *Terai* agroclimatic region and its land uses



was well supported by the highly significant positive relationship with organic carbon ( $r=0.466^{**}$ ). Organic P content also had significant correlation with AEC ( $0.280^*$ ) and CEC ( $r=0.472^{**}$ ) of the soil (Table-13). For each unit increase in organic carbon organic P content of *terai soils* increased by 33.8 unit. The coefficient of variation of total P was 45.7, 45.4, 36.1, 35.5 and 58.0 per cent for *terai* (overall), tea garden, orchard, cultivated land and forest soils respectively. On the basis of organic P content in soils, tea garden land use was significantly different from orchard and cultivated land uses. However, no significant difference was observed among forest, orchard and cultivated land uses in this respect. Highest amount of organic P was recorded in tea garden ranging between 33 and 1312  $\text{mgkg}^{-1}$  with an average of 616  $\text{mgkg}^{-1}$  followed by 47 and 1574  $\text{mgkg}^{-1}$  with a mean of 505  $\text{mgkg}^{-1}$  in forest soils, 43 and 672  $\text{mgkg}^{-1}$  with a mean of 271  $\text{mgkg}^{-1}$  in orchard soils and 16 to 443  $\text{mgkg}^{-1}$  with a mean of 242  $\text{mgkg}^{-1}$  in cultivated land soils.

#### 4.1.3 Total Inorganic P

Total inorganic P which was calculated as the difference between total P and organic P ranged from 150 to 1154  $\text{mgkg}^{-1}$  with a mean of 462  $\text{mgkg}^{-1}$  and constituted about 53 per cent of total P (Table-10, 12 and Fig-3). Total inorganic P content in different land use patterns followed more or less a reverse trend as was observed with total P. However, the extent of variation in this form among the land uses were relatively less in comparison to organic P. Highest amount of inorganic P was recorded in cultivated land soils (average being 538  $\text{mgkg}^{-1}$ ) while the least was recorded in forest soils (average being 365  $\text{mgkg}^{-1}$ ). Soils of tea garden, orchard, cultivated land and forest contained 39.6%, 65.7%, 69.7% and 41.9% of total P as inorganic P, respectively. Patigiri and Datta (1993) and Khan and Mondal (1973) observed that inorganic P in tea growing soils of Assam and rice growing soils of West Bengal constituted 54% and 65% of total P, respectively.

**Table 9. Stepwise regression equations for predicting different types of acidity (Y) by using soil properties.**

Regression Equations	R <sup>2</sup>
<b>Exchange Acidity</b> Y = 0.45±0.096*+0.03+1.19 X <sub>1</sub>	0.99
<b>Total Acidity</b> Y = 0.45±0.78+0.23+1.81 X <sub>1</sub>	0.83
= -1.30±0.56+0.22+1.27 X <sub>1</sub> +0.05+0.16 X <sub>2</sub>	0.91
<b>Total Potential Acidity</b> Y = 8.16±4.15+1.21+6.40 X <sub>1</sub>	0.68
= 0.71±3.54+1.41+4.21 X <sub>1</sub> +0.29+0.67 X <sub>2</sub>	0.76
<b>pH- dependent Acidity</b> Y = -2.0±4.0+0.24+1.08 X <sub>2</sub>	0.60
= -4.79±3.11+0.21+0.75 X <sub>2</sub> +0.56+1.67X <sub>3</sub>	0.76

X<sub>1</sub>, X<sub>2</sub> and X<sub>3</sub> denote exchangeable Al<sup>3+</sup>, CEC and extractable Al<sup>3+</sup>, respectively.

\* Standard error of estimate.

**Table. 10. Amount of P forms (mgkg<sup>-1</sup>) in soils of *terai* agroclimatic Zone**

Soil P form	Range	Mean	CV (%)
Total P	293-1868	871	45.7
Org.P	16-1574	409	86.1
Total Inorg. P	150-1154	462	51.4
Ca P	Trace-561	163	90.8
Fe-P	10-668	114	110.7
Al-P	9-277	64	101.0
RS-P	5-411	111	88.7
Occl-P	3-35	10	50.7

Total inorganic P had a significant positive relationship with exchangeable Ca and Mg ( $r=0.446^{**}$ ). A significant association of total inorganic P with the basic cations like Ca and Mg in these acidic soils signified that the soils were relatively young and immature (Hsu and Jackson, 1960). Soils of this agroclimatic regions, in fact, developed from the deposits brought down from the Himalayan hills and belong to the orders of Entisol and Inceptisol (Anonymous, 1997-98) which supports the above findings. Proportion of inorganic P to total P showed a significant positive relationship with clay content ( $r=0.270^*$ ) but negative relationship with CEC ( $r=-0.321^*$ ) and organic carbon content ( $r=-0.428^{**}$ ), thus indicated that the actual site of inorganic P in soil was the clay fractions.

#### 4.1.3.1 Forms of Inorganic P

Among the different fractions of inorganic P (Chang and Jackson, 1957), Ca-P was the dominant form, contributed about 35.3% of total inorganic P and 18.7% of total P in *Tarai* soils. Different forms of inorganic P in *terai* soils followed the order of Ca-P (varying between trace and  $561 \text{ mgkg}^{-1}$  with a mean of  $163 \text{ mgkg}^{-1}$ ) > Fe-P (varying between 10 to  $668 \text{ mgkg}^{-1}$  with a mean of  $114 \text{ mgkg}^{-1}$ ) > RS-P (varying from 5 to  $411 \text{ mgkg}^{-1}$  with an average of  $111 \text{ mgkg}^{-1}$ ) > Al-P (ranging from 9 to  $277 \text{ mgkg}^{-1}$  with an average of  $64 \text{ mgkg}^{-1}$ ) > Occl-P (ranging 3 to  $35 \text{ mgkg}^{-1}$  with a mean value of  $10 \text{ mgkg}^{-1}$ ) (Table- 10). Fe-P, RS-P, Al-P and Occl-P constituted 24.7, 24.0, 13.9 and 2.2 per cent of total inorganic P, while 13.1, 12.7, 7.3 and 1.1 per cent of total P, respectively, in *terai* agroclimatic soils of West Bengal (Table- 12 and Fig. 4). Doddamani and Rao (1988) also observed similar order of distribution of various inorganic P-fractions in some soil samples of Inceptisols in Karnataka.

The sequence of different inorganic P fractions in various land use patterns were not the same and not consonance with that of overall *terai* soils. In forest land use soils Ca-P ( $173 \text{ mgkg}^{-1}$ ) was the dominant fraction, followed by Fe-P ( $79 \text{ mgkg}^{-1}$ ), RS-P ( $71 \text{ mgkg}^{-1}$ ), Al-P ( $35 \text{ mgkg}^{-1}$ ) and Occl-P ( $7 \text{ mgkg}^{-1}$ ) (Table- 11). The sequence was the same as was observed for overall *terai* soils.

**Fig. 4 Different fractions of soil inorganic Phosphorus in Terai agroclimetic region and its land uses**

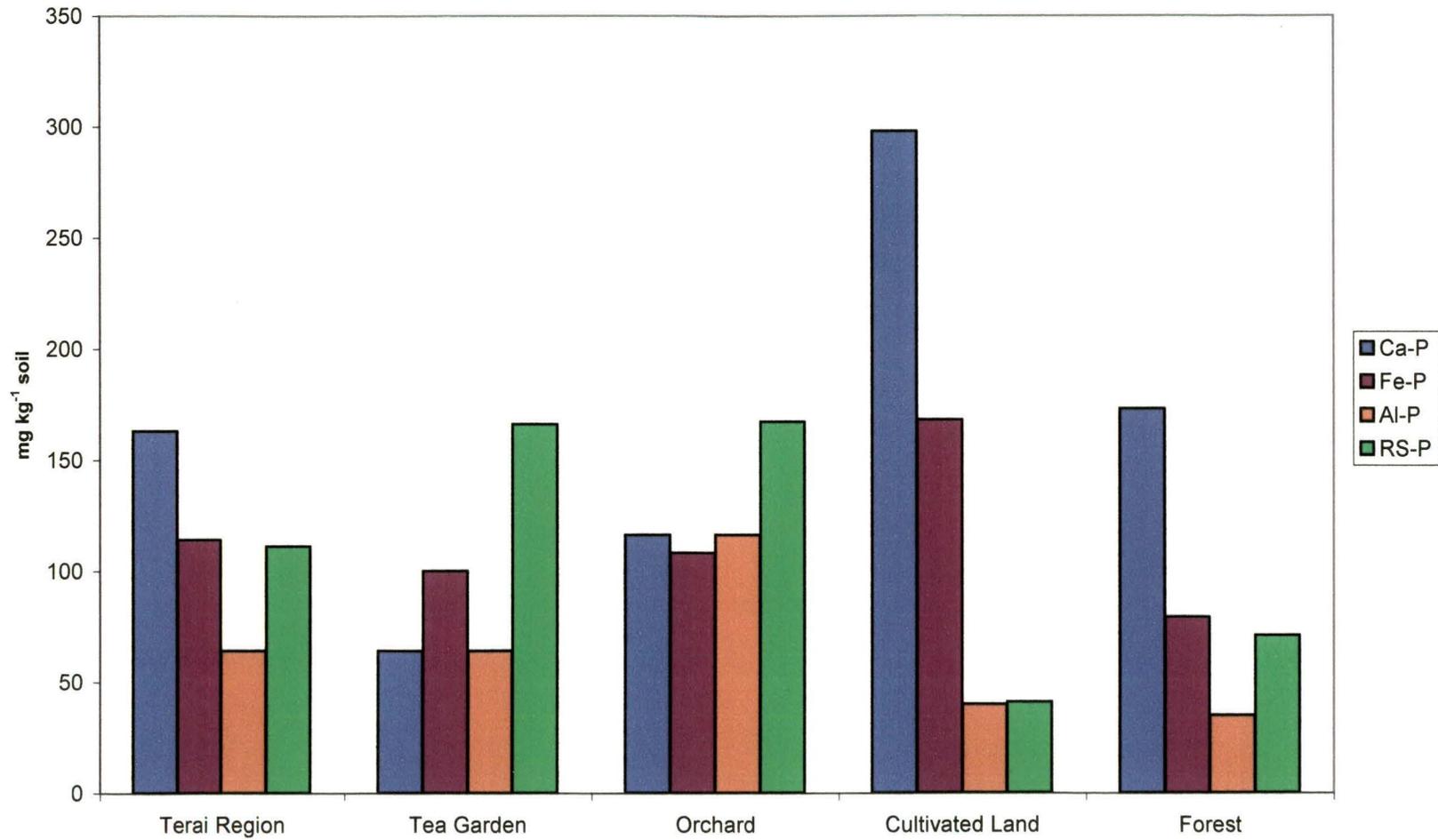


Table 11. Amount of P forms (mgkg<sup>-1</sup>) in soils under different land use patterns

Land use patterns Soil P- forms	Tea Garden			Orchard			Cultivated Lnad			Forest			S. Em(±)	C.D. <sub>1%</sub>
	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)		
Total P	293-1737	1020	45.5	293-1343	792	36.1	425-1212	801	35.5	293-1868	871	58.0	102.3	N.S
Org.P	33-1312	616	68.0	43-672	271	61.9	16-443	242	58.1	47-1574	505	86.8	83.26	303.32
Total Inorg. P	193-837	404	51.7	165-896	520	39.8	222-1154	558	54.4	150-637	365	47.7	59.0	N.S
Ca P	Trace-279	64	119.7	128-405	116	101.2	104-561	298	45.6	30-468	173	84.5	31.51	114.79
Fe-P	50-258	100	60.1	10-253	108	71.5	27-668	168	132.1	36-236	79	71.4	32.1	N.S
Al-P	9-197	64	96.3	20-277	116	71.6	12-112	40	76.2	9-135	35	103.4	14.72	53.62
RS-P	39-404	166	53.8	5-411	167	73.8	5-114	41	79.8	5-180	71	79.5	21.37	77.85
Occl-P	3-16	10	39.6	6-19	13	28.2	5-35	11	36.0	3-12	7	36.0	1.21	4.41

In case of cultivated land soils, though Ca-P ( $298 \text{ mgkg}^{-1}$ ) was the dominant inorganic P form but Fe-P ( $168 \text{ mgkg}^{-1}$ ) rather than RS-P ( $41 \text{ mgkg}^{-1}$ ) occupied the second highest position. In cultivated land soils of *terai* agro-climatic region Ca-P, Fe-P, RS-P, Al-P and Occl-P constituted 53.4, 30.1, 7.4, 7.2 and 2.0 per cent of total inorganically bound P (Table- 12). Khan and Mondal (1973) observed that the different forms of inorganic P followed the same sequence in rice growing soils of West Bengal and the various forms more or less contributed similar extent towards total inorganic P. With respect to Ca-P content in soils of various land uses, cultivated land use was significantly different from others, however, soils of orchard were at par with tea garden and forest. Again, orchard soils differed significantly from the soils of cultivated land and forest, but cultivated land soils had no significant difference from forest and tea garden soils on their Al-P content. In orchard and tea garden soils the dominant fraction was RS-P. However, there were not too much differences in the average content of Ca-P ( $116 \text{ mgkg}^{-1}$ ), Fe-P ( $108 \text{ mgkg}^{-1}$ ), Al-P ( $116 \text{ mgkg}^{-1}$ ) in orchard soils while that in tea garden soils were RS-P ( $166 \text{ mgkg}^{-1}$ ) followed by Fe-P ( $100 \text{ mgkg}^{-1}$ ), Ca-P ( $64 \text{ mgkg}^{-1}$ ), Al-P ( $64 \text{ mgkg}^{-1}$ ). Similar order in the distribution of inorganic P forms in some acidic Entisols from East Khasi hill district of Meghalaya was observed by Patiram *et al.* (1993), in tea growing soils of Himachal Pradesh by Rao and Chakraborty *et al.* (1994) and in acidic soils of Bihar by Chattopadhyay and Kar (1973). Dominance of RS-P in these two land uses was probably due to the relative abundance of free ferric oxide. Though, the soils of cultivated land and forest were at par among them but were significantly different from tea garden and orchard soils with regard to their RS-P content. However, no significant difference was noticed between the later two land uses. In all the land use patterns soils Occl-P contributed the least towards inorganic-P and the saloid-bound P in soils recorded too negligible quantity to mention. Except forest and orchard soils, the land uses did not differ significantly among themselves on the basis of their Occl-P content.

#### 4.1.4 Relation between Forms of Inorganic P and Soil Properties

Al-P ( $r = -0.501^{**}$ ) and RS-P ( $r = -0.573^{**}$ ) had significant negative relationship with pH while Ca-P ( $r = 0.620^{**}$ ) had a positive relation (Table-13). For each unit increase in soil pH, the Al-P and RS-P content of *terai* soils decreased by 41.7 and 73.0 unit, respectively, while Ca-P increased by 119.9 unit. Availability of P from both Ca-P and Al-P is a pH controlled process. It is worth mentioning that Al system is more stable at low pH where Ca system is unstable. Conversely, the Ca-system is more stable under high pH where Al system is unstable. Exchangeable Ca plus Mg had significant positive correlation with Ca-P ( $r = 0.766^{**}$ ) as well as total inorganic P ( $r = 0.446^{**}$ ) but negative with Al-P ( $r = -0.384^{**}$ ), RS-P ( $r = -0.483^{**}$ ) and total P ( $r = -0.464^{**}$ ). Likewise exchangeable Al had positive relationship with Al-P ( $r = 0.673^{**}$ ), RS-P ( $r = 0.664^{**}$ ) and Occl-P ( $r = 0.340^{**}$ ) but reverse with Ca-P ( $r = -0.559^{**}$ ). Ca-P and RS-P content in these soils decreased with increase in organic carbon content probably through complexation of Ca and Fe by organic anions produced during mineralisation of organic residues (Vig *et al.*, 2000). Both the exchange capacities i.e. CEC and AEC had positive relationship with Al-P ( $r = 0.361^{**}$  and  $0.443^{**}$ ), RS-P ( $r = 0.489^{**}$  and  $0.527^{**}$ ), organic P ( $r = 0.472^{**}$  and  $0.280^{*}$ ) and total P ( $r = 0.426^{**}$  and  $0.372^{**}$ ) while negative with Ca-P ( $r = -0.284^{*}$  and  $-0.375^{**}$ ). Proportion of inorganic P to total P increased with increase in clay content ( $r = 0.270^{*}$ ) while decreased with increase in CEC ( $r = -0.321^{*}$ ) and organic carbon ( $r = -0.428^{**}$ ).

#### 4.1.5 Contribution of P Forms towards Total P

Stepwise regression analysis (Table- 14) indicated that organic P alone could explain 64.6% variability in total P and partial contribution of different inorganic P forms were: 20.10% by Fe-P, 3.90% by RS-P, 10.20% by Ca-P, 1.10% by Al-P and only 0.01% by Occl-P.

Table 12. Contribution of different P- forms (%) in soils towards total P/total inorganic P

Land use patterns	Terai soil		Tea garden soil		Orchard soil		Cultivated land soil		Forest soil	
	% of total P	% of total Inorg. P	% of total P	% of total Inorg. P	% of total P	% of total Inorg. P	% of total P	% of total Ins. P	% of total P	% of total Inorg. P
Org.P	47	-	60.4	-	34.2	-	30.2	-	58.0	-
Total Inorg. P	53	-	39.6	-	65.7	-	69.7	-	41.9	-
Al-P	7.3	13.9	6.3	15.8	14.7	22.3	5.0	7.2	4.2	5.6
Fe-P	13.1	24.7	9.80	24.8	13.6	20.8	21.0	30.1	9.1	21.6
Ca-P	18.7	35.3	6.3	15.8	14.7	22.3	37.2	53.4	19.9	47.4
RS-P	12.7	24.0	16.3	41.1	21.1	32.1	5.1	7.4	8.2	19.4
Occl P	1.1	2.2	1.0	2.48	1.6	2.5	1.4	2.0	1.0	1.92

Table 13 . Correlation coefficients (r) between P fractions and soil properties

Soil Properties \ P-forms	P-forms								
	Al-P	Fe-P	Ca-P	RS-P	Occl-P	Total inorg.P	Org.P	Total P	$\frac{\text{Total inorg.P}}{\text{Total P}}$
Clay	-0.217	0.125	0.453**	-0.312*	-0.101	0.148	-0.227	-0.144	0.270*
Silt	-0.301*	-0.076	0.218	-0.292*	-0.027	-0.115	0.143	0.057	-0.208
CEC	0.361**	-0.132	-0.284*	0.489**	0.209	0.066	0.472**	0.426**	-0.321*
AEC	0.443**	0.186	-0.375**	0.527**	0.099	0.207	0.280*	0.372**	-0.135
pH	-0.501**	-0.133	0.620**	-0.573**	-0.113	-0.064	-0.093	-0.080	0.096
Org. C	-0.040	-0.103	-0.410**	-0.342**	0.040	-0.131	0.466**	0.337**	-0.428**
Ex (Ca+Mg)	-0.384**	-0.006	0.766**	-0.483**	-0.086	0.446**	-0.167	-0.464**	0.246
Ex. Al	0.673**	-0.039	-0.559**	0.664**	0.340**	0.062	0.137	0.149	-0.131
E.C.	0.130	0.165	0.163	0.091	0.177	0.229	-0.166	-0.072	0.249

\* and \*\* indicate 5% and 1% level of significances, respectively.

#### 4.1.6 Soil P Forms and Plant Parameters

Simple correlation coefficient ( $r$ ) between soil P forms and dry matter yield as well as P-uptake by wheat were presented in Table- 15.

Aluminium bound phosphorus (Al-P) fraction had a highly significant correlation with dry matter yield of wheat in soils under all the land use patterns. P-uptake by wheat in soils of tea garden, cultivated land and forest were also significantly related to Al-P whereas that for soils of orchard was not significant. Iron-bound phosphorus (Fe-P) in soils of all land use patterns were significantly related to both dry matter yield and P-uptake by wheat. Thus, Al-P and Fe-P were the active inorganic P forms, which controlled the P nutrition in these soils. Similar results were also reported by Mongia and Bandopadhyay (1996) and Rabindra and Ananthanarayana (1999) working with the acid soils of India. In tea garden soils, Ca-P had a significant positive relationship ( $r= 0.517^*$ ) with the P-uptake by wheat suggesting the role of this inorganic P forms in addition to Al-P and Fe-P on P nutrition in this land use soils.

Total P content of the soils of all land use patterns except forest were significantly related with dry matter yield of wheat and was also highly significantly related with P-uptake by wheat in soils of cultivated land use and eventually overall terai agro-climatic zone of West Bengal. Total inorganic P-forms of soils of all land use patterns except forest were significantly related to dry matter yield and P-uptake by wheat. However, no significant relationship was noted between organic P content of soils under all the land use patterns and either of the plant parameter. Therefore, significant positive relationship of total P with dry matter production and P-uptake in some cases was simply an indirect contribution of total inorganic P to total P.

Reductant soluble phosphorus (RS-P) showed positive significant relationship only with dry matter yield of wheat grown in the soils of tea garden and with both the plant parameter for soils of forest. The increase of dry matter yield ( $r= 0.603^*$ ) and P-uptake ( $r= 0.700^{**}$ ) by wheat in forest soils with increase

in RS-P indicated that this form also acted as a potential source of available P through solubilization or removal of  $\text{Fe}(\text{OH})_3$  coating around the soil particles by organic acid produced during mineralization of organic residues and thereby release of soluble Fe-P as these soils were rich in organic carbon.

In the soils of *terai* agro-climatic zone of West Bengal both the plant parameters were highly significantly related to total inorganic-P, Al-P, Fe-P. Based on the above information stepwise multiple regression analysis was worked out between total P-uptake and inorganic P fractions (Table- 16). It showed that 86 per cent of the variation in P-uptake under forest land use was explained by Al-P and RS-P, of which 81.7% of the variation was explained by the Al-P fraction alone. In case of tea garden soils, Al-P contributed 36.2 per cent variability in P-uptake while 57.8 per cent variability was explained when another potential variable Occl-P was included in the equation. However, Al-P and Fe-P alone could explain 84.2 and 38.2 per cent variation in P-uptake in cultivated land and orchard soils, respectively. No other P form could significantly influence the P uptake by wheat in these land use soils.

Thus, the result revealed that with an exception of orchard soils, Al-P was the major source of plant available P as it alone could explain 81.7%, 36.2% and 84.2% of variation in P-uptake of forest, tea garden and cultivated land soils respectively, while in orchard soils Fe-P controlled the P nutrition to wheat. These observations were similar to those of Mongia and Bandopadhyay (1996) and Sharma *et al.* (1995).

Though, all forms of P in soil were known to supply the nutrient to the soil solution, their relative contribution to labile pool from where plants absorbs the nutrient depends mainly on the solubility and relative share of several phosphatic compounds as influenced by the characteristics of the soils. In acid soils, although Fe-P and Al-P are less soluble, yet crops have utilised more of these forms of P which might be due to their relatively high share in soil P (Khera and Balloli, 1994). The observation in this study was also in compliance with that of Ramamoorthy and Basin (1979) and Sharma and Dev (1974) who noticed that wheat crop preferentially absorbed P from Al-P form.

Table 14. Stepwise regression equations of total P with soil P forms.

Equations	R <sup>2</sup>	ΔR <sup>2</sup>	Eqn. No.
Total P= 498 + 0.91 Org. P	0.646	-	(1)
= 323 + 0.95 Org. P + 1.42 Fe-P	0.847	0.201	(2)
= 252 + 0.91 Org. P + 1.38 Fe-P + 0.82 RS-P	0.886	0.039	(3)
= 11+0.99 Org. P+1.22 Fe-P+1.42 RS-P+0.97 Ca-P	0.988	0.102	(4)
= 0.5+1.03 Org. P + 1.0 Fe-P+ 1.0 RS-P + 1.0 Ca-P + 1.04 Al-P	0.999	0.011	(5)
= 0.5+1.03 Org. P+ 1.0 Fe-P + 1.0 RS-P + 1.0 Ca-P + 1.0 Al-P+ 1.03 Occl-P	1.000	0.0001	(6)

Table 15. Simple correlation coefficients ( r ) between soil P forms and dry matter yield and P uptake by wheat

Land use patterns		<i>Terai</i> Soil	Tea garden Soil	Orchard Soil	Cultivated land Soil	Forest Soil
Soil P forms						
Total P	A	0.249	0.840*	0.657**	0.591*	0.431
	B	0.388**	0.285	0.424	0.806**	0.321
Org.P	A	0.175	0.181	0.262	0.321	0.341
	B	0.014	-0.003	-0.066	0.018	0.170
Total Inorg.P	A	0.505**	0.834**	0.693**	0.372	0.392
	B	0.624**	0.633**	0.638*	0.750**	0.506
Al-P	A	0.515**	0.872**	0.580*	0.558*	0.767**
	B	0.391**	0.638*	0.351	0.924**	0.911**
Fe-P	A	0.483**	0.782**	0.655**	0.460	0.770**
	B	0.716**	0.536*	0.652**	0.822**	0.888**
Ca-P	A	-0.092	0.288	0.002	-0.011	-0.280
	B	0.184	0.517*	0.439	0.154	-0.252
RS-P	A	0.366**	0.570*	0.347	0.039	0.603*
	B	0.075	0.253	-0.001	-0.287	0.700**
Occl-P	A	0.398**	0.023	0.340	0.457	0.484
	B	0.009	-0.394	0.231	0.421	0.406

A and B stand for dry matter yield and P-uptake by wheat, respectively, \* and \*\* indicate 5% and 1% level of significance, respectively.

Table 16. Stepwise regression ( $R^2$ ) between soil P fractions and P uptake by wheat (Y)

Equations	$R^2$	$\Delta R^2$	Equation No.
<b>Forest Soil</b>			
Y= 1.10 + 0.093 AI-P	0.817	-	(1)
= 0.39 + 0.077 AI-P + 0.018 RS-P	0.861	0.041	(2)
<b>Tea Garden Soil</b>			
Y= 7.17 + 0.047 AI-P	0.362	-	(3)
= 12.45 + 0.052 AI-P + 0.566 Occl-P	0.578	0.216	(4)
<b>Cultivated Soil</b>			
Y= 1.98 + 0.216 AI-P	0.842	-	(5)
<b>Orchard Soil</b>			
Y= 2.77 + 0.035 Fe-P	0.382	-	(6)

## 4.2 Selection of the most Suitable Available P Index

### 4.2.1 Available Soil P Estimates

The results of five extracting methods (Olsen, Bray-1, Bray-2, Mehlich-1, and AB-DTPA) for the soils of *terai* region and its various land use patterns e.g. tea garden, orchard, cultivated land and forest were shown in Table 17. From *terai* soils of West Bengal, Bray-2 extractant released the highest amount of P ranging from 9 to 339 mgkg<sup>-1</sup> with an average of 80 mgkg<sup>-1</sup>, followed by Mehlich-1 varying from 1 to 113 mgkg<sup>-1</sup> with the mean of 27 mgkg<sup>-1</sup>, Olsen varying from 3 to 177 mgkg<sup>-1</sup> with the mean of 26 mgkg<sup>-1</sup>, Bray-1 varying from 1 to 110 mgkg<sup>-1</sup> with the mean value of 20 mgkg<sup>-1</sup> and AB-DTPA varying from 4 to 75 mgkg<sup>-1</sup> with an average of 19 mgkg<sup>-1</sup>. The higher solubility of Bray-2 may be due to its relatively higher strength of acid, complexing of Al<sup>3+</sup> and Fe<sup>3+</sup> with F<sup>-</sup> ion and consequent release of P adsorbed by these trivalent ions (Ballard). Further inclusion of acids results in the dissolution of the more active Ca-P and prevents the precipitation (as calcium phosphate) of water-soluble P removed during extraction (Jackson, 1973).

Among the various land use patterns, soils of cultivated land contained the highest amount of Olsen-P ranging from 6 to 177 mgkg<sup>-1</sup> with an average of 47 mgkg<sup>-1</sup>, followed by 3 to 74 mgkg<sup>-1</sup> with an average of 25 mgkg<sup>-1</sup> in orchard, 3 to 60 mgkg<sup>-1</sup> with an average of 17 mgkg<sup>-1</sup> in tea garden, 3 to 92 mgkg<sup>-1</sup> with an average of 14 mgkg<sup>-1</sup> in forest soils (Table-18). However, with respect to this P estimate, the soils of different land uses did not have any significant difference. The highest content of Olsen-P in cultivated land soils might be due to the addition of higher amount of Ca-P through of phosphatic P fertilizer which contained P mostly in Ca-P form and on aging was converted to Al-P and Fe-P at low pH soils. Moreover, Olsen extractant removed more P from the surface of Al-P and Fe-P than Ca-P in acidic and neutral soils (Jackson, 1973). Based on the amount of P extracted by Olsen soil test method as outlined by Page *et al.* (1982) about 56.7% soils of *terai* agro-climatic region of West Bengal were of high category (>10ppm). Most of the soils under cultivated land (80.0%) and

Table 17. Amount of P ( mgkg<sup>-1</sup> ) removed by five extractants in *terai* soils of West Bengal

Extractants	Range	Mean	CV(%)
Olsen-P	3-177	26	122
Bray - 1P	1-110	20	145
Bray - 2 P	9-339	80	70
Mehlich 1 P	1-113	27	66
AB-DTPA - P	4-75	19	57

Table 18. Amount of P (mgkg<sup>-1</sup>) removed by five extractants in different land use patterns

Land Use Pattern	Tea Garden		Orchard soil		Cultivated Land soil		Forest soil		S. Em. (±)	C.D.-1%
	Range	Mean	Range	Mean	Range	Mean	Range	Mean		
Extractants										
Olsen-P	3-60	17 (100)*	3-74	25 (88)	6-177	47 (121)	3-92	14 (169)	8.80	N. S.
Bray-1P	9-97	29 (88)	1-54	18 (92)	1-110	25 (127)	1-79	07 (268)	6.14	N. S.
Bray-2P	9-170	69 (84)	7-177	53 (83)	42-339	150 (55)	12-164	49 (76)	14.98	54.57
Mehlich-1	1-47	21 (71)	5-50	32 (41)	10-113	43 (59)	3-27	11 (78)	4.33	15.77
AB-DTPA-P	4-16	07 (50)	6-49	22 (55)	11-75	32 (58)	8-39	13 (58)	3.02	11.00

\* Figures in parentheses indicated coefficients of variation (%).

orchard (73.3%) land use pattern were rated as high, while nearly 60% soils of forest were rated as low (<5 ppm) and 46.7% soils of tea garden as medium (5-10 ppm) category.

Bray-1 extractable P for soils of different land use patterns varied from 9 to 97 mgkg<sup>-1</sup> with an average of 29 mgkg<sup>-1</sup> in tea garden, 1 to 57 mgkg<sup>-1</sup> with an average of 18 mgkg<sup>-1</sup> in orchard, 1 to 110 mgkg<sup>-1</sup> with an average of 25 mgkg<sup>-1</sup> in cultivated land and 1 to 79 mgkg<sup>-1</sup> with an average of 7 mgkg<sup>-1</sup> in forest soils. According to Bray-1-P values, 40% soils of tea garden were grouped in both medium (7-20 ppm) and high (>20 ppm) categories. Like that of Olsen-P, maximum (66.7%) percentage of soils under forest land use were rated as very low (<3 ppm) on this P estimate. About 40% soils of orchard could be grouped in medium category, while each of very low, medium and high category contained around 30% soils under *terai* zone of West Bengal.

Bray-2 extractable P for soils of different land use patterns were decreased in the order of cultivated land > tea garden > orchard > forest, range of which were 9 to 170 mgkg<sup>-1</sup>, 7 to 177 mgkg<sup>-1</sup>, 42 to 339 mgkg<sup>-1</sup> and 12 to 64 mgkg<sup>-1</sup> respectively. With respect to Bray-2-P content in different land use patterns, cultivated land soils were significant different from the other land uses. The highest amount of Mehlich-1-P was recorded in cultivated soils (varying from 10 to 113 mgkg<sup>-1</sup>, average being 43 mgkg<sup>-1</sup>), followed by orchard (varying from 5 to 50 mgkg<sup>-1</sup>, average being 32 mgkg<sup>-1</sup>), tea garden (varying from 1 to 47 mgkg<sup>-1</sup>, average being 21 mgkg<sup>-1</sup>) and forest soils (varying from 3 to 27 mgkg<sup>-1</sup>, average being 11 mgkg<sup>-1</sup>). Cultivated land use was significantly different from tea garden and forest land use in the average magnitude of Mehlich-1-P, but average contents of Mehlich-1-P in tea garden, orchard and forest land uses were comparable. Mehlich-1 extractant being double acid (strongly acidic, pH 1.2) extracted a substantial amount of P from soils. On the basis of Mehlich-1-P content, soils of tea garden were evenly distributed in low (<10 ppm), medium (11-31 ppm) and high (31-56 ppm) categories. Majority of the soils under orchard (60%), cultivated land (73.3%) and eventually under overall *terai* region (46.7%)

were of high category, while about 53.3% soils of forest land use were under medium category. However, very little (around 3%) or no soil of this region could be grouped in very high status (>56 ppm).

Being relatively mild extractant comparatively less amount of P was released by AB-DTPA extractant from the soils of all land use and it increased in the sequence of tea garden < forest < orchard < cultivated land, range of the corresponding soils were 4 to 16 mgkg<sup>-1</sup>, 8 to 39 mgkg<sup>-1</sup>, 6 to 49 mgkg<sup>-1</sup> and 11 to 75 mgkg<sup>-1</sup>. Like that of Mehlich-1-P estimate, soils of cultivated land were significantly different from the soils of tea garden and forest land uses in relation to AB-DTPA-P while tea garden soils were at par with forest and orchard soils in this respect. The basic nature of this extractant is to control the ionic activity of Ca, through the solubility product of calcium phosphate. The reagent also extracts some P from Al-P and Fe-P, which are more abundant in acid and neutral soil by repression of Al and Fe activity by complexation of these metallic ions by DTPA. On the basis of AB – DTPA –extractable P, except tea garden, most of the soils of *terai* region (65%) and its various land uses (80,100,60 percent of orchard, cultivated and forest, respectively) were very high category (>11 ppm). Tea garden soils mostly were of medium (4-7 ppm) status. However, no soils of this region were found to be in low category (<3 ppm) in this P estimate.

Thus, the extracting power of the various extractants was in the order of Bray-2 > Bray-1 > Mehlich-1 > Olsen > AB-DTPA for soils of tea garden which were well supported by Giridhara Krishna and Satya Narayan (1996) for some Vertisols in different agro-climatic zone of Northern Karnataka and Rabindra and Ananthanarayana (1999) for the acid soils of Karnataka. Soils of other land use patterns followed more or less same trend whereas the soils of *terai* agro-climatic zone of West Bengal as a whole followed the order: Bray-2 > Mehlich-1 > Olsen > Bray-1 > AB-DTPA. Similar trend was reported in some acid soils of Meghalaya by Pati Ram *et al.* (1993) and in acidic soils of Uttaranchal hills (Ghosh and Singh, 2002). This differential behaviour of different extractants was

mainly due to their selectivity in solubilizing specific fraction of P to varied extent in different soils.

#### 4.2.2 Interrelationship among Soil Test Methods

The different P soil tests were interrelated among themselves as evident from highly significant positive correlations among the amount of P extracted by different extractants (Table-19). Olsen P recorded the highest correlation with all the extractants, while Bray-1-P recorded the least. Among the methods, Olsen P ( $r=0.862^{**}$ ) showed the highest significant correlation with AB-DTPA-P indicating the possibility of same fractions of soil P dissolved by both the extractants. The dissolution of P from more or less same fractions of soil P by different soil test methods revealed through high significant correlations among the amounts of P extracted by them.

#### 4.2.3 Relationship between Soil Test Methods and Inorganic P Fractions

Olsen extractable P showed significant positive relationship with Fe-P ( $r=0.947^{**}$ ), Al-P ( $r=0.513^{**}$ ), and Occl-P ( $r=0.301^*$ ) (Table- 20). The basic nature of Olsen's extractant (0.5 M NaHCO<sub>3</sub>, pH 8.5) would favour the extraction of available P present in the form of Fe-P and Al-P by their hydrolysis in alkaline solution or adsorbed on clay surface (Lindsay and Moreno, 1960). Bray-1-P also had significant positive relationship with Fe-P ( $r=0.784^{**}$ ), Al-P ( $r=0.564^{**}$ ) and RS-P ( $r=0.279^*$ ). Dongale and Kadrekar (1992), Binod *et al.* (1998) and Ravindra and Ananthanarayana (1999) also reported strong association of Bray-1-P with Fe-P and Al-P. A significant contribution of Al-P and Fe-P fractions to Olsen-P and Bray-1-P were also observed by Kanwar *et al.* (1979) and Mamo *et al.* (1991). Bray-2 extractable P showed significant positive relationship with Fe-P ( $r=0.761^{**}$ ) and Ca-P ( $r=0.548^{**}$ ). Release of P from Ca-P fraction by Bray-2 reagent was due to higher strength of acid favouring its dissolution. Mehlich-1 (0.05 M HCl+0.25 N H<sub>2</sub>SO<sub>4</sub>), a strong reagent correlated significantly with Fe-P ( $r=0.623^{**}$ ), Al-P ( $r=0.453^{**}$ ), Occl-P ( $r=0.385^{**}$ ) and Ca-P ( $r=0.259^*$ ) indicating

the contribution of all these fractions towards available P estimate by this method. AB-DTPA-P showed significant positive relationship with Fe-P ( $r=0.664^{**}$ ), Al-P ( $r=0.435^{**}$ ), Ca-P ( $r=0.385^{**}$ ) and Occl-P ( $r=0.318^*$ ). The result indicated that Fe-P and Al-P were the good sources of available P in these soils as it showed significant relationship with P extracted by almost all the soil test methods and finally it could be inferred that Fe-P and Al-P were the major inorganic P fractions contributed towards available P. For each unit increase in Fe-P content, Olsen-P, Bray-1-P, Bray-2-P, Mehlich-1-P, and AB-DTPA-P increased by 0.266, 0.156, 0.413, 0.100 and 0.090 unit, while that for Al-P, the increments were by 0.283, 0.219, 0.143, 0.093 unit, Olsen-P, Bray-1-P, Mehlich-1-P and AB-DTPA-P respectively. Similar were the findings of Patiram *et al.* (1993), Mongia and Bandopadhaya (1998) and Ravindra and Ananthanarayana (1999) for acid soils of India.

#### 4.2.4 Prediction of Available Soil P from Soil P Forms

Stepwise regression analysis (Table-21) of different available-P estimates with different inorganic P fractions indicated that Fe-P alone could explain 88.6 per cent variation in Olsen-P. When the second variable, Al-P entered into the regression equation  $R^2$  value raised to 0.899. And when all the potential variables Fe-P, Al-P and Ca-P were included in the equation 90.6% of variation in Olsen-P could be explained. Rao and Chakraborty (1994) and Dhillon *et al.* (1998) also observed that Al-P and Ca-P were the dominant P fraction contributing towards the available P in tea growing soils of Himachal Pradesh and flood plain of Punjab, respectively. In case of Bray-1 P, Fe-P accounted for 61.1% variability out of the total variability of 67.5% in which the partial contribution of RS-P was 6.4% only. Ravindra and Ananthanarayana (1999) reported that Al-P and Fe-P collectively explained 63% variability in Bray-1-P in some acid soils of Karnataka. Thus, the regression equations showed that Fe-P was the dominant inorganic P forms, which controlled the available P estimates assessed by Olsen and Bray-1 methods. This result was in agreement with that

Table 19. Correlation (r) among different extractants - P

Extractants	Bray - 1P	Bray -2P	Mehlich - 1P	AB - DTPA-P
Olsen-P	0.813**	0.807**	0.709**	0.862**
Bray - 1P		0.736**	0.593**	0.619**
Bray - 2 P			0.712**	0.772**
Mehlich 1 P				0.703**

\* and \*\* indicate 5% and 1% level of significance, respectively.

Table 20. Correlation (r) between different extractants-P and soil P forms

Extractant P	Soil - P				
	Al -P	Fe - P	Ca - P	RS- P	Occl - P
Olsen-P	0.513**	0.947**	0.190	0.113	0.301*
Bray - 1P	0.564**	0.784**	0.040	0.279*	0.226
Bray - 2 P	0.233	0.761**	0.548**	0.103	0.138
Mehlich 1 P	0.453**	0.623**	0.259*	0.044	0.385**
AB-DTPA - P	0.435**	0.664**	0.385**	0.064	0.318*

\* and \*\* indicate 5% and 1% level of significance, respectively.

of Sharma *et al.* (1995). However, the inclusion of other P fractions improved only marginally (2 to 6.4%) the availability indices.

#### 4.2.5 Indices of P Availability and Soil Properties

Perusal of the data in Table 22 depicted that Bray-2-P and Mehlich-1-P had highly significant negative relationship with organic carbon content ( $r = -0.353^{**}$  and  $-0.343^{**}$ ) while positive relationship with clay content of the soils ( $r = 0.321^*$  and  $0.268^*$ ) respectively. However, Olsen-P did not have any significant relationship with the above two soil parameters. Verma *et al.* (1991) also reported similar results in *terai* soils of U.P. The soils of this study, in general, were loam in texture in which availability of plant nutrients including P also remained higher, therefore, significant correlations existed between clay content and P extracted by different extractants. The observation was well supported by the findings of Misra *et al.* (1994) and Pandey *et al.* (2000). The data also showed that with increase in cation exchange capacity of soil Bray-2 ( $r = -0.333^*$ ) and Mehlich-1 ( $r = -0.286^*$ ) extractable P decreased. Extractable Al content of *terai* soils also had a negative relationship both with Bray-2-P ( $r = -0.432^{**}$ ) and AB-DTPA-P ( $r = -0.357^{**}$ ). Similar relationship was also found between exchangeable Al and Bray-2-P ( $r = -0.327^*$ ) and silt and Mehlich-1-P ( $r = -0.312^*$ ).

#### 4. 2. 6 Available Soil P versus Plant Parameters

The results of Table-23 showed the relationship between the soil tests and dry matter yield as well as P-uptake of wheat in *terai* soils and its different land use patterns e.g. tea garden, orchard, cultivated land and forest. In *terai* soils, dry matter yield of wheat had positive significant relationship with Olsen-P ( $r = 0.524^{**}$ ), Bray-1 P ( $r = 0.727^{**}$ ), Bray-2-P ( $r = 0.426^{**}$ ), Mehlich-1 P ( $r = 0.501^{**}$ ) and AB-DTPA-P ( $r = 0.406^{**}$ ). P-uptake by wheat also had positive significant relationship with Bray-1 P ( $r = 0.879^{**}$ ), Bray-2 P ( $r = 0.760^{**}$ ), Olsen-P ( $r = 0.739^{**}$ ), Mehlich-1 P ( $r = 0.676^{**}$ ) and AB-DTPA-P ( $r = 0.620^{**}$ ). The above

findings showed that Bray-1 extractant was the most suitable one to assess the available P in terms of dry matter yield as well as P uptake by wheat in soils of *terai* agro-climatic zone of West Bengal. With respect to P uptake by wheat, Bray-2 method rated the second best for these soils. Similar observation was reported by Jaggi *et al.* (1990) in wheat growing valley of Himachal Pradesh.

In the soils of tea garden, Bray-1 P ( $r = 0.867^{**}$  and  $0.816^{**}$ ), Olsen-P ( $r = 0.848^{**}$  and  $0.654^{**}$ ), AB-DTPA-P ( $r = 0.825^{**}$  and  $0.796^{**}$ ), Bray-2 P ( $r = 0.751^{**}$  and  $0.865^{**}$ ) and Mehlich-1 P ( $r = 0.565^*$  and  $0.748^{**}$ ) showed significant positive correlation with dry matter yield and P-uptake by wheat. With respect to dry matter production Bray-1 and Mehlich-1 methods were considered to be the best and least suitable, whereas Bray-2 and Olsen methods were the best and least suitable in relation to P uptake by the wheat crop, respectively.

The dry matter yield and P-uptake by wheat in soils under orchard land use pattern was found to be highly significantly correlated with Bray-1 P ( $r = 0.911^{**}$  and  $0.927^{**}$ ), Mehlich-1 P ( $r = 0.658^{**}$  and  $0.610^{**}$ ) and Bray-2 P ( $r = 0.604^{**}$  and  $0.874^{**}$ ). The data also revealed that Bray-1 method was the best with respect to both dry matter yield and P-uptake by the crop. In terms of dry matter production the suitability of the method decreased in the order: Bray-1 > AB-DTPA > Olsen > Mehlich-1 > Bray-2, while in terms of P-uptake by the wheat crop the same decreased in the order of Bray-1 > Bray-2 > AB-DTPA > Mehlich-1 > Olsen.

In cultivated land soils of *terai* agro-climatic region of West Bengal, P-uptake and dry matter yield of wheat also showed very high significant correlation with Bray-1 P ( $r = 0.931^{**}$  and  $0.628^{**}$ ), AB-DTPA-P ( $r = 0.914^{**}$  and  $0.663^{**}$ ), Olsen-P ( $r = 0.863^{**}$  and  $0.596^{**}$ ), Mehlich-1 P ( $r = 0.750^{**}$  and  $0.569^*$ ) and Bray-2 P ( $r = 0.698^{**}$  and  $0.325$ ), respectively. However, with reference to dry matter yield, AB-DTPA and Bray-2 methods were proved to be the best and least suitable, respectively and the efficiency of different soil test methods to predict dry matter production decreased in the order of AB-DTPA > Bray-1 > Olsen > Mehlich-1 > Bray-2. But with regard to P-uptake by wheat in these soils

**Table 21. Stepwise regression equation between available P estimate and soil P forms**

Extractants	R <sup>2</sup>	ΔR <sup>2</sup>	Equation No.
Olsen-P = -4.59+0.266 Fe-P	0.886	-	1
= -7.43+0.25 Fe -P+0.07 Al-P	0.889	0.013	2
= -12+0.24 Fe-P+0.10 Al-P +0.03 Ca-P	0.906	0.007	3
Bray-1P=2.15+0.16 Fe-P	0.611	-	4
=-4.99+0.15 Fe-P+0.07 RS-P	0.675	0.064	5

**Table 22. Relationship (r) between soil tests' P and soil characters.**

Extractant P	Soil Characters								
	Org.C	Clay	CEC	pH	Ca+Mg	Silt	Fe <sub>2</sub> O <sub>3</sub>	ExAl	Extrac. Al
Olsen-P	-0.117	0.192	-0.082	0.183	-0.002	-0.183	0.088	0.058	-0.197
Bray - 1P	-0.073	-0.048	-0.022	-0.211	-0.158	-0.134	0.035	0.084	0.023
Bray - 2 P	0.353**	0.321*	-0.333*	0.174	0.228	-0.153	-0.204	-0.327*	-0.432**
Mehlich 1 P	0.343**	0.268*	-0.286*	-0.165	-0.056	-0.312*	-0.118	-0.044	-0.122
AB-DTPA-P	-0.219	0.237	-0.217	0.033	0.165	-0.061	-0.099	-0.051	-0.357**

\* and \*\* indicate 5% and 1% level of significance, respectively.

the efficacy of the methods decreased in the sequence of Bray-1 > AB-DTPA > Olsen > Mehlich-1 > Bray-2. The result was in conformity with the observation of Jaggi *et al.* (1990) in wheat growing valley of Himachal Pradesh.

In forest soils, the dry matter yield and P-uptake by wheat had significant positive correlation with Bray-2 P ( $r=0.794^{**}$  and  $0.910^{**}$ ), Olsen-P ( $r= 0.752^{**}$  and  $0.907^{**}$ ), AB-DTPA-P ( $r= 0.714^{**}$  and  $0.779^{**}$ ), Bray-1 P ( $r= 0.648^{**}$  and  $0.887^{**}$ ) and Mehlich 1 P ( $r=0.523^*$  and  $0.482$ ), respectively. The results showed that Mehlich-1 was the least suitable while Bray-2 was the most suitable method among the methods tested with respect to both the plant parameters. Similar observation was reported by Kanapathy *et al.* (1973).

The maximum variation in P-uptake by wheat was explained in orchard (86%) and cultivated land (87%) by Bray-1 P, while in tea garden (75%) and forest soil (83%) maximum variability was explained by Bray-2 P. Among the rest three soil tests, AB-DTPA method was found to be relatively superior in all the land use patterns except in forest soils to predict the P removal by wheat crop. The results of this study indicated that a specific extractant did not always hold good to assess the available P status of all soils, as was done in routine soil testing laboratories.

#### **4.2.7 Prediction of Plant Available P from Available Soil P Indices /Soil P Forms**

Stepwise multiple regression between P-uptake (Y) and soil P forms as well as available P indices (Table-24) indicated that Bray-1 P, the major contributors of P supply to wheat crop alone explained 76.9 per cent variation in P-uptake. RS-P, the second variable, bearing a partial contribution of 3.4%, upgraded the said variability to 80.3%, while 81.6% variation in P-uptake was explained when all the potential variable like Bray-1 P, RS-P and Occl-P were included in the equation.

In case of Bray-2 P, the first potential variable (Bray-2 P) could explain 57% variability in P-uptake. All other variables, when allowed to enter in the

**Table 23. Relationship (r) between soil tests P with dry matter yield and P uptake by wheat**

Land use	Terai soil		Tea Garden		Orchard soil		Cultivated Land soil		Forest soil	
	A	B	A	B	A	B	A	B	A	B
Olsen-P	0.524**	0.739**	0.848**	0.654**	0.661**	0.528**	0.596*	0.863**	0.752**	0.907**
Bray-1P	0.727**	0.879**	0.867**	0.816**	0.911**	0.927**	0.628**	0.931**	0.648**	0.887**
Bray-2P	0.426**	0.760**	0.751**	0.865**	0.604*	0.874**	0.325	0.698**	0.794**	0.910**
Mehilch-1	0.501**	0.676**	0.565*	0.748**	0.658**	0.610*	0.569*	0.750**	0.523*	0.482
AB-DTPA-P	0.406**	0.620**	0.825**	0.796**	0.724**	0.791**	0.663**	0.914**	0.714**	0.779**

\* and \*\* indicate 5% and 1% level of significance, respectively.

A and B stand for dry matter yield and P uptake by wheat, respectively.

**Table 24. Stepwise multiple regression between P-uptake (Y) and soil P forms/available P**

Relationship	R <sup>2</sup>	ΔR <sup>2</sup>	Eqn. No.
Y= 3.97 + 0.198 Bray-1 P	0.769	-	1
= 4.97 + 0.212 Bray-1 P – 0.011 RS-P	0.803	0.034	2
= 3.83 + 0.208 Bray-1 P – 0.014 RS-P + 0.146 Occl-P	0.816	0.013	3
Y= 2.99 + 0.061 Bray-2 P	0.570	-	4
= 3.89 + 0.083 Bray-2 P – 0.0001 Ca-P x clay	0.706	0.136	5
= 3.30 + 0.085 Bray-2 P – 0.027 Ca-P x clay + 0.03 Ca-P	0.739	0.033	6
Y= 4.27 + 0.032 Fe-P	0.504	-	7
= 2.67 + 0.022 Fe-P + 0.104 Meh-P	0.583	0.079	8
= 1.63 + 0.062 Fe-P + 0.126 Meh-P – 0.0002 Fe-P x clay	0.615	0.032	9

regression equation, only two variables entered and enhanced the variable in P-uptake upto 73.9% of while partial contribution of second variable, Ca-P  $\times$  clay was 13.6% and that of third variable, Ca-P was 3.3%.

In case of Mehlich-1 P soil test, Fe-P alone could explain 50.4 per cent variation in P-uptake, while Fe-P and Mehlich-1 P jointly contributed 58.3 per variation and further introduction of the third variable, Fe-P  $\times$  clay content improved the variability in P-uptake to about 65%. However, with the rest soil test methods no P forms/soil character could improved the per cent variability in P-uptake.

Thus, it might be inferred that soil P fractions in the form of Fe-P and Al-P (Bray-1 and Bray-2 extractants released P mostly from Al-P and Fe-P fractions from soil) contributed more towards P nutrition of wheat crop in the soils. Accordingly, an extractant dissolving these fractions from these soils would be the best for determining available P. Bray-1 extractable P seems to be the most suitable method as it extracts P from both Fe-P and Al-P fractions and inclusion of RS-P and Occl-P along with Bray-1 P jointly could explain about 82% variation in P-uptake of wheat in *terai* soils of West Bengal. However, contradictory observation was reported by Bates (1990) in Ontario soils (pH 5-7.6) where among five chemical soil P extractants used Bray-Kurtz-1 P was found to be least effective.

## 4.3. Adsorption-Desorption Behaviour of Phosphorus

### 4.3.1 P Sorption

#### 4.3.1.1 Amount of P Sorbed by Soils

To the soils, solutions having several P concentrations viz, 50, 100, 150, 200, 300, 500 and 1000 mgkg<sup>-1</sup> were added and found that the average amount of P sorbed by the soils of *terai* agro-climatic region at different solution P concentrations were 47.8, 94.0, 138.4, 181.7, 268.3, 436.0 and 835.3 mgkg<sup>-1</sup>, respectively (Table 25). The result showed that the amount of P sorbed in the soils increased with increase in the level of solution P added. However, the percent of the added P sorbed followed a reverse trend i.e. decreased progressively with increase in the level of P. The values of sorbed P as percent of added P at the respective solution concentrations were 95.6, 94.0, 92.3, 90.9, 89.4, 87.2, and 83.5. This might be due to the fact that the sites for adsorption of P relative to the amount of P added decreased gradually with increasing the solution P concentration. The results were in agreement with Bala *et al.* (1995).

Table-26 depicted the magnitude of adsorption of solution P at its various levels in four land use soils under *terai* zone of West Bengal. Like *terai*, the soils under different land use patterns showed that with increase in the level of added P, the amount of P sorbed increased but the per cent of added P sorbed decreased (Fig. 5). At any level of P concentration, the amount P sorbed by the soils of four land uses were in close proximity indicating the similarity in the basic nature of soils under different land uses. This observation was again supported by their narrow coefficient of variation among the different land use patterns at a particular solution concentration or among the various solution concentration at a particular land use. However, at the highest level of added P concentration (1000 mgkg<sup>-1</sup>) highest amount of sorbed P was recorded in forest soils (average being 879.5 mgkg<sup>-1</sup>) followed by orchard (average being 843.1 mgkg<sup>-1</sup>), cultivated land (average being 811.8 mgkg<sup>-1</sup>) and tea garden (average being 806.6 mgkg<sup>-1</sup>) and more or less similar trends were followed for other added P levels. At this added solution P concentration with respect to the magnitude of sorbed P, forest soils

Fig : 5 Relationship between P adsorbed and P in equilibrium solution

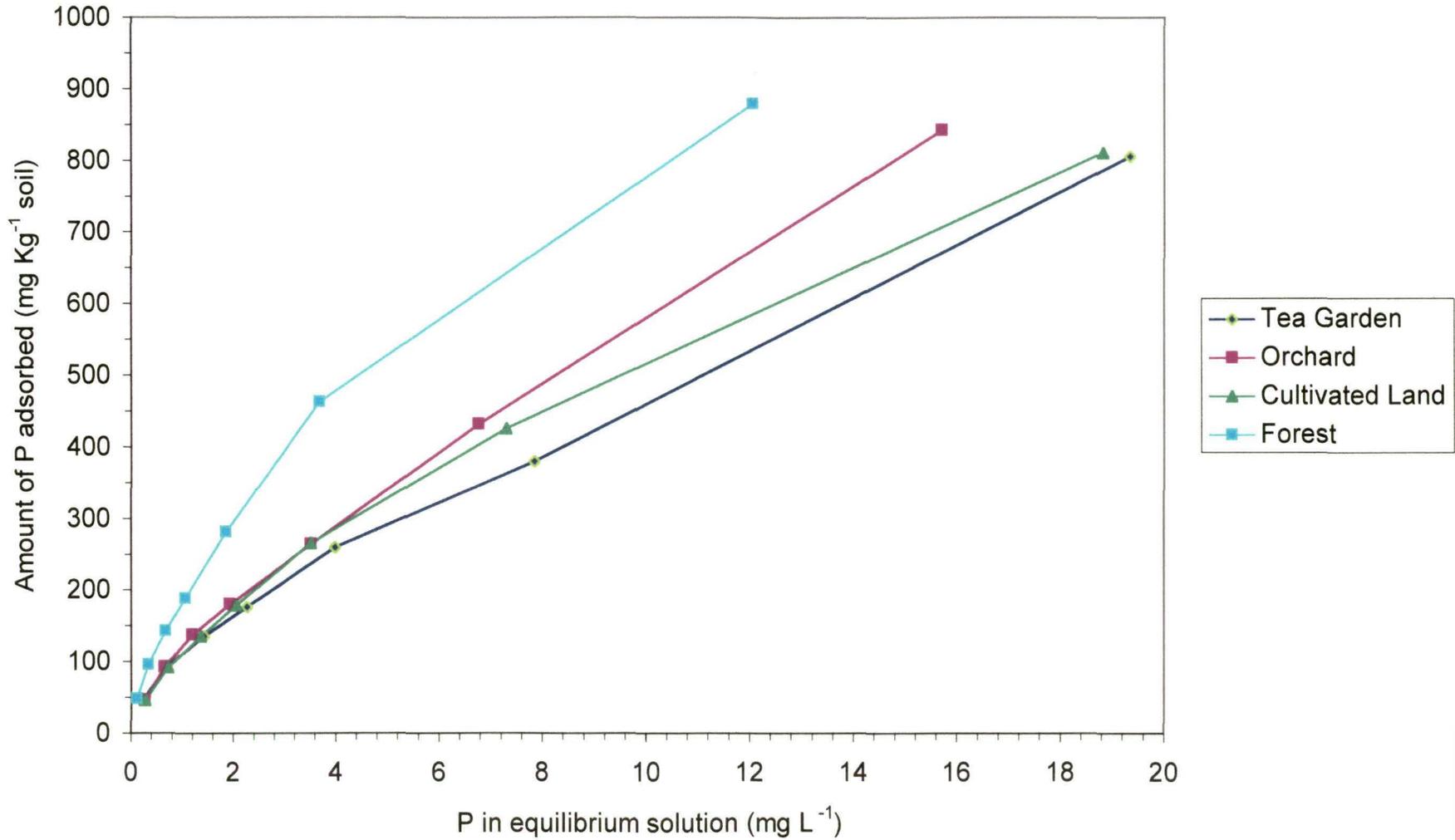


Table 25. Amount of P sorbed ( $\text{mgkg}^{-1}$ ) by soils of *terai* zone

P added ( $\text{mgkg}^{-1}$ soil)	Range	Mean	CV(%)
50	39.1 - 49.6	47.8 (95.6)*	4.8
100	92.4 - 99.0	94.0 (94.0)	5.2
150	105.0 - 148.4	138.4 (92.3)	6.9
200	131.3 - 197.7	181.7 (90.9)	7.7
300	195.7 - 296.4	268.3 (89.4)	8.2
500	324.6 - 486.3	436.0 (87.2)	7.9
1000	646.6 - 933.0	835.3 (83.5)	7.0

Figures in the parentheses indicate sorbed P as percent of added P.

differed significantly from the soils of cultivated land and tea garden land uses, but no significant difference was observed among the soils of tea garden, orchard and cultivated land.

#### 4.3.1.2 Phosphorus Adsorption Isotherms

The adsorption data for the soils of *terai* agro-climatic zone of West Bengal were fitted to four different adsorption equations- Langmuir, Freundlich, modified Freundlich and Tempkin (Table 27 & Figs. 6-9). Freundlich equation ( $R^2= 0.999$ ) best described the P adsorption pattern of *terai* soils followed by modified Freundlich ( $R^2= 0.993$ ), Langmuir ( $R^2= 0.864$ ) and Tempkin ( $R^2= 0.823$ ) equation.

The adsorption data for the soils of four land use patterns were also fitted to four adsorption equations. It was observed that modified Freundlich adsorption isotherm ( $R^2= 0.997$ ) was the best fitted isotherm for tea garden soils and order of goodness of fit to other isotherms were Freundlich ( $R^2= 0.988$ ) > Langmuir ( $R^2= 0.911$ ) > Tempkin ( $R^2= 0.813$ ). This observation was in conformity with that of Singh *et al.* (1996) for some Alfisols of varying agroclimatic region in India. Similar result was also reported by Toor *et al.* (1997). In orchard soils, Freundlich adsorption isotherm ( $R^2= 0.998$ ) was the best fitted, followed by modified Freundlich ( $R^2=0.993$ ), Tempkin ( $R^2= 0.834$ ) and Langmuir ( $R^2= 0.768$ ) isotherms. Identical results was found by Biswas *et al.* (1999) and Saha *et al.* (1999). Freundlich equation ( $R^2= 0.998$ ) best described the adsorption data also for the soils of cultivated land and other adsorption isotherms followed the order of modified Freundlich ( $R^2=0.993$ ) > Langmuir ( $R^2= 0.885$ ) > Tempkin ( $R^2= 0.863$ ). It was found that Freundlich ( $R^2= 0.981$ ) was the most suitable fitted adsorption isotherm, while modified Freundlich ( $R^2=0.977$ ) equation was the second best, followed by Langmuir ( $R^2= 0.916$ ) and Tempkin ( $R^2= 0.852$ ) adsorption isotherms for forest soils.

From the above observation it might be inferred that either Freundlich or modified Freundlich equation described the adsorption pattern better compared to other equations studied for the soils under all land use patterns. Freundlich

Fig. 6. Langmuir Phosphorus adsorption isotherms of different land uses in *terai* region of West Bengal

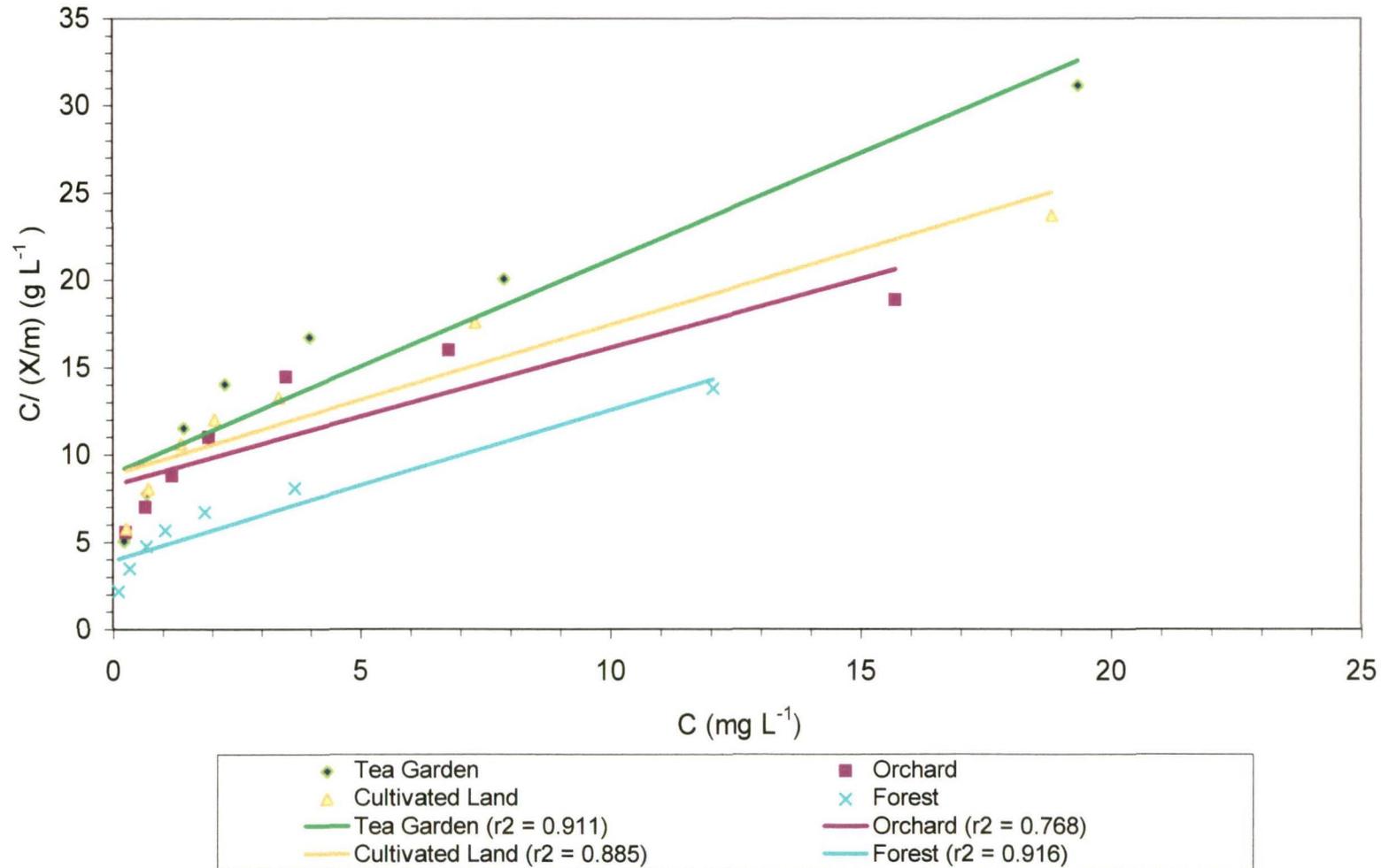


Fig: 7 Freundlich Phosphorus adsorption isotherms of Different Land uses in Terai Region of West Bengal

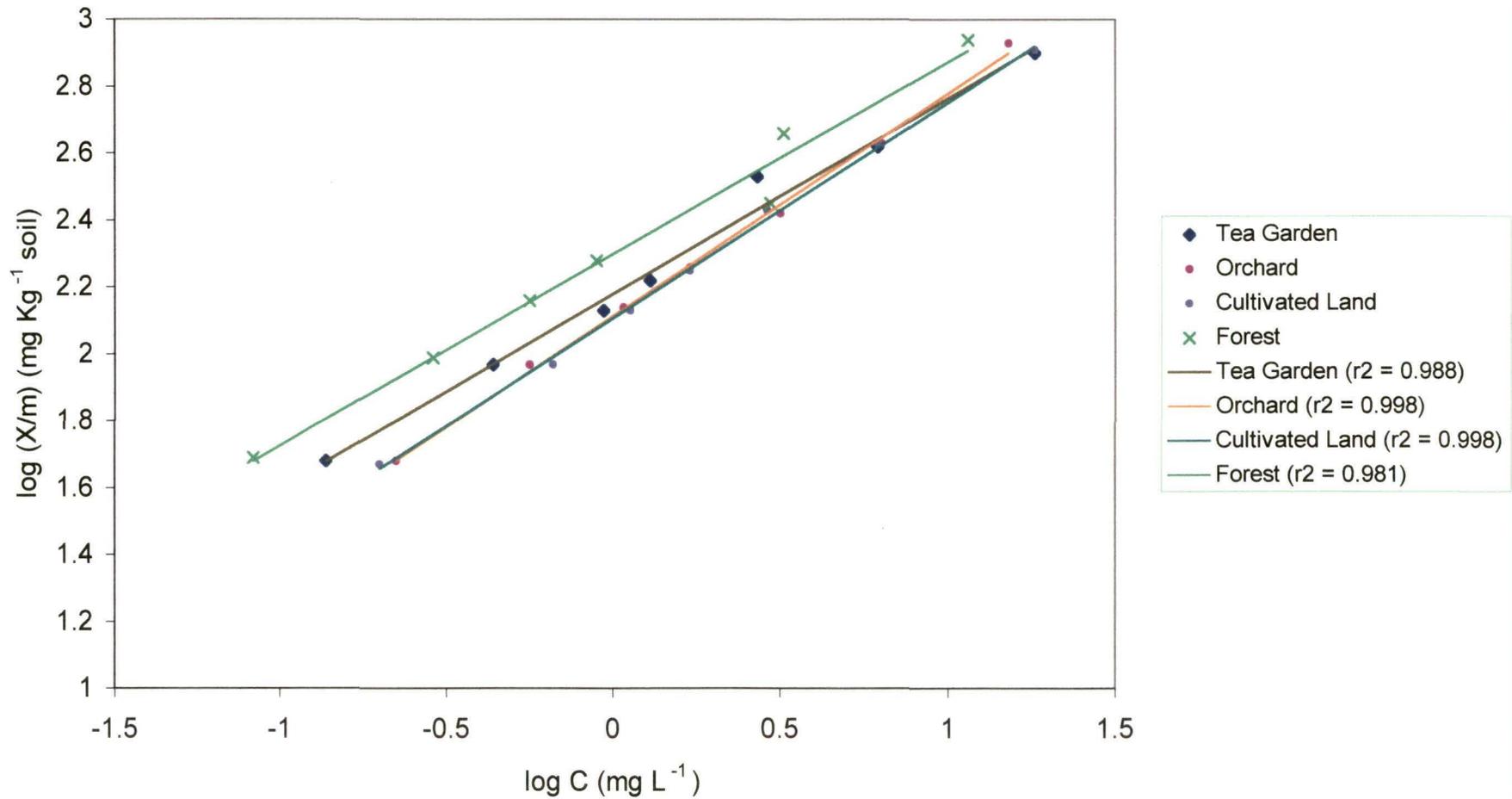


Fig: 8. Modified Freundlich Phosphorus adsorption isotherms of different land uses in *terai* region of West Bengal

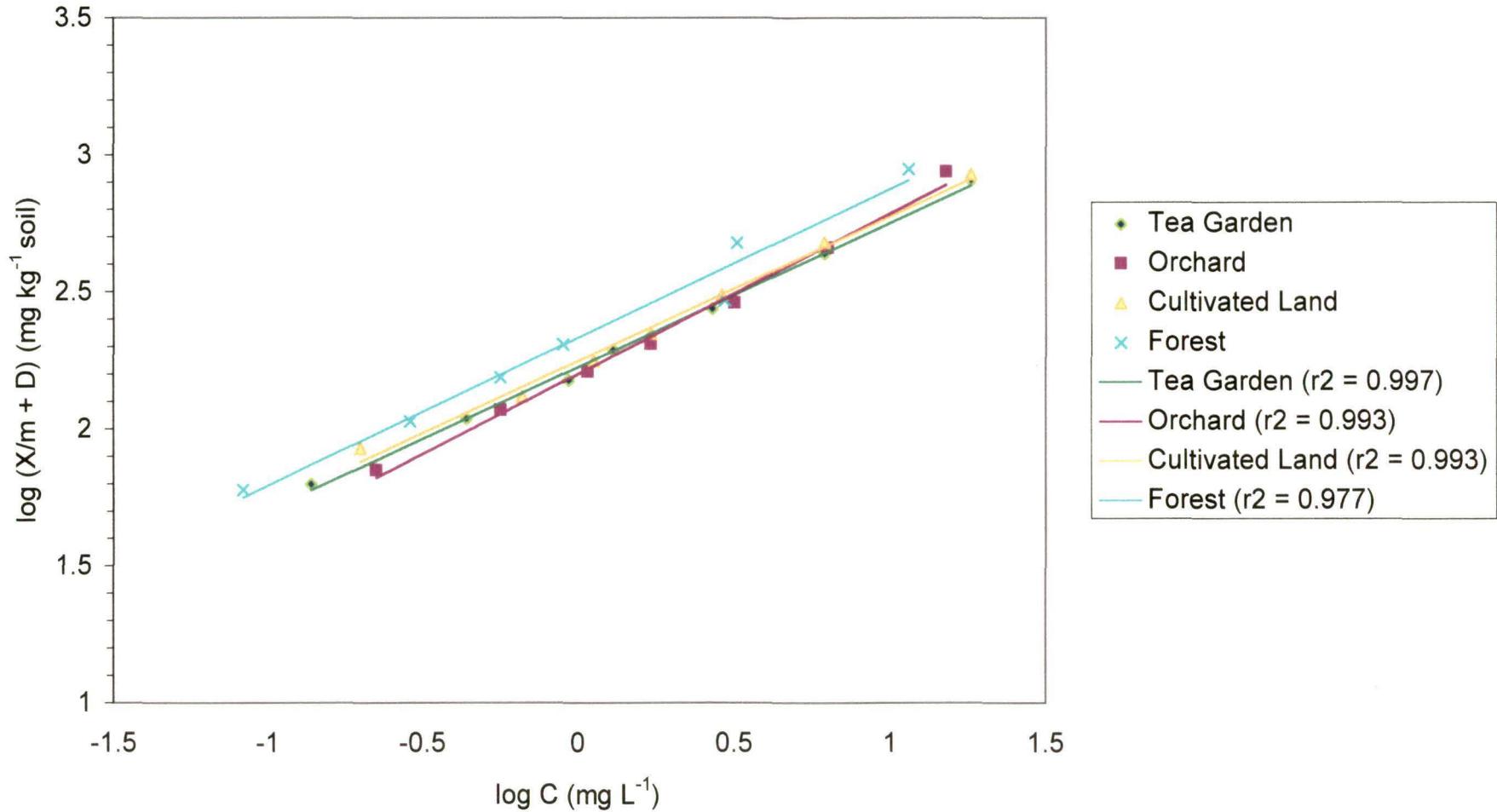


Fig: 9 Tempkin Phosphorus adsorption isotherms of different land uses in *terai* region of West Bengal

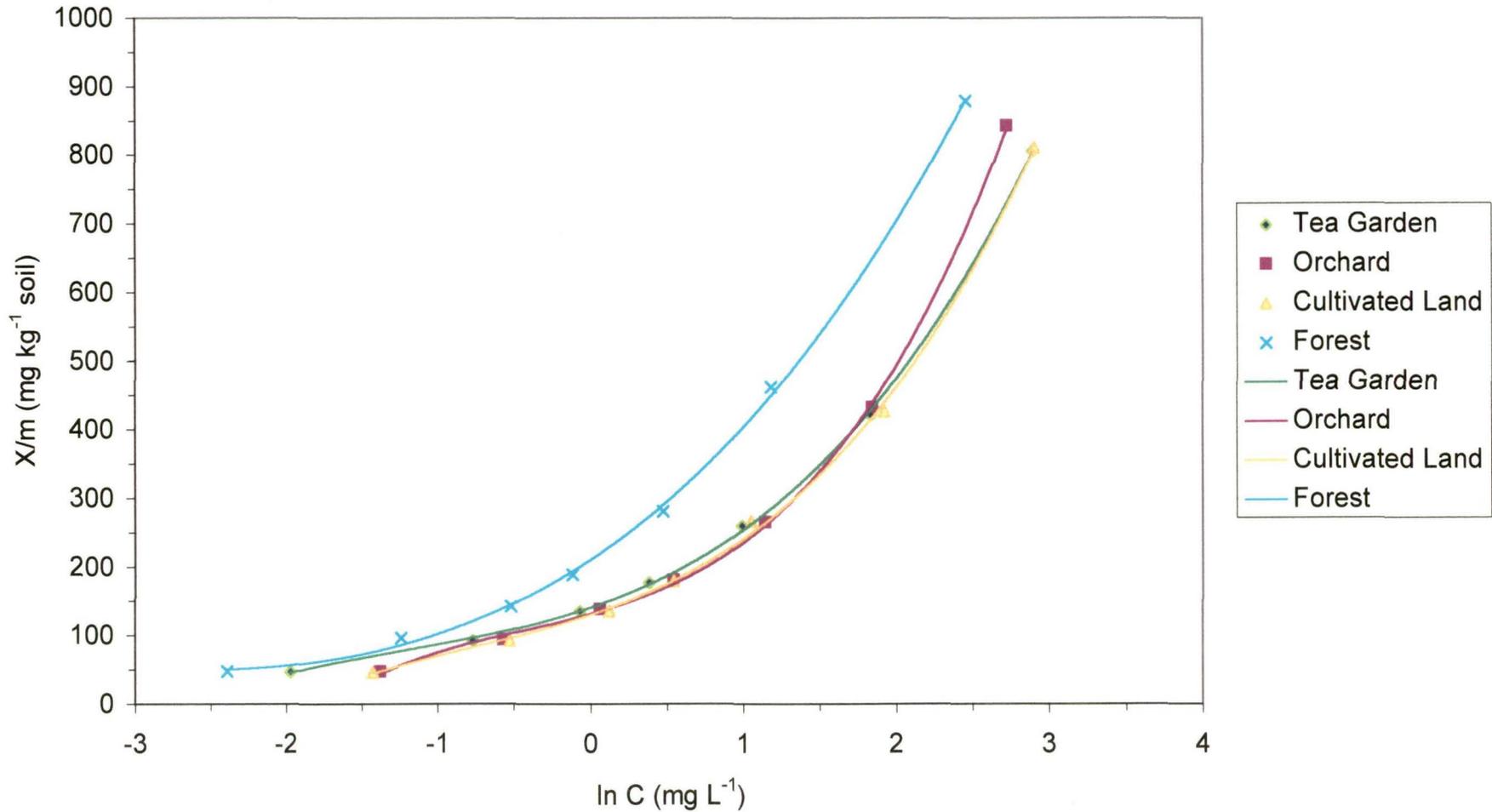


Table 26. Amount of P sorbed ( $\text{mgkg}^{-1}$ ) by soils of different land uses of terai zone

Land use Patterns		Tea garden	Orchard	Cultivated Land	Forest	S.E m( $\pm$ )	C.D <sub>1%</sub>	
P added ( $\text{mgkg}^{-1}$ soil)	50	Range	39.1-49.6	44.5-49.5	43.4-49.5	47-49.5		
		Mean	47.7 (95.4)*	47.4 (94.8)	47.3 (94.6)	48.9 (97.8)	-	-
		CV(%)	5.49	2.9	3.9	1.8		
	100	Range	78.1-99.0	87.4-98.5	81.4-98.0	92.4-98.5		
		Mean	93.1 (93.1)	93.5 (93.5)	92.8 (92.8)	96.7 (96.7)	-	-
		CV(%)	6.50	3.3	5.0	2.0		
	150	Range	105.0-148.4	28.8-145.5	109.2-144.5	133.4-147.5		
		Mean	135.7 (90.5)	138.1 (92.1)	136.3 (90.9)	143.3 (95.5)	-	-
		CV(%)	9.30	4.1	7.0	3.0		
	200	Range	1313-197.7	162.2-193.4	143.0-195.0	175.3-196.0		
		Mean	177.4 (88.7)	180.6 (90.3)	179.5 (89.8)	189.4 (94.7)	-	-
		CV(%)	10.57	5.3	7.5	3.4		
300	Range	195.7-296.4	230.9-288.9	211.8-288.9	256.7-291.9			
	Mean	260.2 (86.7)	264.9 (88.3)	266.4 (88.8)	281.5 (93.8)	-	-	
	CV(%)	11.10	6.3	7.7	3.8			
500	Range	324.6-486.3	380.0-470.3	348.8-462.2	423.9-485.4			
	Mean	421.3 (84.3)	432.4 (86.5)	427.1 (85.4)	463.2 (92.6)	-	-	
	CV(%)	10.97	5.7	6.8	4.1			
1000	Range	646.6-907.0	757.1-898.2	685.0-872.5	821.1-933.0			
	Mean	806.6 (80.7)	843.1 (84.3)	811.8 (81.2)	879.5 (88.0)	13.36	48.67	
	CV(%)	8.91	4.8	6.6	3.7			

\* Figure in the parenthesis indicates sorbed P as per cent of added P.

equation best explained the P- adsorption pattern in the soils of orchard, cultivated land and forest, while modified Freundlich gave a good fit for soils of tea garden. However, high values of  $R^2$  of all the equations for various land use patterns indicated a similarity in their adsorption behaviour despite their variations in land use *vis-à-vis* their chemical properties.

#### 4.3.1.3 P Sorption Parameters

P-sorption parameters e.g. phosphate bonding energy (K), Langmuir adsorption maxima (b), maximum buffering capacity (Kb), Freundlich's constants,  $K'$  and 'n' of each soil of *terai* agro-climatic zone of West Bengal were presented in Table-28. Adsorption maxima (b), expressed in  $\text{mgkg}^{-1}$  were in the range of 845 to 2850 with a mean of 1215.1 and coefficient of variation was 30.07%. The constant relating to bonding energy (K) had very low values varying from 0.012 to 1.052  $\text{Lmg}^{-1}$  with an average of 0.225  $\text{Lmg}^{-1}$ .

The maximum phosphate buffering capacity of soil characterized the dynamic relation between labile solid phase and solution phase phosphate from which plants received their supply, ranged from 34.2 to 1023.6  $\text{Lkg}^{-1}$  with a mean of 241.8  $\text{Lkg}^{-1}$ .

The Freundlich constants,  $K'$  expressed in  $\text{mgkg}^{-1}$  (as a measure of adsorption capacity) and  $1/n$  (as energies of sorption) both expressed in  $\text{Lkg}^{-1}$  were in the range of 37.2 to 358.9 and 0.450 to 0.905 with the mean values of 163.1 and 0.623 respectively.

The sorption parameters of the soils of different land use patterns were shown in Table 29. Sorption maxima (b) was the highest in orchard soils (1036 to 2664  $\text{mgkg}^{-1}$ , mean 1334  $\text{mgkg}^{-1}$ ), followed by cultivated land soils (848 to 2017  $\text{mgkg}^{-1}$ , mean 1204  $\text{mgkg}^{-1}$ ), forest soils (959 to 1476  $\text{mgkg}^{-1}$ , mean 1170  $\text{mgkg}^{-1}$ ) and tea garden soils (845 to 2850  $\text{mgkg}^{-1}$ , mean 1153  $\text{mgkg}^{-1}$ ). The bonding energy for phosphate varied from 0.012 to 1.052  $\text{Lmg}^{-1}$  with an average of 0.293  $\text{Lmg}^{-1}$ ; 0.038 to 0.351  $\text{Lmg}^{-1}$  with an average of 0.137  $\text{Lmg}^{-1}$ ; 0.029 to 0.509  $\text{Lmg}^{-1}$  with an average of 0.160  $\text{Lmg}^{-1}$  and 0.066 to 0.682  $\text{Lmg}^{-1}$  with an average of 0.308  $\text{Lmg}^{-1}$  in tea garden, orchard, cultivated land and forest soils

Table 27. Goodness of fit of adsorption data to different adsorption isotherms( $R^2$ )

Isotherms	Langmuir	Freundlich	Modified Freundlich	Tempkin
<b>Land use patterns</b>				
Terai (overall)	0.864	0.999	0.993	0.823
Tea Garden	0.911	0.988	0.997	0.813
Orchard	0.768	0.988	0.993	0.834
Cultivated land	0.885	0.998	0.993	0.863
Forest	0.916	0.981	0.977	0.852

Table 28. P sorption parameters of the soils in *terai* zone of West Bengal.

Sorption Parameters	Range	Mean	CV(%)
Adsorption maxima (b) ( $\text{mgkg}^{-1}$ )	845 – 2850	1215.1	30.07
Bonding energy (K) ( $\text{Lmg}^{-1}$ )	0.012 – 1.052	0.225	96.9
Buffering capacity (Kb) ( $\text{Lkg}^{-1}$ )	34.20 – 1023.60	241.8	87.9
$K'$ ( $\text{mgkg}^{-1}$ )	37.15 – 358.92	163.1	47.2
$1/n$ ( $\text{Lkg}^{-1}$ )	0.450 – 0.905	0.623	16.3

respectively. The constant relating to the binding energy had quite low values in these soils and tended to vary inversely with 'b' values. Relatively higher bonding energy in forest and tea garden soils indicated that phosphorus was held in these soils more tenaciously than the others possibly by higher amount of organic matter through polyvalent cations like  $\text{Fe}^{3+}$  and  $\text{Al}^{3+}$  (Sanyal and De Datta, 1991).

The maximum buffering capacity ( $K_b$ ) which regulates the partition of P between solution and solid phase ranged from 34.2 to 1023.6  $\text{Lkg}^{-1}$ ; 64.7 to 377.3  $\text{Lkg}^{-1}$ , 36.9 to 465.2  $\text{Lkg}^{-1}$  and 97.4 to 669.0  $\text{Lkg}^{-1}$  with a mean of 293  $\text{Lkg}^{-1}$ ; 162.7  $\text{Lkg}^{-1}$ ; 169.1  $\text{Lkg}^{-1}$  and 342.6  $\text{Lkg}^{-1}$  in the soils of tea garden, orchard, cultivated land and forest respectively. Results showed that the soils of forest land use had the highest buffering capacity and of orchard had the least value. Variation in the buffering capacity among different land uses was attributed to variation in the physico-chemical characteristics. Solution phase phosphate from which plants took up their supply, was inversely related to P buffering capacity of soil (Randhawa *et al.*, 1993); so soils with high buffering capacity e.g. forest soils attributed to higher amount of organic matter would have less amount of P concentration in soil solution for exploitation by plant roots.

The Freundlich constant  $K'$  varied widely among soils of different land use patterns and it followed the sequence forest (102.6 to 299.9  $\text{mgkg}^{-1}$ , mean 216.1  $\text{mgkg}^{-1}$ ) > tea garden (372 to 358.9  $\text{mgkg}^{-1}$ , mean 166.8  $\text{mgkg}^{-1}$ ) > orchard (77.3 to 237.7  $\text{mgkg}^{-1}$ , mean 135.1  $\text{mgkg}^{-1}$ ) > cultivated land (53.8 to 239.3  $\text{mgkg}^{-1}$ , mean 134.3  $\text{mgkg}^{-1}$ ). Forest soils differed significantly from the others with respect to their adsorption capacities (Freundlich constant,  $K'$ ). However, with respect to other sorption parameters the various land uses were at par. Freundlich constant,  $K'$  followed more or less same trend as was observed with Langmuir bonding energy (K), while Freundlich's other constant,  $1/n$  followed the sequence similar to that of Langmuir adsorption maxima (b).

Table 29 P sorption parameters of soils under different use patterns of *terai* zone

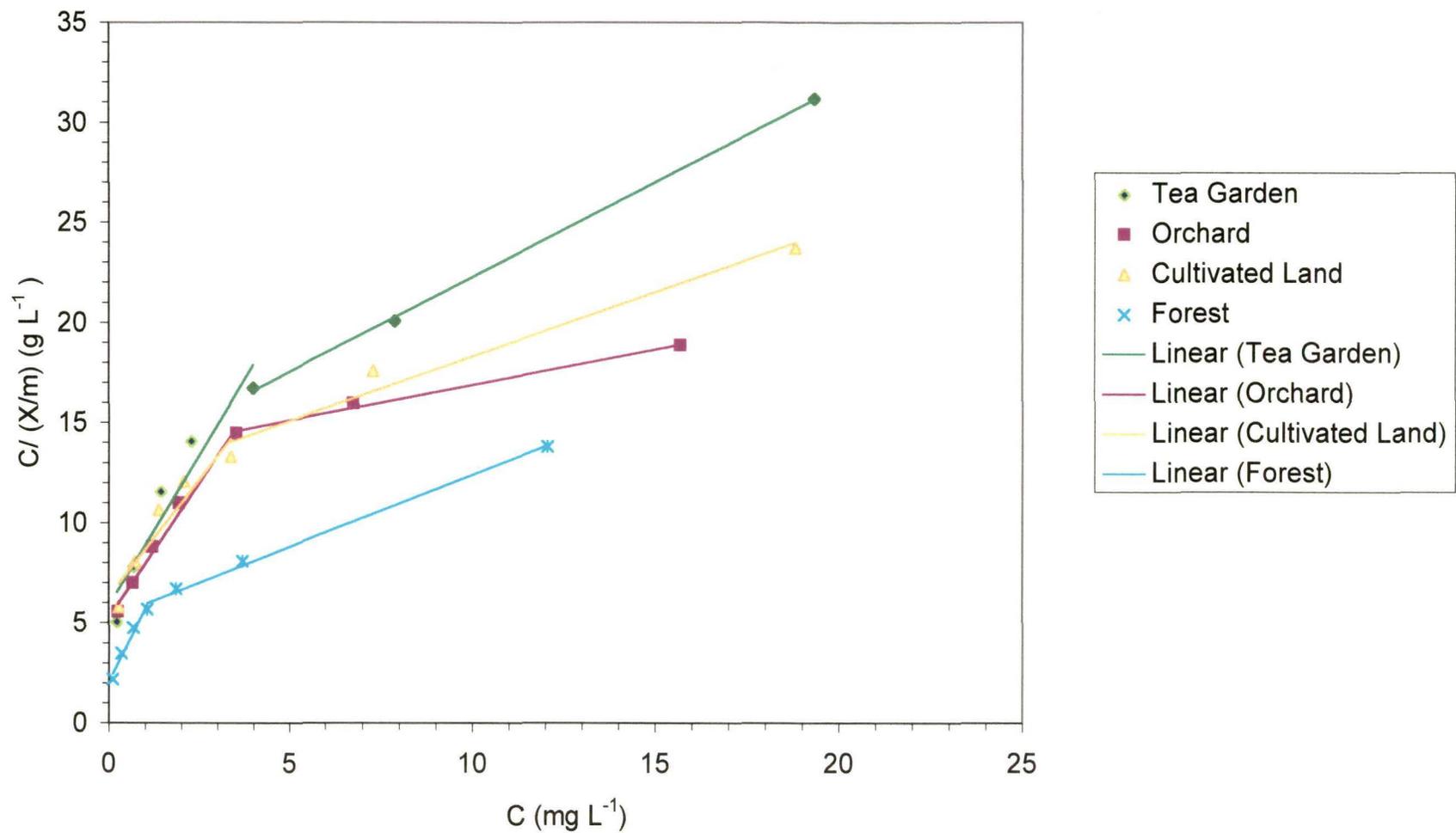
Land use		Tea garden	Orchard	Cultivated land	Forest	S. Em (±)	C.D <sub>1%</sub>
Sorption parameters							
Adsorption maxima (b)	Range	845-2850	1036-2664	848-2017	959-1476		
	Mean	1153(42.2)*	1334(32.4)	1204(24.8)	1170(14.2)	88.9	NS
Bonding energy (K)	Range	0.012-1.052	0.038-0.351	0.029-0.509	0.066-0.682		
	Mean	0.293(116.2)	0.137(71.9)	0.160(81.4)	0.308(58.3)	0.05	NS
Buffering Capacity (K <sub>b</sub> )	Range	34.02-1023.6	64.7-377.3	23.9-465.2	97.4-669.0		
	Mean	293.0(114)	162.7(61.1)	169.1(65.9)	342.6(50.9)	52.3	NS
Freundlich K' during sorption	Range	37.2-358.9	77.3-237.7	53.8-239.3	102.6-299.9		
	Mean	166.8(62.5)	135.1(37.5)	134.3(39.1)	216.1(29.2)	18.3	66.8
1/n	Range	0.450-0.905	0.535-0.868	0.480-0.831	0.403-0.718		
	Mean	0.578(18.3)	0.671(14.1)	0.641(16.0)	0.599(14.4)	0.03	NS
Freundlich K'' during desorption	Mean	20.0	12.9	11.0	20.4		

\* Figure in the parenthesis indicates percentage of CV.

For the P adsorption data taking mean of 15 samples under each land use at each solution P concentration plotted according to Langmuir isotherm correlation coefficients between 'C' and  $C/(x/m)$  (r values varied from 0.876 to 0.957 among the various land uses) were highly significant indicating suitability of the isotherm.

The Langmuir adsorption curves could conveniently be resolved into two straight lines, (Fig.10) suggesting the existence of two different adsorption reactions in operation. For the soils of all land use patterns except tea garden ( $\sim 3 \text{ mgPL}^{-1}$ ) upto about  $2 \text{ mgPL}^{-1}$  equilibrium solution concentration, the adsorption followed one type of reaction and beyond this concentration reaction was of other type. Doddamani and Seshagiri Rao (1989) described that the first type of adsorption reaction (upto  $2 \text{ mgPL}^{-1}$  solution concentration) followed the monolayer adsorption pattern and the second type of adsorption reaction i.e. beyond  $2 \text{ mgPL}^{-1}$  solution concentration was of precipitation type. Accordingly, the constants 'b' and 'K' partitioned into lower and higher values of P concentration (with subscript 1 and 2, respectively) indicated the monolayer adsorption maxima ( $b_1$ ) ranging from 285 and  $402 \text{ mgPkg}^{-1}$  ( $285 \text{ mgPkg}^{-1}$  for cultivated land,  $330 \text{ mgPkg}^{-1}$  for tea garden,  $369 \text{ mgPkg}^{-1}$  for orchard and  $402 \text{ mgPkg}^{-1}$  for forest soils) with corresponding bonding energy ( $K_1$ ) varying from 0.514 to  $0.960 \text{ Lmg}^{-1}$  ( $0.514 \text{ Lmg}^{-1}$  for orchard,  $0.518 \text{ Lmg}^{-1}$  for tea garden,  $0.665 \text{ Lmg}^{-1}$  for cultivated land and  $0.960 \text{ Lmg}^{-1}$  for forest soils) (Table 30). While the  $b_2$  and  $K_2$  values were 1057, 2828, 1463 and 1444  $\text{mgPkg}^{-1}$ ; and 0.074, 0.026, 0.061 and  $0.126 \text{ Lmg}^{-1}$  for tea garden, orchard, cultivated land and forest soil, respectively. From the above results, it was found that ' $b_2$ ' was about 3 to 8 times higher than ' $b_1$ ' and conversely, ' $K_1$ ' was 7 to 20 folds higher than ' $K_2$ '. Higher bonding energy was required for chemisorption occurring at lower concentration on high P affinity sites, while low energy was required for physical adsorption and precipitation of P (Tomar *et al.*, 1995) occurring at higher P concentration after achieving monolayer adsorption. Uptake of P by wheat tended to vary inversely with the 'K' ( $r = -0.284^*$ ) while it had a positive trend with

Fig: 10. Langmuir Phosphorus adsorption isotherms of different land uses in *terai* region of West Bengal



'b' ( $r= 0.171$ ). Results were in conformity with findings of Kumar and Singh (1998).

#### 4.3.1.4 Relationship between Sorption Parameters and Soil Properties

The correlation coefficients ( $r$ ) between various sorption parameters and some important physico-chemical properties in soils of *terai* zone of West Bengal were given in Table 31. Results showed that adsorption maxima ( $b$ ) was significantly associated with AEC ( $r= -0.327^{**}$ ). The value of bonding energy ( $K$ ) increased with increasing organic carbon content ( $r= 0.410^{**}$ ), CEC ( $r= 0.362^{**}$ ) and free  $Fe_2O_3$  ( $r= 0.396^{**}$ ). Similar relationships were reported by Murthy *et al.* (1996) and Douli and Dasgupta (1998).

The maximum buffering capacity ( $K_b$ ) was closely associated with organic carbon content ( $r= 0.440^{**}$ ), free  $Fe_2O_3$  ( $r= 0.418^{**}$ ) and CEC ( $r= 0.386^{**}$ ) indicating the significant roles of organic matter and free  $Fe_2O_3$  in this P sorption behaviour of these soils. Among the soil properties, most closely correlated with Freundlich's constant ( $K'$ ) was organic carbon ( $r= 0.514^{**}$ ), followed by CEC ( $r= 0.438^{**}$ ) and free  $Fe_2O_3$  ( $r= 0.408^{**}$ ). The result was in conformity with Sanyal and De Datta (1991). However, from the data in Table- 31 it was seen that all the sorption parameters were negatively and non-significantly related with clay content of the soil. Non-significant relationship of clay content with adsorption maximum was also reported by Manikandan and Sastry (1988). Results revealed that organic carbon content, CEC and free  $Fe_2O_3$  were significantly related with almost all the sorption parameters indicating their roles in P sorption in these soils. However, it is difficult to differentiate the contribution of organic carbon to sorption process from that of free  $Fe_2O_3$  or CEC because all the components were associated with each other.

The correlation co-efficient ( $r$ ) between the amount of P-sorbed at the highest added P solution concentration ( $100 \text{ mg P L}^{-1}$ ) and some important physico-chemical properties in soils of *terai* agro-climatic zone of West Bengal were recorded in Table-31. Results revealed that P-sorbed at highest P added

Table 30. Langmuir adsorption constants and plant parameters (Mean of fifteen samples for each solution P concentration)

	Adsorption maxima (b)(mgkg <sup>-1</sup> )	Bonding energy (K)(Lmg <sup>-1</sup> )	Dry matter yield of wheat (g 100g <sup>-1</sup> soil)	P- uptake by wheat (mg 100g <sup>-1</sup> soil)
Tea Garden	818 (330,1057)*	0.136 (0.518,0.074)**	2.49	10.19
Orchard	1272 (369,2828)	0.095 (0.514,0.026)	2.23	6.54
Cultivated Land	1160 (285,1463)	0.097 (0.665,0.061)	2.36	10.56
Forest	1162 (402,1444)	0.216 (0.960,0.126)	1.86	4.36

Figures in parentheses are ( $b_1$  and  $b_2$ )\* and ( $K_1$  and  $K_2$ )\*\*, respectively.

Table 31. Correlation (r) between sorption parameters and physico-chemical properties.

Sorption parameters		P <sub>100</sub>	Adsorption maxima(b)	Bonding energy (K)	Buffering capacity (Kb)	K'
Physico-chemical Properties	EC	0.076	-0.031	-0.103	-0.118	-0.028
	Clay	-0.272*	-0.112	-0.158	-0.191	-0.167
	Org.C	0.451**	-0.221	0.410**	0.440**	0.514**
	CEC	0.408**	-0.200	0.362**	0.386**	0.438**
	Fe <sub>2</sub> O <sub>3</sub>	0.451**	-0.051	0.396**	0.418**	0.408**
	Ex Al <sup>3+</sup>	0.082	-0.045	-0.046	-0.030	0.124
	Ext.Al <sup>3+</sup>	-0.106	-0.101	-0.178	0.065	-0.113
	AEC	-0.014	-0.327**	0.197	0.173	0.222

( $P_{100}$ ) decreased with increasing clay content ( $r = -0.272^*$ ) of the soils and increased with increasing organic carbon content ( $r = 0.451^{**}$ ), CEC ( $r = 0.408^{**}$ ) and free  $Fe_2O_3$  ( $r = 0.451^{**}$ ). For each unit increase in organic carbon content, CEC and free  $Fe_2O_3$ , the amount of P-sorbed ( $P_{100}$ ) increased by 250.0, 25.6, 62.5 unit respectively while it decreased by 6.13 unit with each unit increase in clay content.

The partial contribution of different soil properties to the variation of sorbed P in different land use patterns at the highest solution P concentration ( $100 \text{ mgPL}^{-1}$ ) was accounted by stepwise multiple regression analysis (Table-32). Free  $Fe_2O_3$  and exchangeable  $Al^{3+}$  together accounted for 67.1 % variation in sorbed P, of which 52.2 percent variation could be explained by  $Fe_2O_3$  alone in tea garden soils. In forest soils, both the exchange capacities (CEC and AEC) collectively explained 53.4 per cent variation in sorbed P, of which 35.4 per cent variation was explained by CEC alone and about 68.5 per cent variation in the amount P sorbed at its higher solution concentration in forest soils was explained by CEC, AEC and pH jointly. However, none of the soil properties could significantly contribute to explain the variability of sorbed P in cultivated land and orchard soils.

#### 4.3.1.5 Standard Phosphorus Requirement

The quantities of P adsorbed by the soils at  $0.2 \text{ mgL}^{-1}$  equilibrium solution concentration of P were determined from the plot of P adsorbed *versus* P in equilibrium solution concentration (Fig-5) and presented in Table-33. Selection of  $0.2 \text{ mgPL}^{-1}$  as the criterion had been made after Beckwith (1965) who found this concentration adequate for optimum growth of many crops. Standard phosphorus requirement (SPR) values i.e. the amount of P adsorbed at  $0.2 \text{ mgPL}^{-1}$  equilibrium concentration solution, varied from 11 to  $108.2 \text{ mgkg}^{-1}$  with an average of  $74.6 \text{ mgkg}^{-1}$ ; 23.4 to  $105.1 \text{ mgkg}^{-1}$  with an average of  $47.6 \text{ mgkg}^{-1}$ ; 15.1 to  $98.0 \text{ mgkg}^{-1}$  with an average of  $48.3 \text{ mgkg}^{-1}$ ; 35.8 to  $123.0 \text{ mgkg}^{-1}$  with a mean of  $79.9 \text{ mgkg}^{-1}$ , in the soils of tea garden, orchard, cultivated land and

forest land use patterns, respectively, while that for overall *terai* soils were in the range of 11 to 108.2 mgkg<sup>-1</sup> with the mean value of 62.6 mgkg<sup>-1</sup> (Table-33).

Based on the values of standard phosphorus requirement, Juo and Fox (1977) classified the P adsorption capacity of soils into 5 groups as follows:

Standard P requirement ( $\mu\text{gP/g soil}$ )	Scale
<10	Very low
10 – 100	Low
100 – 500	Medium
500 – 1000	High
> 1000	Very high

According to the above criterion, the average P adsorption capacities of these soils were rated as low. SPR was significantly negatively associated with the P-uptake by wheat ( $r = -0.280^*$ ). Thus SPR value could be considered as a good index of plant available P in these soils.

#### 4.3.1.6 Supply Parameter (SP) of Phosphorus

An attempt had been made by Vig *et al.*, (1978) and Sharma *et al.* (1993) to predict the availability of applied P to crops through the combined use of quantity (q), intensity (c) and phosphate buffering capacity (Kb) in a dimensionless parameter known as supply parameter (SP):  $(qc)^{1/2} / (Kb)^{1/4}$ .

The range, mean and coefficient of variation of SP of *terai* soils of West Bengal at seven concentrations (50, 100, 150, 200, 300, 500 and 1000 mgkg<sup>-1</sup>) of added P were presented in Table-34. The results showed that SP values were increased sharply with increase in the concentration of added P.

Range and corresponding mean and coefficient of variation of the supply parameters for soils of different land use patterns were presented in Table-35. In tea garden soils, the average of supply parameters (SP) at seven solutions concentration of 50, 100, 150, 200, 300, 500 and 1000 mgPkg<sup>-1</sup> were 0.916,

Table 32. Stepwise multiple regression between P sorbed (Y) at highest solution concentration and soil properties

Land use patterns	Equations	R <sup>2</sup>	Δ R <sup>2</sup>	Equation No.
Tea Garden	Y= 611.2 + 21.66 Fe <sub>2</sub> O <sub>3</sub>	0.522	–	(1)
	=507.6 + 23.98 Fe <sub>2</sub> O <sub>3</sub> + 45.21 Ex. Al	0.671	0.149	(2)
Forest	Y=814.7 + 3.53 CEC	0.354	–	(3)
	=933.7 + 5.99 CEC– 40.48 AEC	0.534	0.180	(4)
	=855.0 + 6.00CEC – 43.42 AEC + 16.94 pH	0.685	0.151	(5)

Table 33. Standard phosphorous requirement (SPR) in mgkg<sup>-1</sup> soils of different land use patterns

Land uses \ SPR	Terai (overall)	Tea Garden	Orchard	Cultivated land	Forest
Range	11-108.2	11-108.2	23.4 – 105.1	115.1 – 98.0	35.8 – 123.0
Mean	62.6	74.6	47.6	48.3	79.9
CV(%)	50.9	72.1	46.3	43.0	33.7

Table 34. Supply parameters (SP) of soils of Terai region

S.P.	Level of P added (mgkg <sup>-1</sup> )						
	50	100	150	200	300	500	1000
Range	0.21-2.70	0.56-5.41	0.87-8.93	1.20-12.33	1.84-18.55	4.57-30.99	16.51-62.08
Mean	0.88	2.09	3.51	5.02	8.06	14.68	32.86
CV(%)	54.7	43.9	48.6	47.3	45.6	39.8	30.9

2.29, 3.95, 5.65, 9.14, 16.55 and 36.28 respectively. The results revealed that like overall *terai* soils with increasing the level of P added, SP increased steadily and the coefficient of variation computed for supply parameters at the corresponding concentrations narrowed down gradually in all land use patterns. In orchard soils, similar trend was observed. The mean SP were 1.02, 2.27, 3.74, 5.44, 8.85, 15.79 and 33.73 for corresponding concentration of P added. In these soil SP values were somewhat lower than tea garden soils except in the lowest concentration of added P. The coefficient of variation computed for said parameter showed that the variations were relatively less than that of tea garden at the corresponding of P concentrations. In cultivated land soils, the SP values were in the range of 0.34 to 2.01 (mean 1.03); 0.95 to 4.99 (mean 2.40); 1.54 to 8.56 (mean 3.97); 2.13 to 11.58 (mean (5.57)); 3.86 to 17.53 (mean (8.71)) 8.78 to 29.75 (mean 16.40) and 25.38 to 59.57 (mean 36.39) at the respective solution P concentrations. The mean SP in forest land use soils were 0.54, 1.38, 2.37, 3.42, 5.52, 9.99 and 25.02 at added seven solutions containing 50, 100, 150, 200, 300, 500 and 1000 mgPkg<sup>-1</sup>, respectively.

From the above results it might be concluded that the SP values were comparable in all the land use patterns barring forest land use which were somewhat lesser than the others. The lower SP values coupled with higher bonding energy and higher MPBC in forest soils might have explained the lowest dry matter yield and P-uptake of wheat, on the other hand, higher SP value coupled with lower bonding energy and lower MPBC in cultivated land soils yielded higher dry matter of wheat and recorded highest P-uptake (Table-30). At lower solution P concentration (upto 100 mgPkg<sup>-1</sup> soil) dry matter yield ( $r= 0.325^{**}$ ), P-uptake ( $r= 0.438^{**}$ ) and Olsen-P ( $r= 0.778^{**}$ ) had significant relationship with SP. Thus the results indicated that the supply parameter which combined the effect of the amount of P adsorbed, the equilibrium solution P concentration and buffering capacity could be considered as a suitable index for predicting crop response to P application or for characterization of P-flux to plant at lower solution P concentration (only upto 100 mg Pkg<sup>-1</sup> soil) for these soils.

Table 35. Supply parameters (SP) of soils in different land use patterns of *terai* region

Land use patterns			Tea garden	Orchard	Cultivated land	Forest
Level of P (mgkg <sup>-1</sup> soil) added	50	Range	0.21-2.70	0.36-1.74	0.34-2.01	0.31-1.19
		Mean	0.916	1.02	1.03	0.54
		CV(%)	71.4	37.3	50.7	52.3
	100	Range	0.56-5.41	0.87-3.70	0.95-4.99	0.76-2.67
		Mean	2.29	2.27	2.40	1.38
		CV(%)	64.8	35.4	45.9	42.8
	150	Range	0.87-8.93	1.93-5.67	1.54-8.56	1.19-4.74
		Mean	3.95	3.74	3.97	2.37
		CV(%)	63.7	34.7	46.7	45.5
	200	Range	1.20-12.33	2.91-8.58	2.13-11.58	1.72-6.62
		Mean	5.65	5.44	5.57	3.42
		CV(%)	61.6	34.9	44.6	44.1
	300	Range	1.84-18.55	4.56-13.84	3.86-17.53	3.02-10.61
		Mean	9.14	8.85	8.71	5.52
		CV(%)	57.1	33.3	42.4	41.7
	500	Range	4.57-80.99	8.50-23.4	8.78-29.45	5.48-18.08
		Mean	16.55	15.79	16.40	9.99
		CV(%)	49.6	27.7	32.0	38.1
1000	Range	16.51-62.08	21.75-46.99	25.38-59.57	16.72-36.45	
	Mean	36.28	33.73	36.39	25.02	
	CV(%)	38.5	22.3	25.9	24.9	

The result was in agreement with Brar *et al.* (1986) and Damodar Reddy *et al.* (1999).

### 4.3.2 Desorption of Phosphorus

#### 4.3.2.1 First Desorption

The range, mean and corresponding coefficient of variations of P desorbed in first desorption run from soils of different land use patterns at seven solution concentrations 5, 10, 15, 20, 30, 50 and 100 mgPL<sup>-1</sup> were recorded in Table-36. The result showed that the amount of P released in first desorption increased with increasing the amount of sorbed phosphorus or the level of phosphorus in solution added. The mean values of the desorption of phosphorus in the above corresponding solution concentration were 13.5 mgkg<sup>-1</sup>, 33.3 mgkg<sup>-1</sup>, 46.4 mgkg<sup>-1</sup>, 59.0 mgkg<sup>-1</sup>, 80.2 mgkg<sup>-1</sup>, 109.5 mgkg<sup>-1</sup> and 142.7 mgkg<sup>-1</sup> in tea garden soils of *terai* agro-climatic zone. However, the proportion of desorbed P to sorbed P increased upto a certain limit of solution P concentration and thereafter decreased steadily.

In orchard soils, P released in the first desorption showed a similar trend as was observed in tea garden soils. The mean values of P-desorption were 15.4, 39.4, 60.5, 78.5, 111.4, 153.3 and 206.2 mgkg<sup>-1</sup> for the solutions having 5, 10, 15, 20, 30, 50 and 100 mgPL<sup>-1</sup> concentrations respectively and corresponding attainable recovery i.e. proportion of desorbed P to sorbed P were 32.5, 42.1, 43.8, 43.5, 42.1, 35.5, and 24.5 per cent, indicated that the amount of P desorption increased with increasing P-solution concentrations but recovery was maximum at a certain solution P concentration.

In cultivated land soils, the average values of P released in first desorption were 16.1, 45.7, 76.3, 101.4, 138.9, 185.2 and 225.7 mgkg<sup>-1</sup> at seven solution P concentrations and attainable recovery for the corresponding concentrations were 34.0, 49.2, 56.0, 56.5, 52.1, 43.4, 27.8 percent. Forest soils also showed similar results.

The coefficients of variation of P desorption at different solution P concentration decreased steadily with increasing the level of added P in the

Table 36. Amounts of P released in first desorption run from soils under different land use patterns of *terai* region

Land use patterns		Desorption of sorbed P (mgkg <sup>-1</sup> ) at different concentrations (mgPL <sup>-1</sup> )								Mean	Mean attainable recovery (%)
		5	10	15	20	30	50	100			
Tea Garden	Range	5-37.3	13.1-71.6	24.2-102.8	34.3-114.9	46.4-146.2	63.5-184.5	88.7-230.8			
	Mean	13.5 (28.3)*	33.3 (35.8)	46.4 (34.2)	59.0 (33.3)	80.2 (30.8)	109.5 (26.0)	142.7 (17.7)	69.2	29.4	
	% CV	66.8	50.8	48.0	44.6	35.6	29.7	25.6			
Orchard	Range	7.1-23.2	17.1-64.5	24.2-87.7	35.3-111.9	65.5-158.3	93.8-219.8	135.0-312.5			
	Mean	15.4 (32.5)	39.4 (42.1)	60.5 (43.8)	78.5 (43.5)	111.4 (42.1)	153.3 (35.5)	206.2 (24.5)	95.0	37.7	
	% CV	43.9	37.9	30.7	28.0	24.5	26.0	20.5			
Cultivated Land	Range	6.0-28.3	28.2-91.0	39.3-101.0	44.4-142.1	69.6-187.5	78.6-254.0	136.1-324.6			
	Mean	16.1 (34.0)	45.7 (49.2)	76.3 (56.0)	101.4 (56.5)	138.9 (52.1)	185.2 (43.4)	225.7 (27.8)	112.8	45.6	
	% CV	35.1	34.8	26.5	26.0	25.5	24.9	27.3			
Forest	Range	6.0-19.2	23.2-60.5	39.3-102.8	69.6-117.9	96.8-171.4	138.1-263.1	122.0-328.6			
	Mean	12.0 (24.5)	39.5 (40.8)	66.9 (46.7)	90.3 (47.7)	125.9 (44.7)	180.4 (38.9)	231.3 (26.3)	106.6	38.5	
	% CV	37.7	32.2	28.9	25.1	19.8	22.2	19.1			

\* Figures in the parentheses indicate attainable recovery (%)

soils of all land use patterns. It thus indicated that though at lower P concentration there were some variations in the desorption pattern but at higher concentration the pattern was more or less similar for the soils under each land use. The above findings led us to conclude that the highest percent of desorption from sorbed P in different land use patterns was observed in between 10 and 20 mgL<sup>-1</sup> solution P concentrations. It was also found that the average maximum desorption of phosphorus in the first desorption run was observed in cultivated land (112.8 mgkg<sup>-1</sup>) and minimum in tea garden (69.2 mgkg<sup>-1</sup>) soils. Mean attainable recovery of P in different land use patterns also followed the same trend as was recorded for mean P released in the first desorption run and the order was : cultivated land > forest > orchard > tea garden.

#### 4.3.2.2 Second Desorption

The amount (range, mean and coefficient of variation) of phosphorus released in the second desorption run from soils under different land use patterns in *terai* agro-climatic region of West Bengal were presented in Table-37.

In tea garden soils the average phosphorus released during second desorption were 6.1, 13.7, 21.7, 28.0, 38.2, 57.8 and 92.7 mgkg<sup>-1</sup> at seven solution P concentration in ascending order, indicated that like first desorption run the amount of P released increased progressively with increasing the level of solution P added. The corresponding attainable recovery percentages being 12.8, 14.6, 16.1, 15.8, 14.7, 13.7 and 11.5 indicated that recovery percent increased up to 15 mgPL<sup>-1</sup> solution P concentration and then tended to decrease. The coefficient of variation of P released decreased steadily with increasing solution P concentration.

In soils of other land use patterns, though the magnitude of P desorbed as well as desorption of P in relation to sorbed P at different solution P concentrations (recovery percentage) during second desorption were different, but the nature of desorption remained same. It was also observed that the mean values of total P released percent followed exactly the same trend among different land use patterns as was recorded during first desorption run and the sequence was – cultivated land > forest > orchard > tea garden.

Table 37. Amount of P released in second desorption run from soils under different land use patterns of *terai* region

Land use patterns		Desorption of sorbed P ( $\text{mgkg}^{-1}$ ) at different concentrations ( $\text{mgPL}^{-1}$ )								Mean	Mean attainable recovery (%)
		5	10	15	20	30	50	100			
Tea Garden	Range	2.0-14.6	8.6-29.2	15.1-48.4	20.2-51.9	29.2-59.5	38.3-86.6	58.5-113.4			
	Mean	6.1 (12.8)*	13.7 (14.6)	21.7 (16.1)	28.0 (15.8)	38.2 (14.7)	57.8 (13.7)	92.7 (11.5)	36.9	14.2	
	CV (%)	64.0	49.3	44.6	37.5	32.6	29.5	23.6			
Orchard	Range	2.5-15.1	9.6-31.8	19.2-42.3	26.7-60.0	40.8-97.3	55.4-117.9	60.5-215.2			
	Mean	7.9 (16.7)	18.4 (19.7)	29.7 (26.3)	39.1 (21.6)	55.8 (21.0)	85.5 (19.7)	137.9 (16.3)	53.4	20.2	
	CV (%)	41.8	36.6	30.4	22.1	29.5	28.0	27.3			
Cultivated Land	Range	2.5-12.5	6.6-28.2	12.1-40.8	24.2-51.9	40.8-78.6	66.0-149.2	101.3-210.1			
	Mean	7.2 (15.3)	20.3 (22.0)	27.2 (20.0)	37.8 (21.0)	62.5 (23.5)	101.9 (23.8)	155.6 (26.2)	58.9	21.7	
	CV (%)	35.0	30.9	27.2	24.8	21.1	24.8	21.5			
Forest	Range	2.0-10.6	10.6-34.3	17.6-42.8	27.2-54.9	43.3-86.7	75.1-160.8	106.9-203.6			
	Mean	6.0 (12.3)	16.8 (17.4)	27.5 (19.2)	38.0 (20.1)	58.3 (20.7)	101.1 (21.8)	161.7 (08.5)	58.5	18.6	
	% CV	36.0	34.7	26.5	20.9	23.0	22.4	15.4			

\* Figures in the parenthesis indicates attainable recovery (%).

#### 4.3.2.3 Cumulative Release of Phosphorus

Total amount of P released (range, mean and CV) during first and second desorption collectively (CRP) at various levels of P in solution in *terai* soils was depicted in Table-38. Results revealed that the mean values of total P desorbed and corresponding proportion of P desorbed to sorbed P were 21.1 and 44.1; 56.8 and 60.4; 89.1 and 65.6; 118.0 and 64.9; 167.8 and 62.4; 243.7 and 55.7; and 338.5 mgkg<sup>-1</sup> and 42.2 per cent at seven solution concentrations of 5, 10, 15, 20, 30, 50 and 100 mgPL<sup>-1</sup> respectively. It was thus observed that the amount of P desorption increased with increasing the concentration of solution P. Dhillon *et al.* (1986) and Sharma *et al.* (1993) also reported that the rate of P release increased with increase in P status of soil. However, the attainable recovery increased upto 15 mgPL<sup>-1</sup> and then decreased progressively. The coefficient of variation of total P released at different solution concentrations were decreased steadily ranging from 42.4 to 22.2%. However, the mean attainable recovery was around fifty percent (average being 56.5%) varying from 42.2 to 65.6 per cent.

Range, mean and coefficient of variation on the amount of cumulative release of P (CRP) by two successive desorption runs at seven solutions P concentration ranging from 5 to 100 mgPL<sup>-1</sup> for soils of four land use patterns in *terai* agro-climatic zone of West Bengal were recorded (Table-39). Results revealed that in all land use patterns the amount of P desorbed increased progressively with increasing solution P concentration, but the proportion of desorbed P to sorbed P increased upto a certain limit (10 mgPL<sup>-1</sup> for tea garden, 15 mgPL<sup>-1</sup> for orchard and 20 mgPL<sup>-1</sup> for cultivated land and forest soils) of solution P concentration and thereafter decreased steadily. Thus, the highest percentage of P release during desorption of sorbed P in different land use patterns was observed in between 10 to 20 mgL<sup>-1</sup> solution P concentration. However, desorption of sorbed P was maximum (171.7 mgkg<sup>-1</sup>) in cultivated land use and was minimum (106.1 mgkg<sup>-1</sup>) in tea garden soils. The mean attainable recovery was also worked out for each land use as the percentage of total

Table 38. Cumulative release of P (CRP) from soils of *terai* zone of West Bengal

Added solution concentration (mgPL <sup>-1</sup> )	Desorption of sorbed P (mgkg <sup>-1</sup> )		
	Range	Mean	CV(%)
5	8.0- 47.8	21.1 (44.1)*	42.4
10	21.7 – 92.3	56.8 (60.4)	35.9
15	39.3 137.6	89.1 (65.6)	32.8
20	50.4 – 183.9	118.0 (64.9)	28.3
30	68.1 – 253.0	167.8 (62.4)	25.6
50	99.-8 – 423.9	243.7 (55.7)	24.9
100	157.8 – 523.2	338.5 (42.2)	22.2
<b>Mean</b>		147.8 (56.5)	

\* Figure in the parenthesis indicates percent desorption to sorbed

Table 39. Cumulative release of P (CRP) from soils under different land use patterns of *terai zone*

Land use patterns		Desorption of sorbed P (mgkg <sup>-1</sup> ) at different concentrations (mgPL <sup>-1</sup> )								
		5	10	15	20	30	50	100	Mean	Mean attainable recovery (%)
Tea Garden	Range	8.5-47.8	21.7-92.3	39.3-120.0	50.4-149.7	68.1-192.6	99.8-255.6	157.8-322.1		
	Mean	19.6 (41.1)*	47.0 (50.4)	68.2 (50.3)	87.0 (49.1)	118.4 (45.5)	167.3 (39.7)	235.4 (29.2)	106.1	43.6-
	CV (%)	62.1	47.5	42.8	38.8	30.5	26.0	21.2		
Orchard	Range	9.6-44.3	35.3-84.2	51.4-130.0	70.1-164.8	109.4-243.5	173.4-375.5	49.9-469.8		
	Mean	23.3 (49.2)	57.8 (61.8)	90.2 (70.1)	117.6 (65.1)	167.2 (63.1)	238.8 (55.2)	344.1 (40.8)	148.4	57.9
	CV (%)	42.2	31.6	26.7	23.2	23.9	25.0	19.6		

Land use patterns		Desorption of sorbed P ( $\text{mgkg}^{-1}$ ) at different concentrations ( $\text{mgPL}^{-1}$ )								
		5	10	15	20	30	50	100	Mean	Mean attainable recovery (%)
Cultivated Land	Range	15.6-35.4	39.3-88.2	58.5-130.8	71.1-166.8	108.9-249.0	144.1-382.0	252.0-523.2		
	Mean	23.3 (49.3)	66.0 (71.2)	103.5 (76.0)	139.2 (77.5)	201.4 (75.6)	287.1 (67.2)	381.3 (54.0)	171.7	67.3
	CV (%)	24.1	23.4	23.3	22.4	20.6	22.6	22.6		
Forest	Range	8.0-26.8	35.8-81.2	75.1-137.6	103.8-183.9	148.7-253.0	225.3-423.9	315.0-516.1		
	Mean	18.0 (36.8)	56.3 (58.2)	94.4 (65.9)	128.3 (67.8)	184.2 (65.4)	281.5 (60.7)	393.0 (44.8)	165	57.1
	CV (%)	32.0	28.2	25.9	21.7	18.7	20.2	14.3		

Figure in the parenthesis indicates percent desorption relative to sorbed P.

amount of P extracted to total amount of P sorbed at different concentrations of solution P. The range in per cent P desorbed relative to the sorbed P and mean attainable recovery in four land uses followed the order: cultivated land 49.3 to 77.5 (mean 67.3%) > orchard 39.2 to 70.1 (mean 57.9%) > forest 36.8 to 67.8 (mean 57.1%) > tea garden 29.2 to 50.4 (mean (43.6%). Adsorption data during desorption run for the soils of four land use patterns were also fitted to Langmuir, Freundlich and Tempkin equations. The phosphate retained was calculated by subtracting the amount of phosphate extracted from the amount of phosphate adsorbed during sorption run. The desorption isotherm patterns (Figs. 11 to 13) were more or less similar with the sorption isotherms for the soils of all land uses. The results of this study indicated that P desorption to be a function of the same soil properties, which were also associated with sorption process. This observation was in close agreement with the results of Mendoza and Barrow (1987) and Douli and Dasgupta (1998).

Table-40 presented the amount of P desorbed at 100 mgPkg<sup>-1</sup> added solution P concentration in *terai* and its four land use soils in two successive desorption runs by 0.5 M NaHCO<sub>3</sub> (pH 8.5). The amount of P released during first and second desorption were 29.0 and 15.8; 21.0 and 11.2; 28.3 and 16.3; 34.4 and 17.8; and 32.4 and 17.8 per cent for overall *terai* soils, and soils of tea garden, orchard, cultivated land and forest land use, respectively. Results revealed that the highest amount of desorption of added P was recorded in cultivated land (52.2%), while tea garden recorded the least (32.2%). From the data it was quite evident that the first desorption released higher amount of P than the second desorption. Similar observation was also reported by Singh *et al.* (1996) in some Alfisols of varying agro-climatic region of India. However, a substantial quantity of P was desorbed in the second desorption also (11.2 to 17.8%). Though it was lesser in quantity compared to that of the first desorption run, a reasonable amount of P might be available to plants even after exhaustion of Olsen-P. This probably explained the lack of response to applied P in some soils testing as low for Olsen-P.

Fig: 11(a). Langmuir Phosphorus desorption isotherms of different land uses in *terai* region of West Bengal

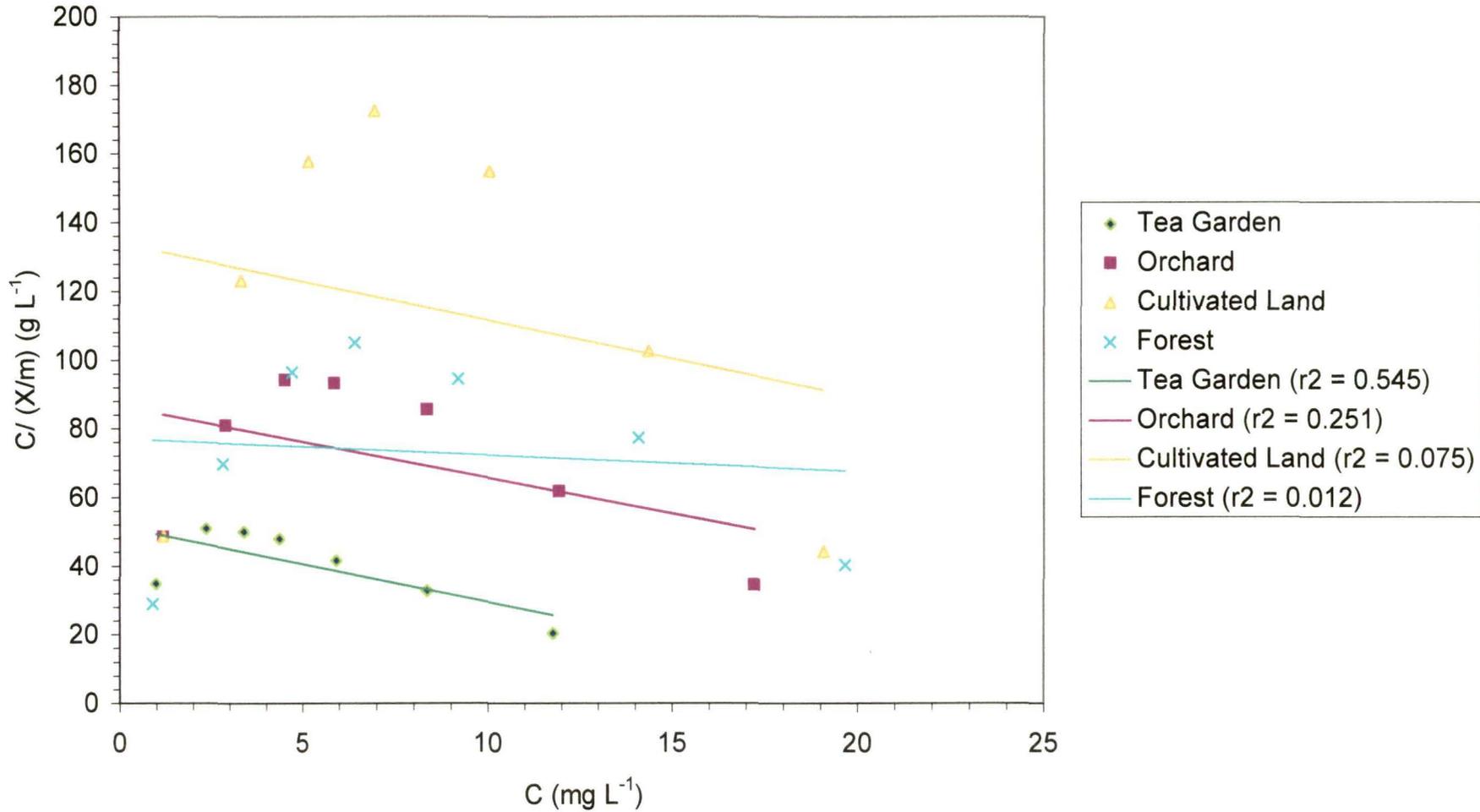


Fig: 11(b). Langmuir Phosphorus desorption isotherms of different land uses in *terai* region of West Bengal

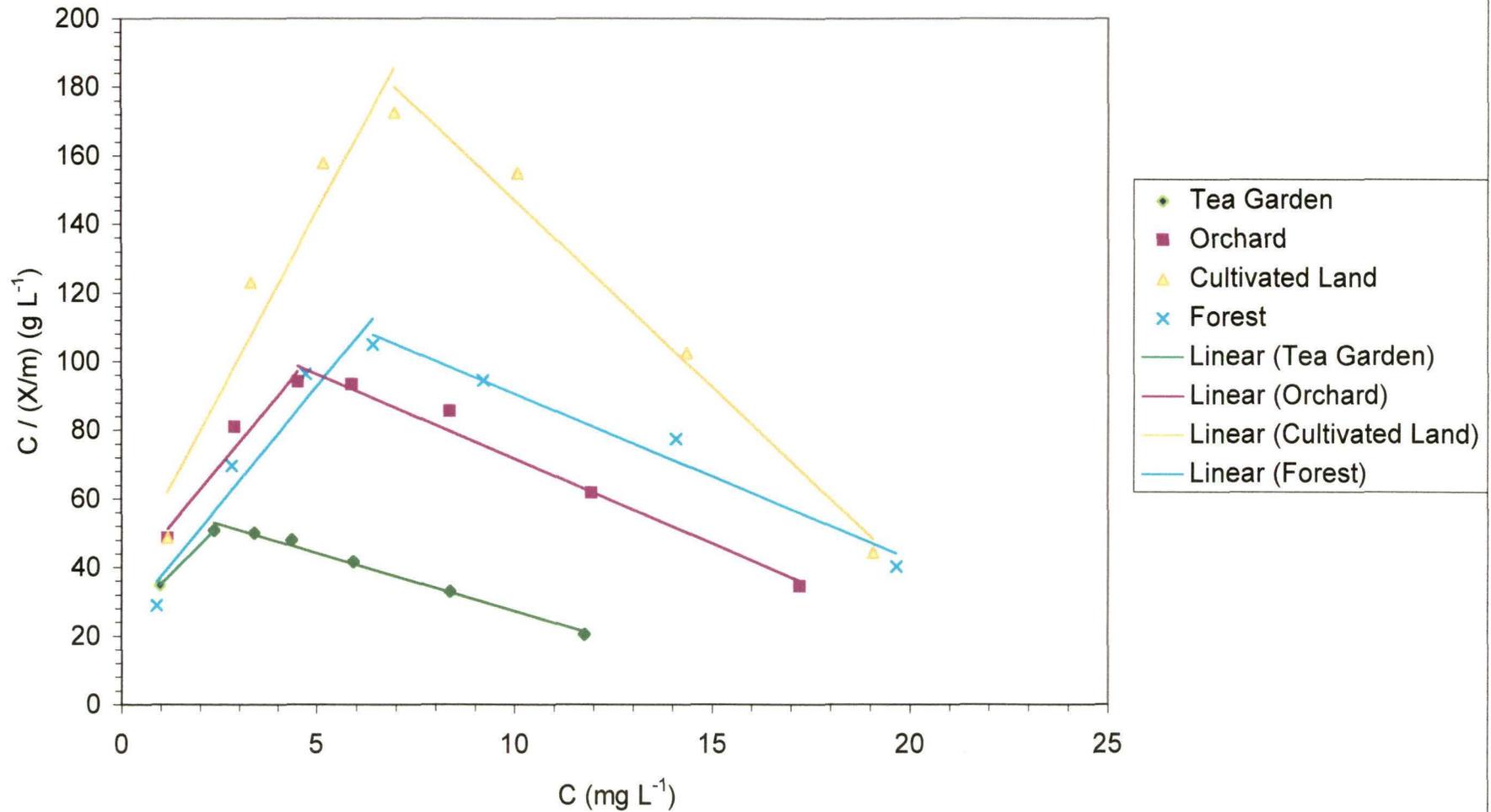


Fig: 12. Freundlich Phosphorus desorption isotherms of different land uses in *terai* region of West Bengal

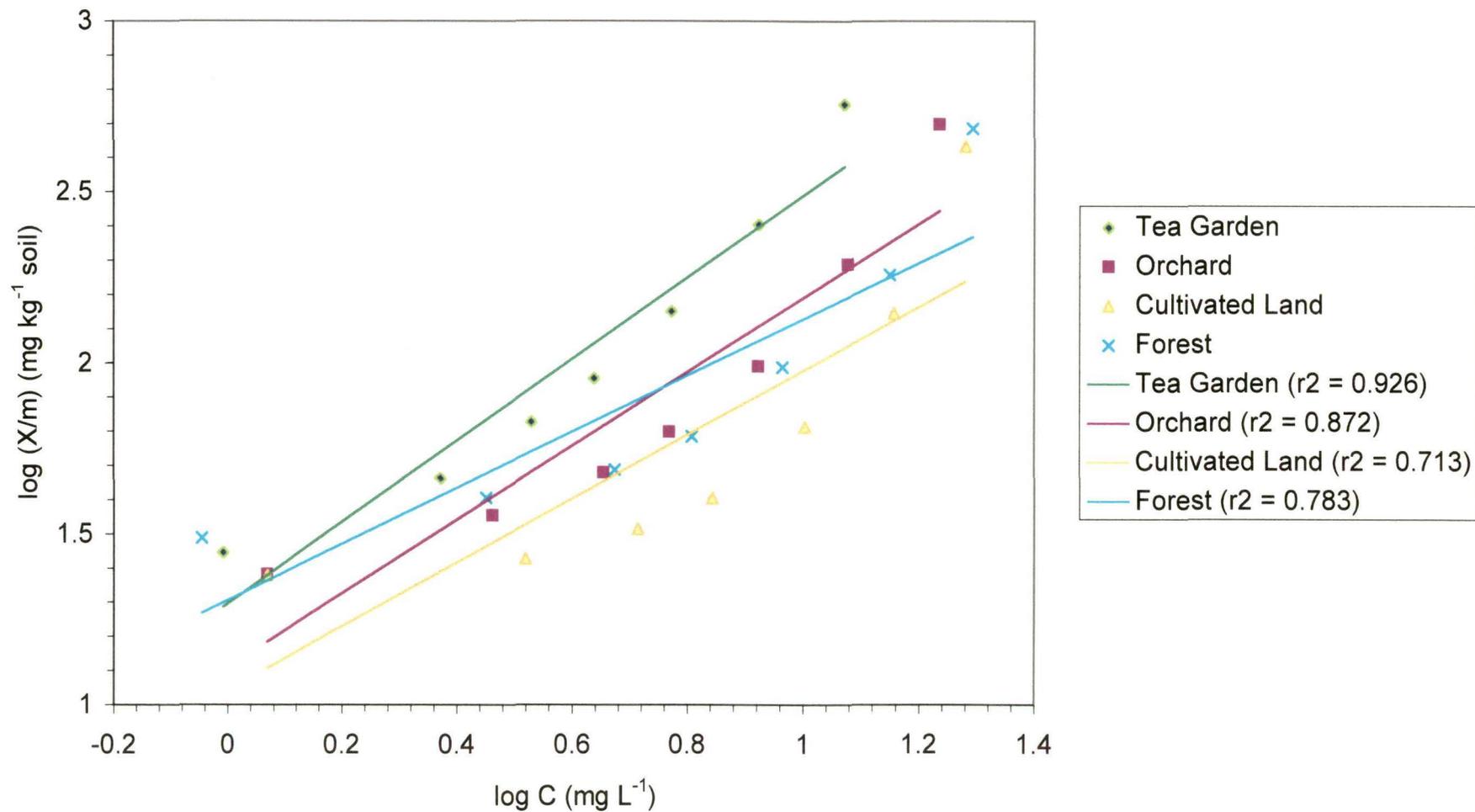
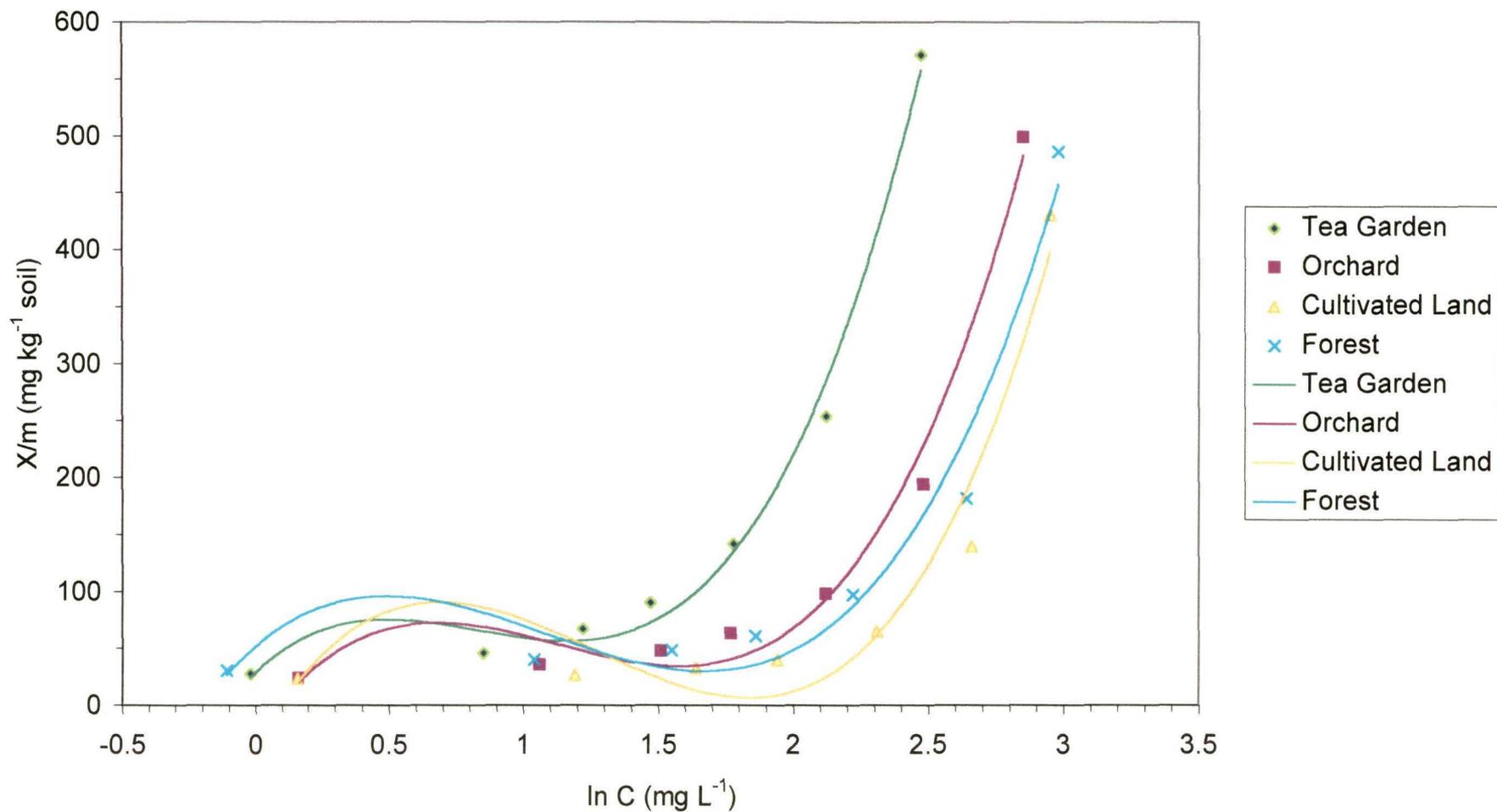


Fig: 13. Tempkin Phosphorus desorption isotherms of different land uses in *terai* region of West Bengal



#### 4.3.2.4 Hysteresis Effect of Phosphorus in Sorption-Desorption Process

During desorption, the amount of phosphate sorbed at a given equilibrium concentration in solution was always lower than that during sorption. The present observation contradicted to the findings of number of scientists (Okajima *et al.*, 1983; Sanyal *et al.*, 1993; Saha *et al.*, 1999) who reported higher amount of P sorbed at a given equilibrium solution P concentration during desorption than that during sorption. This contradiction might be attributed to the use of different extractant ( $\text{NaHCO}_3$ ) during desorption and also two successive desorption runs which extracted higher amount of sorbed P than single run. However, such hysteresis effect revealed a lower estimation of the replenishing ability of soils to supply P to the soil solution, when sorption isotherm was used for this purpose. In other words, during desorption run at any level of sorbed P, the equilibrium solution P concentration was always higher than during sorption process (Fig.14 to17). This was evident from the corresponding lower values of Freundlich K obtained during desorption run than their values for adsorption (Table-29). Hysteresis effect was maximum in the soils of forest land use, while the said effects were comparable for other land use patterns. These lower values of Freundlich K obtained during phosphate desorption also imply the corresponding extents of hysteresis effect involved in the given phosphate sorption processes. However, this observation was corroborated well by Saha *et al.*(1999)who reported a strong association of phosphate sorption characteristics of soils with the extent of hysteresis.

Fig: 14 Hysteresis effect of phosphorus in tea garden soils under terai region of West Bengal

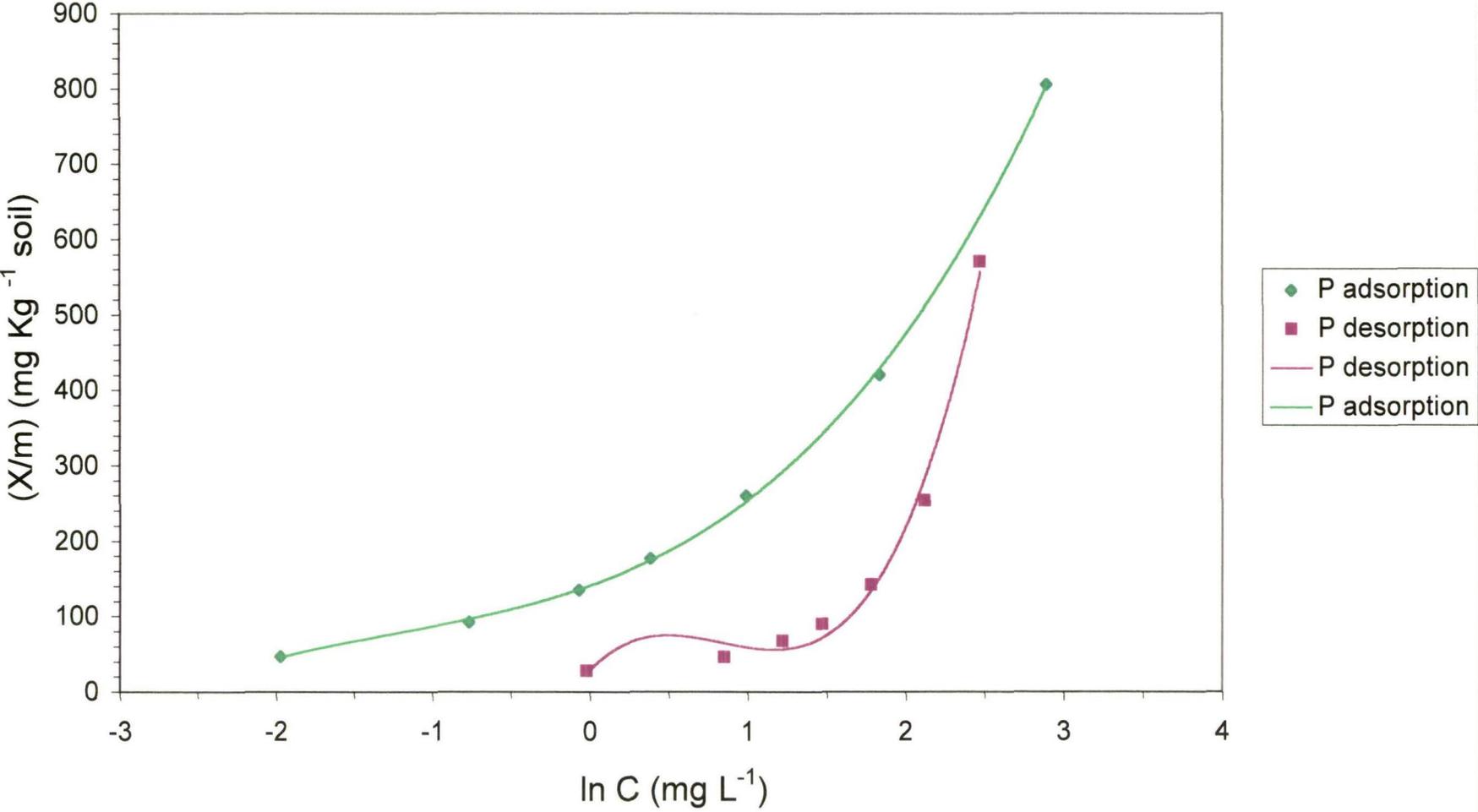


Fig: 15 Hysteresis effect of phosphorus in orchard soils under terai region of West Bengal

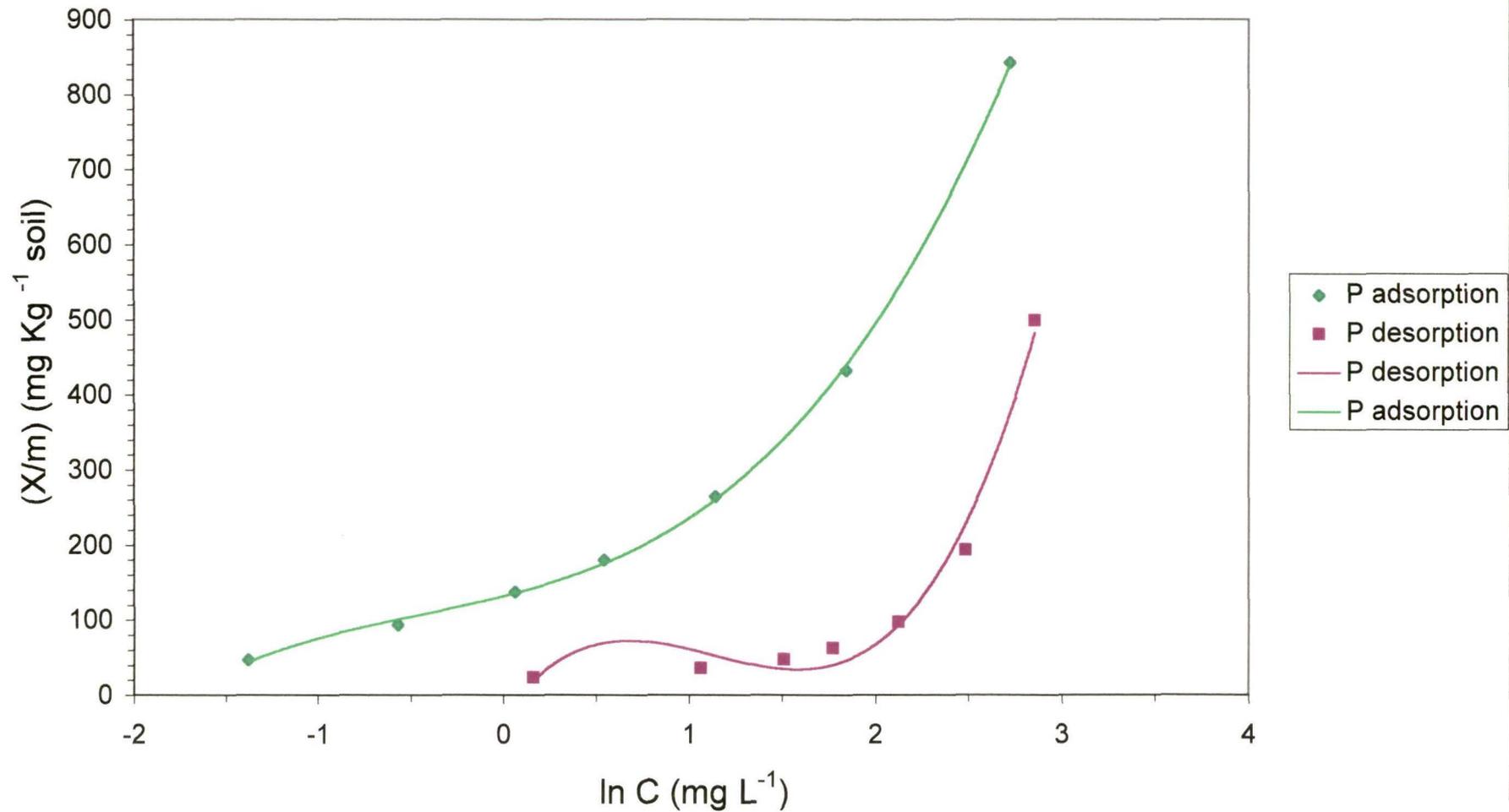


Fig: 16 Hysteresis effect of phosphorus in cultivated land soils under terai region of West Bengal

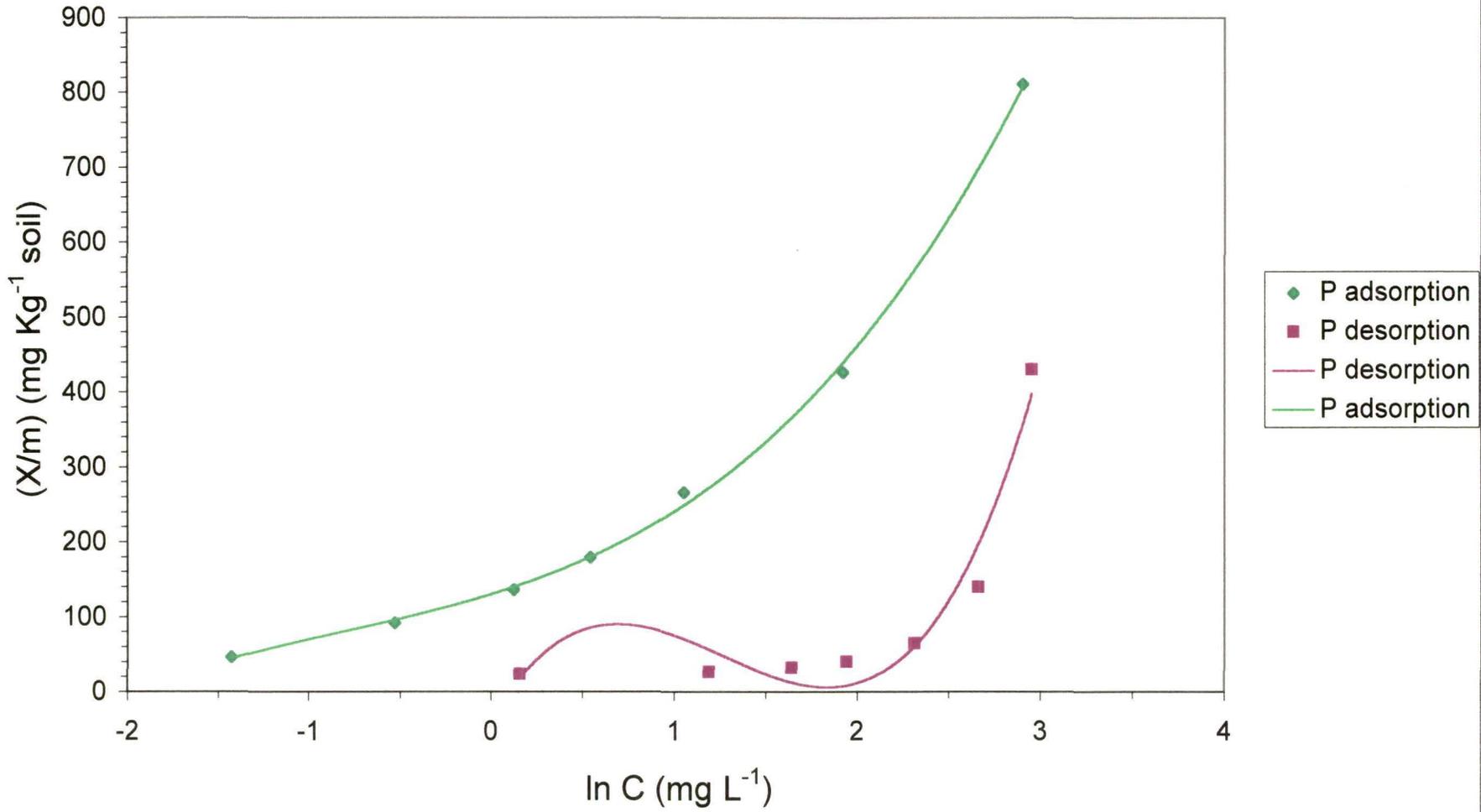


Fig: 17 Hysteresis effect of phosphorus in forest soils under terai region of West Bengal

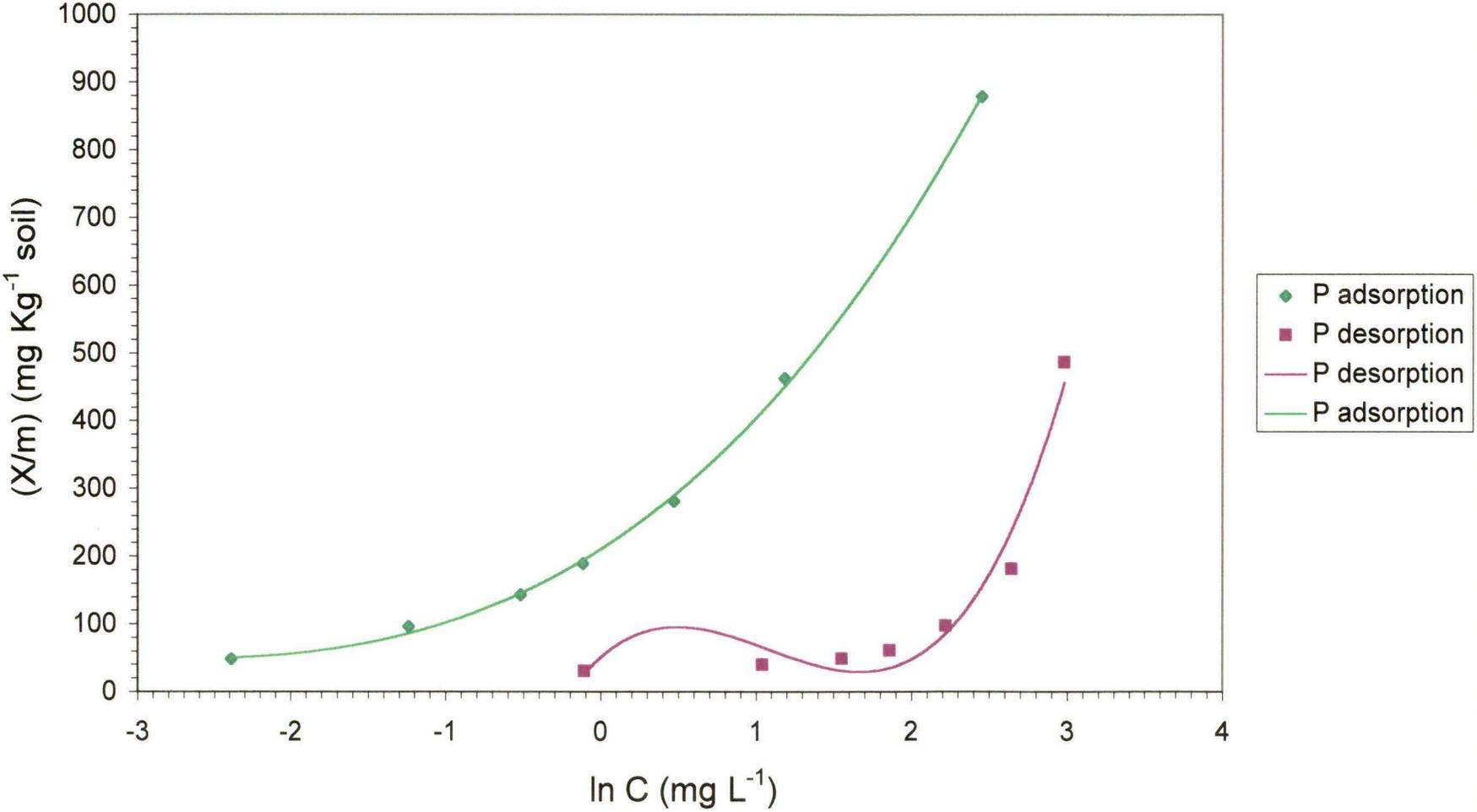


Table 40. Phosphorus desorbed by 0.5 M NaHCO<sub>3</sub> (pH 8.5) during two successive desorptions at 100 mgPkg<sup>-1</sup> added

Land use patterns	P added (mgkg <sup>-1</sup> )	P desorbed (mgkg <sup>-1</sup> )		Cumulative desorption (% recovery)
		1st desorption	2nd desorption	
<i>Terai</i> Soil	100	29.0	15.8	44.8
Tea Garden	100	21.0	11.2	32.2
Orchard	100	28.3	16.3	44.6
Cultivated Land	100	34.4	17.8	52.2
Forest	100	32.4	17.8	50.2