Natural Rubber Research, **18**(1) : 31-37, 2005

PHOSPHORUS FRACTIONS AND FIXATION OF ADDED P IN RUBBER GROWING SOILS OF KERALA

A. Ulaganathan, G.C. Satisha, M. Karthikakuttyamma, K.K. Ambily and A.N. Sasidharan Nair
Rubber Research Institute of India, Kottayam – 686 009, Kerala, India.

Submitted: 01 December 2003 Accepted: 30 June 2005

Ulaganathan, A., Satisha, G.C., Karthikakuttyamma, M., Ambily, K.K. and Nair, A.N.S. (2005). Phosphorus fractions and fixation of added P in rubber growing soils of Kerala. *Natural Rubber Research,* **18**(1) : 31-37.

The availability of soil applied phosphorus (P) to rubber (*Hevea brasiliensis*) cultivated in Kerala State in India is a major limiting factor as the soils are prone to P fixation due to high content of Fe and Al oxides. Phosphorus fractions and fixation of added P were determined in four major soil series *viz.*, Kanjirapally (Kpl), Thiruvanchoor (Tvr), Kadambanad (Kdb) and Kunnathur (Ktr) representing Central Kerala, where rubber is grown extensively. The relationship of the soil properties with P fractions and P fixation capacity of soil were worked out. The results revealed that total and active P varied and a fairly good P reserve was present in the soil. Iron-P was the dominant P fraction in all the soils and was present in relatively higher amounts in soils of Tvr series. All these soils had appreciable amounts of reductant soluble P (11 to 69 mg/kg) which is regarded as the most difficult fraction to release P. Fixation of added P ranged from 84 to 91 per cent, with a mean value of 86 per cent, indicating a high P retention capacity of these soils. Among the four soil series, the fixation of P in Kpl series (88%) was higher. P fixation had significant positive correlation with clay content, organic carbon, oxalate extractable Al and Fe contents and negatively with Bray II-P.

Key words: *Hevea brasiliensis*, Phosphorus fixation, Phosphorus fraction, Rubber growing soil, Soil property.

INTRODUCTION

Phosphorus (P) nutrition is indispensable for rubber (*Hevea brasiliensis*) as the crop is raised mostly in highly weathered soils in Kerala, the principal rubber growing state in India. Since these soil contain high amounts of sesquioxides (Karthikakuttyamma *et al.*, 2002), the phosphate availability is one of the major problems in the management of soil fertility for rubber cultivation. Bulk of the added P is fixed in such soils due to dominance of Fe and Al oxides and acidic reaction, rendering little change in available phosphorus status of soil. Response to P fertilizer by rubber trees was expected when the amount of Bray II-P was less than 11 mg/g soil (Guha and Yeow, 1966). Pushparajah *et al.* (1976) reported that phosphate fertilizer application not only increased yield but also improved the latex quality. However, in spite of 5 mg/g of Bray II-P content, there was no response to P application for the rubber grown in Kerala. The prediction of response to P fertilizer is generally based on available P status of the soil and on the rate at which the added P is reverted to insoluble forms (Tek Chand and Tomar, 1995). The transformation and reversion of applied P in soil depend on many factors such as duration of contact with soil, prevailing temperature, moisture content, soil texture and organic matter (Vig and Dev, 1984; Borling *et al.*, 2001). Therefore, the present investigation was undertaken to

Correspondence: G.C. Satisha (E-mail: sathisha@rubberboard.org.in)

study the factors influencing P fraction and fixation of added P in the major soil series under rubber in Kerala.

MATERIALS AND METHODS

Rubber is cultivated in a region with an elevation of 30 to 450 m, mostly in the midlands and, to a small extent, in the lower part of the highlands of Kerala State. Although rubber cultivation is widespread in Kerala, Kottayam, Ernakulam and Pathanamthitta districts in Central Kerala contribute more than 50 per cent of the total area.

Twenty representative surface soil samples (0-0.30 m) belonging to different soil series *viz.*, Kanjirapally (Kpl), Thiruvanchoor (Tvr), Kadambanad (Kdb) and Kunnathur (Ktr) representing Kottayam and Pathanamthitta districts of Kerala were collected from smallholdings. Kanjirapally and Thiruvanchoor series consist of deep to very deep, well drained soils formed over charnokite landforms and have slopes of three to more than 33 per cent. Kadambanad and Kunnathur series consist of moderately deep to deep, well drained soils developed over khondalite landforms. Kaolinite is the most dominant clay material followed by illite along with mixed layer silicates and smectites in small amounts (NBSS & LUP, 1999).

The sieved soil samples (<2 mm) were analysed for pH, texture, organic carbon and cation exchange capacity (CEC) following standard procedures (Jackson, 1958). Fractionation of inorganic P was carried out by the method of Peterson and Corey (1966). The amorphous Fe and Al (Fe_{ox} and Al_{ox}) were determined by extraction with ammonium oxalate in the dark (McKeague and Day, 1966) while the dithionite-citrate-bicarbonate extractable Fe and Al (Fe_{dcb} and Al_{dcb}) were determined by the method of Mehra and Jackson (1960).

Phosphorus fixation at different levels of added P was determined by the method outlined by Baruah and Barthakur (1998). Different concentrations of P, ranging from 10 to 60 mg/kg, were added to a known quantity of soil and incubated for 96 h. After incubation, the available P content of soil was determined. The P fixation capacity was calculated from the difference of added and extracted P.

RESULTS AND DISCUSSION

Soil characteristics

Important physico-chemical properties of the soils of different series are presented in Table 1. All the soils were acidic in reaction with pH ranging from 4.12 to 5.36. Organic carbon varied from 4.5 to 18.0 g/kg and most of the soils fell in the medium to high category of organic carbon. The cation exchange capacity of the soils ranged between 4.10 and 8.70 cmol (p+)/kg. Texturally, the soils varied from sandy clay loam to sandy clay.

The contents of iron and aluminium oxide differed greatly among the soils. The dithionite-extractable aluminium (Al_{dcb}) varied from 10 to 13, 12 to 20, 15 to 25 and 13 to 25 g/kg for Kpl, Tvr, Kdb and Ktr series respectively, while oxalate-extractable aluminium (Al_{ox}) ranged from 13 to 19 g/kg for Kpl, 11 to 15 g/kg for Tvr, 8 to 11 g/kg for Kdb and 12 to 14 g/kg for Ktr series. The range in variation for dithionite-extractable iron (Fe_{dcb}) for Kpl, Tvr, Kdb and Ktr was from 10 to 23, 23 to 30, 19 to 26 and 20 to 24 g/kg with mean values of 15, 25, 24 and 22 g/kg respectively. The con-

Table 1. **Physico-chemical properties of different soils under rubber**

Soil propery	Soil series			
	Kanjirapally	Thiruvanchoor	Kadambanad	Kunnathur
Soil separates				
Clay (%)	33.2(30.0-32.8)	30.3(25.0-40.0)	33.9(27.5-37.5)	34.5(27.5-35.0)
Silt (%)	10.4(6.9-17.0)	14.6(10.0-20.0)	13.6(6.5-20.0)	7.8(5.0-10.0)
Sand (%)	53.7(49.0-58.6)	51.2(43.0-59.5)	50.5(39.0-56.5)	54.7(45.1-59.0)
Soil texture	Scl	Scl	Scl	Sc
Taxonomical class	Ustic Kandihumults	Ustic Kanhaplohumults	Ustic Kanhaplohumults	Ustic Kanhaplohumults
pH	4.59(4.12-5.09)	4.72(4.42-4.94)	4.90(4.63-5.05)	5.11(4.84-5.36)
OM (g/kg)	15.1(13.2-18.0)	11.8(6.0-17.4)	11.1(9.0-13.2)	7.9(4.5-13.5)
CEC	6.7(5.6-7.6)	6.5(5.4-8.0)	6.2(5.7-7.4)	6.2(4.1-8.7)
Al and Fe extractables (g/kg) in *dcb* and *ox*				
Al_{dcb}	12.0(10.0-12.5)	15.5(11.9-20.1)	17.5(15.0-25.3)	16.0(12.5-24.0)
Al_{ox}	15.0(12.5-19.0)	13.5(10.5-15.0)	10.5(7.5-11.0)	13.5(11.5-14.0)
Fe_{dcb}	14.5(10.0-22.5)	24.5(22.5-30.0)	24.0(19.0-26.0)	22.0(20.0-24.0)
Fe_{ox}	12.6(10.8-15.0)	10.6(9.5-15.0)	10.6(9.0-12.0)	8.4(6.6-9.5)

Figures in parentheses are ranges. OM : organic matter; CEC : cation exchange capacity (cmol(p+)/kg); pH at 1:2.5 soil-water ratio; *dcb* : dithionite-citrate bicarbonate; *ox* : ammonium oxalate.

centration of oxalate-extractable Fe (Fe_{ox}) ranged from 11 to 15, 10 to 15, 9 to 12 and 7 to 10 g/kg in Kpl, Tvr, Kdb and Ktr respectively.

Phosphorus fractions

The different forms of P in soils are presented in Table 2. The highest total P content was observed in soils of Tvr series (575 to 813 mg/kg) followed by Kpl (546

Table 2. **Forms of P (mg/kg) in different soils under rubber plantations**

P fraction	Soil series			
	Kanjirapally	Thiruvanchoor	Kadambanad	Kunnathur
Total P	632(546-750)	697(575-813)	618(513-675)	610(492-663)
Bray II-P	2(1-4)	7(1-16)	5(1-12)	4(1-12)
Saloid-P	1.1(0.8-2.0)	1.6(1.0-2.0)	2.8(1.0-3.0)	0.8(0.4-2.0)
Al-P	28(17-45)	39(23-112)	10(7-12)	16(7-33)
Fe-P	79(73-107)	123(93-397)	88(67-133)	65(53-73)
Ca-P	38(13-57)	23(13-33)	11(7-20)	10(7-13)
R.S.P	14(11-17)	31(14-42)	43(36-53)	61(6-69)

Figures in parentheses are ranges. R.S.P. : Reductant soluble phophorus to 750 m/kg), Kdb (513 to 675 m/kg) and Ktr (492 to 663 m/kg). All these soils had total P above 300 mg/kg, indicating that the reserve P is fairly good (Chakraborty *et al.*, 2002). Active P comprising saloid-P, Al-P, Fe-P and Ca-P fractions ranged from 104 to 211 mg/kg in Kpl, 130 to 554 mg/kg in Tvr, 82 to 168 mg/kg in Kdb and 67 to 121 mg/kg in Ktr series.

The Fe-P was the dominant P fraction in all the soils. The soils of Tvr series contained higher quantity of Fe-P, followed by Kdb and Kpl series compared to Al-P and Ca-P. The soils of Ktr series contained the lowest amount of Fe-P and Ca-P. The build-up of Fe-P and Al-P may be attributed to the higher activity of Fe and Al cations in complexing P in these soils (Karthikakuttyamma *et al.*, 1991). Further, the dominance of Fe-P over Ca-P in these soils indicates that they have undergone intense weathering (Sharma *et al.*, 1995). Sharma and Tripathi (1992) explained the degree of weathering or the stage of maturity of the soil on the basis of the relative abundance of the P fractions. According to them, in the early stages of weathering, Ca-P and Al-P are more dominant in comparison to Fe-P, but as the weathering reaches an advanced stage, there is a shift in the relative abundance from Ca-P towards Al-P and Fe-P. Moreover, the Fe-P and Al-P are the main sources of available P in acid soils as most of the fertilizer P added to such soils gets transformed into relatively insoluble inorganic compounds of Al and Fe. Therefore, the value of phosphatic fertilizers depends primarily on the release of phosphorus from these reaction products rather than the fertilizer *per se* (Lindsay *et al.*, 1962; Ghosh and Sarkar, 1997; Chakraborty *et al.*, 2002).

The soils also had appreciable quantity of reductant soluble P. The highest value of reductant soluble P was recorded for the soils of Ktr series (55 to 69 mg/kg) followed by Kdb (36 to 53 mg/kg), Tvr (14 to 42 mg/kg) while the lowest was for Kpl (11 to 17 mg/kg) series. According to Beauchemin and Simard (2000), the reductant soluble P is regarded as the most difficult P fraction to release P under upland situations. The predominance of reductant soluble P in these soils may be considered as the main cause for the non-responsiveness to phosphatic fertilizer. Bachik and Baert (1981) reported similar results for rubber-cultivated soils in Malaysia.

Fixation of added phosphorus

The quantity of P fixed ranged from 9.08 to 53.10 mg/kg for Kpl, 8.62 to 50.40 mg/kg for Tvr, 8.74 to 50.50 mg/kg for Kdb and 8.55 to 51.00 mg/kg for Ktr series. When P was added at the rate of 10 mg/kg soil, the per cent P fixed varied from 85.5 (Ktr series) to 91 (Kpl series). When P added was increased to 60 mg/kg, the values ranged from 84 (Tvr series) to 88 (Kpl series) per cent. Among the soil series, the quantity of P fixed was the highest for Kpl series (88%) and the lowest for Tvr series (85%) (Fig. 1). However, the P fixation capacity of whole soils ranged from 77 to 91 per cent, with a mean value of 86 per cent indicating a high retention capacity of P in these soils. Such higher P fixation in these soils might be attributed to the presence of higher quantities of Fe and Al oxides and sesquioxides (Sanyal and DeDatta, 1991; Krishnakumar *et al.*, 2003).

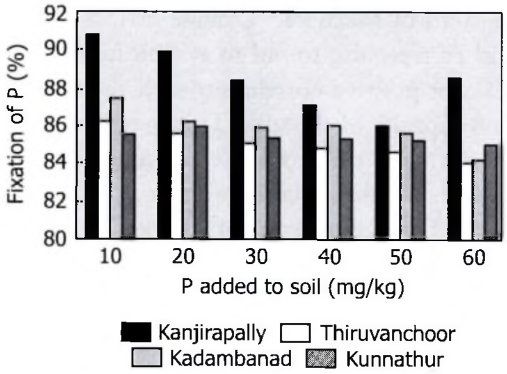

Fig. 1. Phosphorus fixation capacity of soils of different soil series under rubber

Relationship of soil properties with P fractions and P fixation capacity of soils

Correlation coefficients were worked out to understand the nature and degree of association of soil properties with P fractions and fixation capacity of soils (Table 3). The results showed that Al-P was significantly and positively correlated with organic carbon, oxalate extractable Al and Fe. Iron-P also showed significant and positive correlation with oxalate-extractable Fe. Sharma and Tripathi (1992) also reported significant and positive correlation between Fe-P and amorphous Fe, and suggested that there is a possibility of added P or native P to be converted into Fe-P as the clay is rich in Fe. The association of Fe-P with amorphous Fe was also demonstrated (Dongala, 1993). There was significant positive correlation between Ca-P and organic carbon, oxalate extractable Al and Fe. The reductant soluble P had significant positive relationship with pH but was significantly and negatively related with organic carbon and oxalate extractable Fe. The negative association could be due to sorption rather than precipitation. When soils are exposed to free oxygen, the active forms of Fe such as crystalline, extractable and amorphous types exist as ferric oxy-hydroxide which can occlude soil and fertilizer P in their matrices through a sorption process (Agbenin, 2003). The occlusion of soluble phosphate in ferric oxy-hydroxide films can lead to the formation of reductant soluble P as observed in these soils.

Phosphorus fixation was significantly and positively correlated with clay content of the soil, which could be due to larger specific surface area of the clay associated with higher anion exchange capacity. The effect of clay on the P fixing ability has, previously, been attributed to the presence of more reactive and extensive surfaces besides the association of various forms of Al and Fe with clay, which are considered as the active com-

Table 3. **Coefficient of correlation of soil properties with P fractions and P fixation capacity of soils**

Soil property	Total P	Saloid-P	Al-P	Fe-P	Ca-P	RSP	P Fixation
Clay	0.014	0.288	-0.023	0.274	0.007	0.213	0.657**
pH	-0.138	0.197	-0.162	-0.026	-0.341	0.534*	0.270
Organic carbon	0.323	0.053	0.459*	0.477*	0.530*	-0.633**	0.551*
Bray II-P	0.307	0.006	0.014	-0.274	-0.299	0.163	-0.697**
Al_{dcb}	0.324	-0.089	-0.204	-0.173	-0.345	0.382	-0.319
Al_{ox}	0.130	-0.274	0.504*	-0.100	0.462*	-0.312	0.461*
Fe_{dcb}	-0.090	0.195	-0.154	-0.237	-0.300	0.394	-0.345
Fe_{ox}	0.247	0.126	0.547*	0.641**	0.484*	-0.606**	0.544**

* significant at p<0.05 ** significant at p<0.01
RSP : Reductant soluble phosphorus; dcb : dithionate citrate bicarbonate;
ox : ammonium oxalate

ponents of P fixation (Sanchez, 1976; Lekwa and Whiteside, 1986). The positive association of clay with P fixing capacity can also be explained on the grounds that it presents electropositive charges that act as sorbents of phosphates (Broomfield, 1965). Kaistha *et al.* (1997) observed similar results for alfisols of Himachal Pradesh region in India.

There was significant positive correlation between P fixation and organic carbon content. Probably due to the formation of phospho-humic compounds by the interaction of P and organic compounds (Mallikarjuna *et al.*, 2003). There was a negative but significant correlation of Bray II-P with P fixing capacity of soil. This could be due to gradual dissolution of Fe and Al oxides and their subsequent precipitation as phosphates, thereby converting the available P into non-available forms. These findings are in close agreement with the findings of Bachik and Baert (1981) for rubber growing soils of Malaysia. Oxalate extractable Al and Fe were also found to exhibit highly significant positive correlation with the P fixation capacity of the soil. This may be due to the formation of insoluble phosphates of Fe and Al, which is a common feature of acidic soils. The active forms of Al and Fe such as extractable, amorphous and crystalline are the potential P fixation sites (Borling *et al.*, 2001). These forms, upon hydrolysis, expose a much larger surface area where high affinity fixation of P could take place on protonated sites (Yuan and Lavkulich, 1994). The fixation could also take place by the exchange of hydroxyl displacement by H_2PO_4 ions from the surface of hydrous oxides of Al and Fe (Agbenin and Tiessen, 1994).

The observed properties of the four soil series under rubber cultivation in Central Kerala region thus provide explanations for the lack of response to P fertilizer application in these soils.

REFERENCES

Agbenin, J.O. (2003). Extractable iron and aluminium effects on phosphate sorption in a savanna Alfisol. *Soil Science Society of America Journal*, 67:589-595.

Agbenin, J.O. and Tiessen, H. (1994). The effect of soil properties on the differential phosphorus sorption by semi-arid soils from northeast Brazil. *Soil Science*, 157:36-45.

Bachik, A.T.B. and Baert, L. (1981). Factors controlling phosphate fixation and release in selected soils under rubber cultivation. *Journal of Rubber Research Institute of Malaysia*, 29 (3):163-170.

Baruah, T.C. and Barthakur, H.P. (1998). A Textbook of Soil Analysis, Vikas Publishers Pvt. Ltd., New Delhi, pp. 140-141.

Beauchemin, S. and Simard, R.R. (2000). Phosphorus status of intensively cropped soils of the St. Lawrence Lowlands. *Soil Science Society of America Journal*, 64:659-670.

Börling, K., Otabbong, E. and Barberis, E. (2001). Phosphorus sorption in relation to soil properties in some cultivated Swedish soils. *Nutrient Cycling in Agroecosystem*, 59:39-46.

Broomfield, S.M. (1965). Studies of the relative importance of iron and aluminium in the sorption of phosphate by some Australian soils. *Australian Journal of Experimental Agriculture and Animal Husbandry*, 5:52-58.

Chakraborty, T., Ghosh, G.K. and Laha, P. (2002). Fertility status and phosphorus fractionations in lateritic soils under different agro-ecosystems of West Bengal. *Indian Journal of Agricultural Sciences*, 72 (1): 42-44.

Dongala, J.H. (1993). Depth distribution and different forms of phosphorus in lateritic soils of coastal region. *Journal of the Indian Society of Soil Science*, 41:62-66.

Ghosh, G.K. and Sarkar,A.K.(1997). Indices of P availability and fixation of added P in acid Alfisols of Chotanagpur plateau of Bihar. *Journal of the Indian Society of Soil Science*, 45(3):455-460.

Guha, M.M. and Yeow, K.H. (1966). Content of major nutrients in rubber growing soils of Malaya. *Proceedings of 2nd Malaysian Soil Conference*, Kuala Lumpur, 1966, pp.171-180.

Jackson, M.L. (1958). Soil Chemical Analysis, University of Wisconsin, Madison, USA, pp. 47-58.

Kaistha, B.P., Sharma, P.K. and Sharma, R.P. (1997). Influence of soil components on phosphorus fixing capacity of some Alfisols of Himachal Pradesh. *Journal of the Indian Society of Soil Science*, 45(2):261-264.

Karthikakuttyamma, M., Nair, A.N.S., Krishnakumar, A.K., Potty, S.N. and Mathew, M. (1991). Important inorganic phosphorus fractions in rubber growing soils. *Indian Journal of Natural Rubber Research*, 4(1):72-76.

Karthikakuttyamma, M., Satisha,G.C., Suresh, P.R., Aiyer, R.S. and Krishnakumar, A.K. (2002). Impact of rubber (*Hevea brasiliensis*) cultivation of ion exchange and pedogenic components of the soils, relative to the natural forest. *National Seminar on Developments in Soil Science 2002*, 11-15 November 2002, Jabalpur, India: Abstracts, pp. 41.

Krishnakumar, A.K., Karthikakuttyamma, M., Datta, B., Potty, S.N., Mary, C.P., Thomas, M.J. and Aleyamma, A. (2003). Soils under *Hevea* in India : Physical, chemical and mineralogical investigations. *Indian Journal of Natural Rubber Research*, 16(1&2):1-20.

Lekwa, G. and Whiteside, E.P. (1986). Coastal plain soils of south eastern Nigeria: 2. Forms of extractable Fe, Al, and phosphorus. *Soil Science Society of America Journal*, 50:160-166.

Lindsay, W.L., Frazier, A.W. and Stephenson, H.F. (1962). Identification of reaction products from phosphate fertilizer in soils. *Soil Science Society of America Proceedings*, 26:446-452.

Mallikarjuna, G., Sudhir, K., Srikanth, K. and Srinivasamurthy, C.A. (2003). Phosphorus fixation capacity and its relationship with the soil characteristics in laterite soils of Karnataka. *Journal of the Indian Society of Soil Science*, 51(1):23-25.

McKeague, J.A. and Day, J.H. (1996). Dithionite and oxalate extractable iron and aluminium as aids in differentiating various classes of soil. *Canadian Journal of Soil Science*, 46:13-32.

Mehra, O.P. and Jackson, M.L. (1960). Iron oxide removal from soils and clays by dithionite-citrate systems buffered with sodium bicarbonate. *Clays and Clay Minerals*, 7:317-327.

NBSS & LUP (1999). Resource soil survey and mapping of rubber growing soils of Kerala and Tamil Nadu, National Bureau of Soil Survey and Land Use Planning, Indian Council of Agricultural Research, Nagpur, India, pp. 220-230.

Petersen, G.W. and Corey, R.B. (1966). A modified Chang and Jackson procedure for routine fractionation of inorganic soil phosphates. *Soil Science Society of America Proceedings*, 30:563-565.

Pushparajah, E., Soong, N.K., Yew, F.K. and Zainol Eusof (1976). Effects of fertilizers on soils under *Hevea*. *Proceedings of International Rubber Conference*, 1975, Kuala Lumpur, Malaysia, 3 : 37-47.

Sanchez, P.A. (1976). Properties and Management of Soils in the Tropics. Ed 2, John Wiley and Sons, Inc. New York, USA, 605 p.

Sanyal, S.K. and DeDatta, S.K. (1991). Chemistry of phosphorus transformation in soils. *Advances in Soil Science*, 16:1-120.

Sharma, P.K. and Tripathi, B.R. (1992). Fractions of phosphorus from some acid hill soils of North-West India. *Journal of the Indian Society of Soil Science*, 40:59-65.

Sharma, S.P., Dhyani, B.P. and Minhas, R.S. (1995). Inorganic phosphorus fractions in an Alfisol under long term fertilizer experimentation. *Journal of the Indian Society of Soil Science*, 43:466-468.

Tek Chand and Tomar, N.K. (1995). Effect of soil properties on the kinetics of phosphorus fixation in acid soils. *Journal of the Indian Society of Soil Science*, 43(1):24-27.

Vig, A.C. and Dev, G. (1984). Phosphors adsorption characteristics of some acid and alkaline soils. *Journal of the Indian Society of Soil Science*, 32:235-239.

Yuan, G. and Lavkulick, L.M. (1994). Phosphate sorption in relation to extractable Fe and Al in Spodosols. *Soil Science Society of America Journal*, 58:343-346.