

# INORGANIC AND ORGANIC SOIL PHOSPHORUS FRACTIONS IN HUMID TROPICAL TEA PLANTATION OF WEST BENGAL, INDIA

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## ABSTRACT

Inorganic ( $P_i$ ) and organic phosphorus ( $P_o$ ) fractions were studied in some soils of humid tropical tea gardens of West Bengal, India. In particular,  $P_o$  fractions were estimated following a cheaper and routine method involving differential solubility of organic P compounds to acidic/alkaline extractants. Because of strong acid reaction of soils calcium phosphate fraction was less (7.11% of total P) than the iron and aluminium phosphates and these moderately labile inorganic P constituted 28.23-171.9 mg kg<sup>-1</sup> (mean 76.18) of 422.6-1231 mg kg<sup>-1</sup> total P in these soils. Reductant soluble P (22.09% of total P) was found the major fraction among all  $P_i$  fractions in soils. Among organic fractions moderately resistant fulvic P (45.66% of  $P_o$ ) was highest varying from 90.07 to 219.3 mg kg<sup>-1</sup>, followed by non-labile humic acid P (28.6% of  $P_o$ ). Microbial P ( $LP_m$ ) was strongly correlated ( $P < 0.001$ ) with the total labile P suggesting the role of biological cycle in the labile pool of  $P_o$  in these tea garden soils. It was estimated that a minimum of 9-28 kg of phosphate might have supplied by the soil resource itself to the growing crops which corresponded to 36-100% of phosphate removed by tea from the soil ha<sup>-1</sup> year<sup>-1</sup>.

## INTRODUCTION

Tea (*Camellia sinensis* L.) is a popular beverage and cultivated in many parts of the humid and sub-humid tropical regions of the world mainly in acid soils having pH ( $H_2O$ ) of 4.5 – 5.5 (Zoyza, 1999). In such acid soils phosphorus (P) deficiency is greatly attributed to not only low P availability to plants but also their capacity to fix fertilizer P in insoluble forms. This occurs by way of reacting with amorphous iron and aluminium oxides in soil (Islam *et al.*, 2014) which reduces the efficiency of applied phosphorus fertilizer (Pallavi and Gupta, 2013). But such fixation does not make phosphate totally unavailable to plants, especially for the perennials. Aulakh and Pasricha (1999) viewed that only 10-40% of the applied P is available to plants and the rest gets accumulated in reaction products of lower solubility. Information on the chemical forms of P is fundamental to understand P dynamics and its interaction in acidic soils which are necessary for management of P (Abolfazli *et al.*, 2012) and balance agronomic, economic and environmental considerations.

Tea agro system is characterized by addition of fresh organic matter in soil through tea leaf fall off occurring naturally and through the process of pruning bushes periodically. It is

estimated that about 60 per cent of phosphate absorbed by tea is removed from and 40 per cent is returned to the soil through organic matter by the above processes (Ranganathan 1976). There is no literature available particularly on the organic P fractionation data for the acid Inceptisol and/or Entisols of tea plantations in the Northern India. Thus the basic idea of this study is to investigate the more actively cyclic forms of organic P (labile  $P_o$ ) which contribute to the available pool per year from those that have slower turnover rates.

Among various inorganic forms, the reductant soluble P is mostly unavailable to plants and constituting about 19 to 40 per cent of total phosphate in tea soils (Banerjee 1993), the iron and aluminium phosphate fractions make-up 7-17% of total phosphate and is considered to be slowly available pool of P (Dey and Bhattacharyya 1980). At the same time, organic phosphorus fraction ( $P_o$ ) is an important source of plant nutrient in both natural and managed environments because of mineralization of organic matter and release of inorganic P. Despite importance of  $P_o$ , the chemical nature, dynamics and method of speciation or quantification of soil  $P_o$  is largely unknown partly because of analytical limitations.

Organic forms of soil P varied from 19% (255 mg kg<sup>-1</sup>) of total P in the garden soil of Hunan, China (Huang *et al.* 2004),

29.6% (42.7–106.8 mg kg<sup>-1</sup>) in the arid and semi arid calcareous soils of western plain of Rajasthan (Devra *et al.* 2014) to 34.1–41.9% (241.6–501.1 mg kg<sup>-1</sup>) of total P in the sediments of North canal river of China (Li *et al.* 2010). All these show that P<sub>o</sub> may vary greatly depending upon environmental condition and therefore contribute differently to the labile pool of plant P. Kuo (1996) advocated fractionation of P<sub>o</sub> into labile, moderately labile and non-labile fractions which has been widely used to evaluate organic P in diverse soils under varying management (Ivanoff *et al.* 1998). This involved a cheaper and routine method for characterizing their stability by acidic and/or alkaline extraction.

The paper deals with estimation of the P reserve of these tea soils in respect of the inorganic fractions that collectively contribute to the available and/or slowly available pool, and application of a chemical fractionation scheme, developed by Ivanoff *et al.* (1998) for quantitative grading of large store of soil P<sub>o</sub> in these soils in view of a very specific crop and environmental condition having a very long-term fertilization history.

## MATERIALS AND METHODS

### Study area

The study area lies in the foothills of Eastern Himalayas; the *Terai* and the *Dooars* regions of West Bengal, India, between 26°30'–27°30'N latitude and 88°–89°45' E longitude, covering a geographical area of about 4950 km<sup>2</sup>. The study area is on average 130 m above mean sea level. During the period from May to September this zone receives monsoon rains on average 3000 mm. Soil samples, collected from 0–0.2m and 0.2–0.4m soil depths of eight tea estates, were passed through 2 mm sieve for chemical analysis. A portion of wet soil was also stored in a refrigerator at 4 ± 1°C before any subsequent analysis.

### Soil analysis

The soil pH was measured in 1:2.5, soil:water suspensions and other relevant properties were determined following standard methodologies (Table 1).

The total phosphorus in the soils was determined by digestion method (Jackson 1958). Soil sample was digested with 60 per cent perchloric acid (HClO<sub>4</sub>) (1:50) at 130°C and the P was estimated in the extract. Available P was determined by extracting the soil with 0.03N NH<sub>4</sub>F in 0.025N HCl by the method of Bray and Kurtz (1945) as described by Jackson (1975).

The procedure as outlined by Chang and Jackson (1957) and later modified by Peterson and Corey (1966) was adopted for determination of the following forms of inorganic P.

Saloid bound P (SP) was determined by extracting the soil with 1N NH<sub>4</sub>Cl, (1:50). The easily soluble and loosely bound P comes in the extract. Aluminium phosphate (Al-P) was determined by using 0.5N NH<sub>4</sub>F (pH 8.2) extractant (1:50). After extraction of Al-P, the residual soil was washed with saturated solution of sodium chloride (NaCl) and extracted with sodium hydroxide (1:50). The supernatant solution was made free from organic matter with the help of concentrated sulphuric acid before estimation of iron phosphate (Fe-P). The residual

soil was washed with saturated NaCl and extracted with sulphuric acid (1:50) for estimation of calcium phosphate (Ca-P). After extraction of Ca-P the residual soil was washed with saturated NaCl solution and extracted with 0.3M sodium citrate and 1M sodium bicarbonate (1:40:5) for estimation of reductant soluble P. Phosphorus in each extract was estimated by L-ascorbic acid blue colour method (Murphy and Riley 1962) using a visible spectrophotometer.

### Organic phosphorus fractionation scheme

Total organic phosphorus was determined by following the method of Mehta *et al.* (1954), by subtracting the amount of P extracted by HCl digestion (mineral P) from the total amount extracted by hydrogen peroxide treatment followed by HCl digestion.

Different fractions of organic P, namely, labile, moderately labile and nonlabile P were estimated by following the method of Bowman and Cole (1978) and later modified by Sharpley and Smith (1985) and Ivanoff *et al.* (1998). The P associated with live soil microbial biomass was estimated using chloroform fumigation technique (Hedley and Stewart 1982). The entire fractionation scheme has been outlined in Fig. 1.

## RESULTS AND DISCUSSION

Some relevant properties of the soils used are presented in Table 1. Soils are fine loam and coarse loam type and strongly acidic in nature ranging pH from 4.21 to 5.02. The soils were high in organic carbon ranging from 0.82 and 2.27%. This could be the reason for high water holding capacity of the soils varying between 56–68%. The cation exchange capacity varied within a narrow range of 9.2 to 12.5 cmol (p<sup>+</sup>)kg<sup>-1</sup>.

### Distribution of inorganic phosphorus fractions

The distribution of major inorganic P (P<sub>i</sub>) fractions is given in Table 2. A major fraction of total P was moderately labile P<sub>i</sub> enabling its release with time to the available pool; the moderately labile P<sub>o</sub> was just a fraction of total soil P. Strong acid reaction of soils and high sesquioxide content locks the soluble P quickly to less soluble or moderately labile form and this fact invites P application 500 times the nutritional need in a growing season (Islam *et al.*, 2014). The saloid bound P, the easily available part and the Ca-P was very low in soils which may be due to the low pH of the soils. Similar result was also reported by Watham *et al.*, 2014. The Fe-P fraction varied widely from 72.26 to 209.7 mg kg<sup>-1</sup> being greater than the Al-P ranging from 62.34 to 112.7 mg kg<sup>-1</sup> and these two fractions together constituted 26.43 to 33.71% of total P (422.6–1231 mg kg<sup>-1</sup>) in surface soils. A lower content of Al-P seems to be indicative of strong weathering under well drained humid tropics (Sarkar *et al.* 2014). Because the soils were strongly acidic, the calcium phosphate fraction varied from 22.86 to 73.83 mg kg<sup>-1</sup> (4.72 to 11.4% of total P) and was less than both the iron and aluminium phosphate fractions. This is indicative of higher degree of soil maturity. However, this contrasts the findings of Mondal *et al.* (2002), where the authors obtained Ca-P as the dominant fraction in the *terai* soils of West Bengal. The reductant soluble P (RSP) is the highest inorganic fraction, mostly unavailable to plants, ranging from 95.26 to 324 mg kg<sup>-1</sup> in surface soil with a mean 166.1 mg kg<sup>-1</sup>, which constituted 22.09% of total P on average. This

**Table 1: Some properties of the soils used (0-0.2m)**

Tea gardens	Texture	Classification	pH (1:2.5)	<sup>a</sup> CEC (cmol(p <sup>+</sup> ) kg <sup>-1</sup> )	<sup>b</sup> Organic carbon (%)	<sup>c</sup> Sand (%)	<sup>c</sup> Silt (%)	<sup>c</sup> Clay (%)	<sup>d</sup> Amorphous Fe(g kg <sup>-1</sup> )	<sup>d</sup> Amorphous Al(g kg <sup>-1</sup> )
Kamalpur	Coarse loam	UmbricDystrochrepts	4.25	12.1	1.71	56	29	15	12.0	6.68
Hansqua	Fine loam	FluventicEutrochrepts	5.02	10.6	0.87	59	29	12	9.06	5.36
Kumlai	Coarse loam	TypicHaplaquents	4.21	11.4	1.27	58	28	14	9.69	5.95
Washabarie	Fine loam	FluventicEutrochrepts	4.54	10.5	2.27	52	32	16	15.2	9.90
Bhagatpur	Coarse loam	UmbricDystrochrepts	4.23	12.5	2.1	64	24	12	13.5	9.07
Lakhipara	Fine loam	FluventicEutrochrepts	4.46	11.2	1.9	59	27	14	10.9	5.29
Karbala	Coarse loam	TypicHaplaquents	4.63	11.6	1.38	62	23	15	9.21	4.85
Atal	Fine loam	FluventicEutrochrepts	4.64	9.2	0.82	67	23	10	6.83	4.38

<sup>a</sup>Dewis and Freitas (1984); Walkley and Black (Jackson 1973); <sup>c</sup>International Pipette method (Piper 1966); <sup>d</sup>Saunders (1965) and Jackson (1975)

**Table 2: Distribution of different forms of Phosphorus (mg kg<sup>-1</sup>) in the tea garden soils studied at (0-0.2 m) and (0.2-0.4 m) depths**

Name of the Tea Gardens	Different forms of Phosphorus (mg kg <sup>-1</sup> )													
	Saloid P		Al-P		Fe-P		Ca-P		Reductant soluble P		Organic P		Total P	
	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m
Kamalpur	6.43	5.46	92.59	90.06	131.4	131	71.55	70.77	165.3	162.8	304.1	301.2	771.3	761.3
Hansqua	5.78	5.52	95.72	93.45	113.4	112.2	73.83	71.35	124.6	121.8	234.5	231.3	647.8	635.6
Kumlai	7.05	6.68	98.23	97.56	118.6	115.5	32.32	30.28	153.7	151.5	268.3	264.4	678.2	665.9
Washabarie	12.47	12.08	160.8	157.9	209.7	207.5	58.10	56.92	324	323.2	465.2	463.6	1231	1222
Bhagatpur	9.89	8.24	112.7	109.3	125.5	124.2	68.76	67.3	218.6	215.2	334.8	333.6	870.2	857.8
Lakhipara	5.79	4.87	80.34	76.56	101.3	99.45	32.86	31.52	109	108.56	209.6	207.5	538.8	528.5
Karbala	6.28	5.69	95.62	94.34	109.5	108.7	52.43	50.64	138.2	136.7	317.4	316.3	719.4	712.3
Atal	4.29	3.67	62.34	58.56	72.26	70.45	22.86	21.52	95.26	93.7	165.6	163.6	422.6	411.5

**Table 3: Multiple regression equation indicating the relationship of P availability indices with various forms of P**

Dependent variable	Regression equation	R <sup>2</sup>
Available P (Y)	Y = -8.201 + 5.175 SP + 0.734 Al-P - 0.439 Fe-P - 0.277 Ca-P - 0.081 Organic P	0.686
	Y = -14.153 + 3.035 SP + 0.601 Al-P - 0.298 Fe-P - 0.099 Organic P	0.681
	Y = -15.858 + 1.642 SP + 0.483 Al-P - 0.352 Ca-P	0.669
	Y = -16.586 + 0.587 Al-P - 0.363 Ca-P	0.664
	Y = -24.651 + 0.502 Al-P	0.601

is close to the mean value of 111 mg kg<sup>-1</sup> (24% of total P) reported by Mondal *et al.* (2002) as above. Long-term phosphate fertilization in our studied soils might have penetrated P through the pores of amorphous Fe and Al oxides resulting P as an integral part of crystal lattice rendering it unavailable.

We noted that total P had significant positive correlation with organic carbon ( $R^2 = 0.687$ ,  $P = 0.05$ ), silt ( $R^2 = 0.832$ ,  $P = 0.05$ ), crystalline and amorphous forms of Fe ( $R^2 = 0.946$ ,  $P = 0.05$ ) and Al ( $R^2 = 0.950$ ,  $P = 0.05$ ) suggesting the association of total P with these soil properties. Multiple regression study (Table 3) revealed that Al-P alone accounted for 60% variation in the available pool of P, and 68.1% is accounted by saloid-P, Al-P, Fe-P and P<sub>o</sub>.

#### Distribution of organic phosphorus fractions

The distribution of P<sub>o</sub> fractions is presented in Table 4. The NaHCO<sub>3</sub> extracted P<sub>o</sub> in soil is termed labile P<sub>o</sub> and typically just a fraction of total P<sub>o</sub>. Microbial phosphorus mainly belongs to this fraction. The microbial P (labile P<sub>m</sub>) in the surface soil ranged from 7.76 mg kg<sup>-1</sup> in the Karbala (3.58% of P<sub>o</sub>) to 28.24 mg kg<sup>-1</sup> in the Washabarie soil (5.77% of P<sub>o</sub>). The main

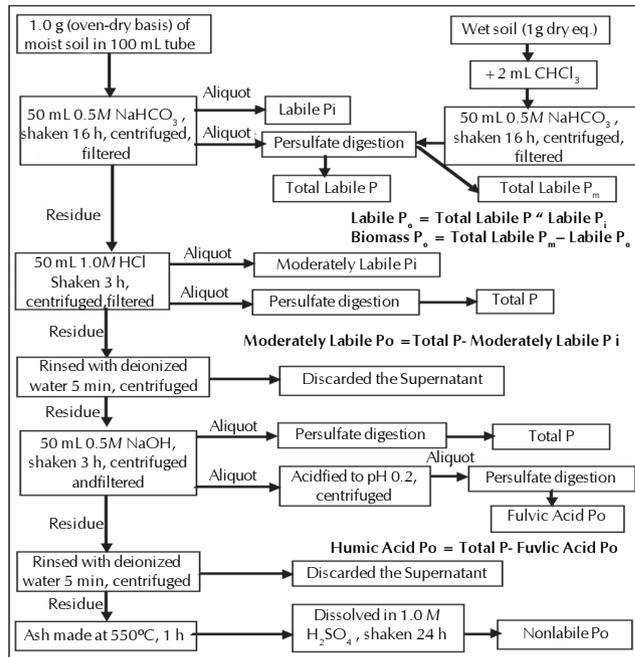
constituents of this fraction are phosphate diester, phospholipids and teichoic acid which are potentially mineralizable. Data have shown that regardless of soil depth the labile P<sub>o</sub> in soils varied between 2.53 and 21.4 mg kg<sup>-1</sup>, which is 1.07 to 4.38% of total P<sub>o</sub>. Both labile and moderately labile fractions are considered as readily plant available than the moderately resistant fulvic acid and highly resistant humic acid fractions extracted by NaOH. The moderately labile P<sub>o</sub>, in general, was lower than the labile P<sub>o</sub> and varied between 0.59 and 3.70% of P<sub>o</sub>.

The P<sub>o</sub> extracted in NaOH was separated into moderately resistant fulvic acid associated part usually containing orthophosphate, phytic acids and a major unidentified portion, and mainly non-labile humic acid associated part having high molecular weight compounds (> 50,000 Da) (Turner *et al.* 2005). Among P<sub>o</sub> forms, the moderately resistant fulvic P was highest varying between 90.07 and 219.3 mg kg<sup>-1</sup> similar to the citation of Huang *et al.* (2004) for the garden soils of China.

In the tea estate soils, fulvic acid P contents were on average 45.66% and 48.07% of P<sub>o</sub> in the surface and sub-surface soils, respectively. Such high fulvic P content is in agreement with the findings of Li *et al.* (2010) for the sediments of the

**Table 4: Distribution of different fractions of organic phosphorus (mg kg<sup>-1</sup>) in the tea garden soils studied at (0-0.2 m) and (0.2-0.4 m) soil depths**

Name of the Tea Gardens	Different fractions of organic phosphorus (mg kg <sup>-1</sup> )		Labile organic P		Moderately Labile organic P		Fulvic P		Humic P		Non-labile		Total Organic P	
	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m	0-0.2 m	0.2-0.4 m
Kamalpur	28.07	23.58	10.33	8.77	12.83	10.24	67.06	65.89	1.85	5.46	158.7	155	79.93	79.54
Hansqua	20.27	19.1	3.12	2.53	10.62	9.04	61.6	59.65	4.48	3.7	107.6	104.9	65.5	66.67
Kumlai	23.19	21.44	6.43	6.04	18.03	15.62	64.72	61.4	3.7	3.12	133.3	128.5	73.69	76.42
Washabarie	67.3	67.25	21.44	20.47	28.24	26.44	171.9	169.2	18.13	16.96	219.3	215	136.9	139.4
Bhagatpur	56.34	51.34	17.55	16.57	16.15	14.63	85.37	79.37	12.67	11.89	187.9	186.1	78.95	79.93
Lakhipara	33.23	27.23	10.92	9.94	16.38	15.27	73.24	67.24	6.82	5.26	159.1	156.9	82.85	84.02
Karballa	27.36	21.36	7.21	5.26	8.93	7.76	57.29	51.29	4.48	3.51	100.9	97.86	71.35	72.52
Atal	18.67	13.67	4.48	3.7	14.27	13.15	28.23	25.23	3.51	2.73	94.55	90.07	35.48	34.51



**Figure 1: Schematic representation of organic phosphorus fractionation**

North Canal river of China. The humic P in our soils varied between 34.5 and 139.4 mg kg<sup>-1</sup> soil contributing 20.5 to 28.6% of total P<sub>o</sub>. The extremely nonlabile fraction of soil P<sub>o</sub> ranged from 20.47 to 68.43 mg kg<sup>-1</sup>, accounting 11.8 to 20.6% of total P<sub>o</sub>. This fraction in soil arises due to strong adsorption of negatively charged P<sub>o</sub> compounds to clays and hydrous Fe- and Al-oxides through polyvalent bridging cations, e.g., Ca<sup>2+</sup> or Fe<sup>3+</sup>. Also under acidic condition, DNA might have penetrated the interlayer spaces of clays to become extremely non-labile as reported by Greeves and Wilson (1969). The total P<sub>o</sub> was calculated as the sum of all the P<sub>o</sub> fractions. This value was least in the Atal (172.7) and highest in the Washabarie (489.3) (Table 4) with mean 300.9 mg kg<sup>-1</sup>. Mondal *et al.* (2002) obtained P<sub>o</sub> values ranging from 16 to 1574 with mean 409 mg kg<sup>-1</sup> in the *terai* soils of West Bengal. Huang *et al.* (2004) reported 255 mg kg<sup>-1</sup> P<sub>o</sub> on average in garden soils of Hunan, China and Li *et al.* (2010) recorded 241.6-501.1 mg kg<sup>-1</sup> in the sediments of North Canal River of China. The surface soil contained higher amount of all these P<sub>o</sub> fractions than the sub-surface soil except for humic and non-labile P<sub>o</sub>.

According to the present fractionation scheme, P<sub>o</sub> ranged between 30.8 and 61.5% of total P in soils (mean 41.6). The readily labile P (P<sub>o</sub> and P<sub>i</sub> together) was 3.61 to 8.49% of total P in the surface soils indicating that these soils are well humified and have high P sorption capacities. The labile fractions are mainly due to fertilizer residues. The extremely non-labile part indicates that P is associated with highly stable organic materials such as lignin and organo-metallic complexes.

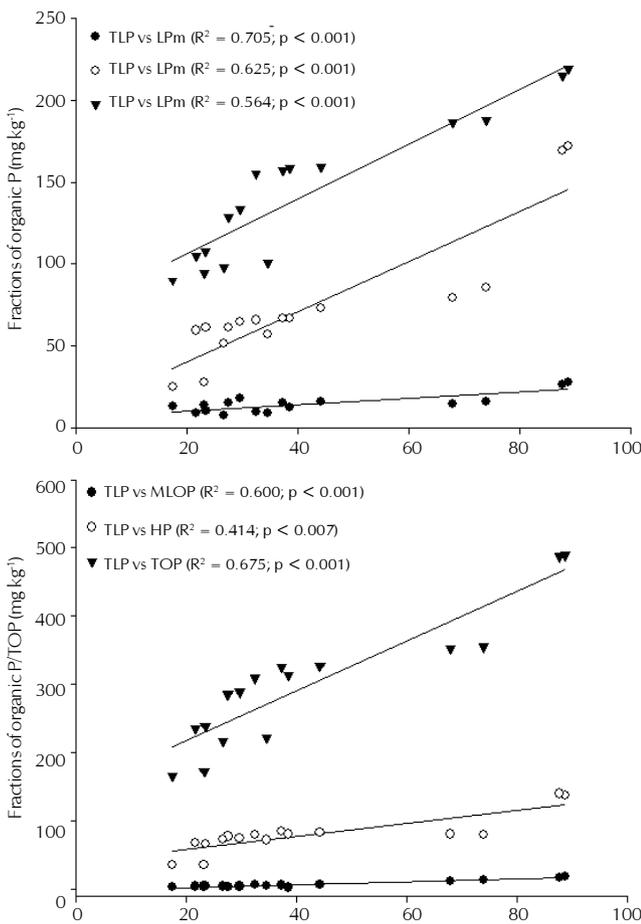
**Correlation and linear regression Study**

The coefficients of correlation values between different forms of inorganic and organic P fractions are presented in table 5. The data revealed that all the forms were well correlated

**Table 5: Correlation among different inorganic and organic phosphorus fractions**

Forms of P	SP	AIP	FeP	CaP	RSP	LIP	LOP	LPM	MLIP	MLOP	FFP	HP	NP
SP		0.957**	0.906**	0.395	0.980**	0.948**	0.911**	0.783*	0.926**	0.916**	0.876**	0.871**	0.635
AIP	0.957**		0.969**	0.463	0.965**	0.852**	0.799*	0.738*	0.953**	0.847**	0.781*	0.918**	0.698
FeP	0.906**	0.969**		0.453	0.948**	0.802*	0.787*	0.765*	0.963**	0.770*	0.809*	0.953**	0.773*
CaP	0.395	0.463	0.453		0.416	0.335	0.297	-0.125	0.327	0.226	0.329	0.349	0.313
RSP	0.980**	0.965**	0.948**	0.416		0.912**	0.886**	0.793*	0.936**	0.872**	0.853**	0.879**	0.627
LIP	0.948**	0.852**	0.802*	0.335	0.912**		0.979**	0.752*	0.884**	0.959**	0.911**	0.821*	0.524
LOP	0.911**	0.799*	0.787*	0.297	0.886**	0.979**		0.754*	0.860**	0.894**	0.952**	0.827*	0.549
LPM	0.783*	0.738*	0.765*	-0.125	0.793*	0.752*	0.754*		0.846**	0.795*	0.792*	0.770*	0.673
MLIP	0.926**	0.953**	0.963**	0.327	0.936**	0.884**	0.860**	0.846**		0.886**	0.865**	0.970**	0.763*
MLOP	0.916**	0.847**	0.770*	0.226	0.872**	0.959**	0.894**	0.795*	0.886**		0.817*	0.784*	0.493
FFP	0.876**	0.781*	0.809*	0.329	0.853**	0.911**	0.952**	0.792*	0.865**	0.817*		0.856**	0.745*
HP	0.871**	0.918**	0.953**	0.349	0.879**	0.821*	0.827*	0.770*	0.970**	0.784*	0.856**		0.825*
NP	0.635	0.698	0.773*	0.313	0.627	0.524	0.549	0.673	0.763*	0.493	0.745*	0.825*	

\*Correlation is significant at the 0.05 % level; \*\* Correlation is significant at the 0.01 % level



**Figure 2: Linear regression of total labile P with different fractions of organic P and Total P. TLP = Total labile P (Labile inorganic P + labile inorganic P); LP<sub>m</sub> - microbial P; MLIP - Moderately labile inorganic P; MLOP - Moderately labile organic P; FP - Fulvic P; HP - Humic P; TOP - Total organic P**

between them, except the Ca-P and non labile P. The saloid bound P which is the easily available inorganic P was highly correlated with labile inorganic ( $R^2 = 0.948$ ) and organic P ( $R^2 = 0.911$ ) of organic P fractions. The highest inorganic fraction i.e. reductant soluble P was also showed significant correlation with different organic fractions of P and coefficient

**Table 6: Common forms of phosphate in the studied soils and their availability**

Source	Per cent of total P	Availability*
Fe-P and Al-P	27.2-33.7	Slowly available
Organic P	14.2-30.0	Slowly available
Ca-P	4.54-11.4	Slowly available
Total	46.0-75.1	

\*(Bhattacharyya and Singh 1990)

values were highest for labile inorganic P ( $R^2 = 0.912$ ) and moderately labile inorganic P ( $R^2 = 0.936$ ). Such correlation suggests these two was the main P source to the inorganic P fraction and the transformation among these fractions would be the key to understand the potential P release and availability. Linear regression between total labile P (TLP) (labile inorganic P + labile organic P) and different fractions of organic P was done to evaluate the contribution of different organic P fraction to the labile pool (Fig. 2). The correlation of microbial P (LP<sub>m</sub>) was found most significant ( $R^2 = 0.705$ ;  $P < 0.001$ ) with the TLP suggesting the role of biological cycle in the labile pool of P<sub>o</sub> in these tea garden soils. These results are in consistent with the idea that LP<sub>m</sub> fraction provides a measure of labile P<sub>o</sub> (Bowman and Cole 1978).

Finally, the availability of the common forms of P showed (Table 6) that on average 46 to 75 % of total P is slowly available to plants at a rate of 1% year<sup>-1</sup> (Bhattacharyya and Singh, 1990). The total P content in the surface soil varied from 422.6 to 870.2 mg kg<sup>-1</sup> (1936 to 3984 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) with exception of 1231 mg (5638 kg) in the Washabarie soil. This amounts to a minimum phosphate (P<sub>2</sub>O<sub>5</sub>) supply of around 9 to 30 kg ha<sup>-1</sup> year<sup>-1</sup>. On the other hand phosphate content of made tea varies from 0.5 % to 1.0%, and a section producing on average 2500 kg made tea ha<sup>-1</sup> year<sup>-1</sup>, (Bhattacharyya and Singh 1990), therefore, removes about 12.5 to 25 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> year<sup>-1</sup>. This shows that about 36 to 100% of phosphate removed from soil is supplied by the native soil source.

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