Indian Journal of Natural Rubber Research, **16** (1 & 2) : 1-20, 2003

SOILS UNDER *HEVEA* IN INDIA: PHYSICAL, CHEMICAL AND MINERALOGICAL INVESTIGATIONS

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

The physical, chemical and mineralogical properties of the soils under rubber (*Hevea brasiliensis*) from the south western region of Peninsular India were studied and classified as per soil taxonomy. The texture of the soils varied from sandy clay loam at the surface to clay in the lower solum. The soils in general were deep and profiles exhibited distinct A and Bt horizon indicating clay migration by illuviation. Bulk density showed a decrease with depth while porosity showed an increase. Soils had dominantly kaolinitic mineralogy with lesser amounts of iron oxide, gibbsite along with illite in degraded forms, which warrants attention with respect to potassium nutrition. The soils were acidic in reaction (pH 4.5-5.9) and ΔpH values suggested that these were near to zero point charge. The mean profile cation exchange capacity (CEC) values ranged from 4.1 to 11.7 cmol (p+) per kg soil. The organic matter content was high and it decreased with depth. The C/N ratio of the surface layer was around 10 suggesting that the organic matter was highly decomposed. The soil analysis for total and available nutrients revealed that they were extremely deficient in available phosphorus and low in available potassium. The available magnesium content was found to be high in some regions calling for rescheduling of K fertilizer recommendation. The soils were classified into three great groups, Kanhaplustults, Kandiustults and Kandihumults.

Key words : Available and total nutrients, C/N ratio, Clay mineralogy, Fertilizer recommendation, *Hevea brasiliensis*, Nutrition, pH, Soil texture.

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INTRODUCTION

Natural rubber (NR), nature's most versatile raw material with multifarious uses, is obtained from the latex of the rubber tree, *Hevea brasiliensis*. In India, the development of rubber plantation industry was confined to a narrow tract in the western side of Western Ghats mainly in Kerala state and in the adjoining districts of its neighbouring states, accounting for 90 per cent of the area. The best performance of *Hevea* is in the tropics and it thrives well in the laterites, lateritic and red soils of India formed under wet-dry climate (Pushpadas and Karthikakutty amma, 1980). Evolution of an appropriate management practice has become all the more essential with the advent of high yielding planting materials, which are sensitive to soil and agroclimatic factors. At present the gap between the potential and attained yield is too wide. To bridge this gap, agro-management practices are to be substantially improved and refined. Nutrient management has been recognized as the most important agro-management practice for rubber (Potty and Mannothra, 1993). The growth of *Hevea* is greatly influenced by soil physical, chemical and mineralogical properties (Eshett and Omueti, 1989; Kharche *et al.*, 1995). A comprehensive and in-depth study on properties of soil under *Hevea* in the western region of the Indian peninsula is lacking. The present investigation was therefore taken up to study the physical, chemical and mineralogical properties of rubber growing soils in this region to generate data for refining the nutrient management practices of *Hevea*.

MATERIALS AND METHODS

The traditional rubber growing regions of India on the western side of Western Ghats covering Kerala and adjoining districts of Tamil Nadu, Karnataka and Goa, (a non-traditional area on the West Coast) were selected for this study. The sites for excavation of profiles were selected considering the climatic data and available information on the soils. The details of profiles collected are given below:

Profile 1. Bethany Estate, Kulashekaram. Kanyakumari region, southern Tamil Nadu, 45 km from Trivandrum (8° 29' N and 76° 57' E) about 30 years under rubber cultivation. Slope 10-15%, undulating terrain on the foot hills. Water table >2 m. Rainfall 2000 mm. Main rock types are charnockites, granulites and garnet-biotite gneiss.

Profile 2. Kinalur Estate, Thamarassery, Calicut region, Northern Kerala, about 50 km from Calicut (11° 15' N and 75° 47' E). The site had been under rubber plantation for more than 50 years. Slope 1-15%, undulating topography, on the foot hills. Water table >2 m. Rainfall 3200 mm. Main rock types are charnockites and granite gneiss.

Profile 3. Rubber Research Institute of India, Central Experiment Station, Chethackal, Central Kerala, 50 km from Kottayam (9° 32' N and 76° 36' E). Altitude 73 m above MSL. The site was under forests up to 1972 and under rubber thereafter. Slope 10-15%. Rainfall 3500-4000 mm. Major rock types are charnockites and khondalites. This profile represents natural ground cover.

Profile 4. Canacona, Fondassorem, Shusheval, Goa (15° 53' N and 73°40' E). Altitude about 100 m above MSL. The site was under forests prior to 1967 and thereafter under rubber plantation. Slope 10-15%, undulating topography. Water table >2 m. Rainfall about 2700 mm. Laterites on Barcern formation/intrusives.

Profile 5. Koduchar plantations, Puttur Taluk, Karnataka, (12° 45' N and 74° 30' E). Altitude about 300 m above MSL. The area was under forests up to 1969 and thereafter under rubber. Slope 20-25%. Highly undulating topography. Water table >2 m. Major rocks are granite gneiss with basic intrusions, pegmatites and schists.

The profiles were excavated to more than 1.5 m depth (wherever possible), or up to the parent material. The samples were collected from each horizon after examination of the profile for morphological features. Composite surface samples (0-30 cm) were collected from each site. Each surface sample collected was a composite of five samples. The method followed was the sampling procedure for routine soil testing recommended by the Rubber Research Institute of India (Karthikakuttyamma *et al.*, 2000). Undisturbed standard core samples were collected from each horizon in three replicates for bulk density determination. The samples were dried, sieved through 2 mm sieve and were stored for physical, chemical and mineralogical analyses.

Morphological features

The profiles were described for their macro-morphology on the basis of the criteria established by the United States Soil Survey Staff (1975). Colours were recorded following the Munsell color chart. Soils were classified up to sub-group level as per the keys to soil taxonomy (Soil Survey Staff, 1996).

Physical properties

The soils (< 2 mm) were analyzed for particle size distribution by the international pipette method as outlined by Piper (1950). Bulk density and particle density were determined as per the method described by Black (1965a). Total porosity was calculated from the equation

$S_t = 100 (1 - D_b / P)$

where, S_t is total porosity, P is the particle density and D_b is the bulk density.

Physico-chemical analysis

The pH of soil samples was measured in an Orion ion-analyzer set to pH mode, using 1 : 2.5 soil-water and 1N KCl suspension.

Cation exchange capacity (CEC) of soils and clay were determined using neutral normal ammonium acetate solution (buffered to pH 7) as suggested by Black (1965b). Ammonium acetate extract of the soluble salt free soils was analyzed for exchangeable cations. Exchangeable calcium and magnesium were analyzed using Atomic Absorption Spectrophotometer and potassium using Flame Photometer. The exchangeable iron and manganese were determined colorimetrically after extraction with neutral normal ammonium acetate and exchangeable aluminium after extraction with 1 N KCl, as outlined by Black (1965b).

Percentage base saturation was calculated using the following equation suggested by Jackson (1973).

$$\text{Base saturation \%} = \frac{\text{Total exchangeable bases, (cmol(p+)/kg soil)}}{\text{Cation exchange capacity, (cmol(p+)/kg soil)}} \times 100$$

Chemical analysis

Organic carbon was estimated by the wet digestion method of Walkley and Black (Jackson, 1973). Total nitrogen was determined following the Kjeldahl digestion method (Black, 1965b). Available nitrogen was estimated by the alkaline permanganate method of Subbiah and Asija (1956). Total phosphorus in the soils was determined in the sodium carbonate fusion extract colorimetrically as described by Jackson (1973). Available phosphorus in soils was determined colorimetrically using Bray II reagent (Bray and Kurtz, 1945). Total potassium, calcium, magnesium, iron, aluminium, zinc and manganese were determined from the soil sodium carbonate fusion extract as per the methods outlined by Black (1965b). Standard analytical methods were followed for the analysis of free iron oxide, sesquioxide, silica and loss on ignition.

For the routine soil test methods, the available potassium, calcium and magnesium were determined after extraction with Morgan's reagent. Employing the same procedure, the content of the above nutrients in the profiles as well as surface samples were also determined (Karthikakuttyamma, 1977).

Clay mineralogical analysis

The separation of clay in the soil sieved through 2 mm sieve was done following the method of Jackson *et al.* (1950). The mineralogical composition of the clay fraction (< 2 mm) of samples was determined qualitatively by X-ray diffractometry. Diffraction patterns were obtained using CuK α radiation in a Jeol X-ray diffractometer. The samples were step-scanned between 2 and 35°2θ, using 0.1 and 0.05°2θ increments with a 5-r counting time per increment. The clay fraction was separated by sedimentation in distilled water and identified by their basal reflections.

The same clay fraction was used for the differential thermal analysis (DTA) and cation exchange determination. The DTA of clay was done in static atmosphere at a temperature range of 30-800°C in a Stanton / Shimadzu DTA TGA apparatus.

RESULTS AND DISCUSSION

Morphological features

The description of the five profiles studied is given in Table 1. Munsell notations refer to dry conditions unless otherwise specified.

The profiles in general had distinct A and Bt horizon. However, the differentiation within the A or the B horizons was not conspicuous. The study of the colour indicated that the hue ranged from 2.5YR to 10R and value from 3 to 8 in dry as well as in moist samples. The chroma ranged between 3 and 8 for dry and 2 and 8 for moist samples. The colour of the surface horizons was brown, reddish brown or dark reddish brown. As the depth increased, the hue tended to be reddish. The darker colour of the surface layers can be attributed to the organic matter content (Durairaj, 1961) and the variation in the intensity of redness within the profile could be due to the integrated effect of organic matter, iron oxides and clay content under the prevailing redox environment (Palaskar *et al.*, 1981). Such variations in soil colour were also reported by Satisha and Badrinath (1994) for soils of the Western Ghats in Karnataka.

Morphological examination of the soils revealed that the structure of the surface layer in all the profiles was crumb, which could be due to organic matter, clay and amorphous oxides of iron and aluminium. The texture of the surface layers was clayey for the profiles from Kanyakumari, Central Kerala and Goa, it was sandy clay loam for profiles from Calicut and Karnataka. The performance of *Hevea* was reported to improve with increasing clay content from a textural class range of sandy clay loam to sandy clay in the surface layer and sandy clay to clay in the subsoil (Chan *et al.*, 1974). There was an abundance of roots in the surface horizon of all the profiles, which is quite likely as rubber is basically a surface feeder. The consistence of these soils was slightly hard to hard when dry, very friable to friable when moist, and slightly sticky and plastic under wet condition in all the profiles indicating a good soil-water-air relationship.

Rubber trees are mostly grown under highly undulating terrain and hence physiographic features like depth and slope play an important role in their growth and performance. The performance of *Hevea* was reported to be favoured in deeper soils with depth well over 125 cm (Chan *et al.*, 1974). A deeper profile also reduces wind damage and maintains a higher stand per hectare giving a higher yield (Chan and Pushparajah, 1972). The soils under the present study were deep (150 cm or more in all the profiles) without any physical barrier, suggesting that the subsoil depth could not be a major limiting factor for the growth and anchorage of *Hevea*.

Steeper slopes affect the growth of *Hevea* adversely by inducing surface runoff, denuding the top fertile layer and reducing water intake into the soil (Chan *et al.*, 1974). Slopes up to 26 per cent have a favourable effect on aeration by promoting drainage, growth, leaf nutrient content and yield of *Hevea*. The profiles under study presented a slope in the range of 5 to 35 per cent. The profiles are texturally heavy but being well aggregated are capable of maintaining good aeration. Therefore, free growth of feeder root is not likely to be adversely affected even under high slope situation.

Physical properties

The physical properties of the profile samples are summarized in Table 1. The coarse sand distribution in general showed a decrease down the profile while the fine sand did not show any such definite pattern. The textural class varied from clay loam to clay through sandy clay loam in the profile samples, and sandy clay loam to clay in surface samples. Fig. 1 illustrates the summation curves of texture of the profile samples. From the point of view of growth of *Hevea* the clay content encountered is within the tolerance limit. *Hevea* is reported to thrive well in soils of varied texture, the clay content of which ranges from 14.8 to 71.7 per cent (Soong and Lau, 1977).

The clay content in general showed an increase down the profile (Fig. 2). The increase in the clay content with depth could

Table 1. Profile description of the soils

	Horizon	Depth (cm)	Description
Profile 1	Ap	0-15	Reddish brown (5YR4/3), clay; dark reddish brown (5YR3/4) moist; crumb structure; dry loose, moist friable; wet sticky and plastic; abundant roots; moderately rapid permeability; clear smooth boundary.
	A2	15-30	Red (2.5YR4/6) clay; dark reddish brown (2.5YR3/4) moist; moist friable; wet sticky and plastic; abundant roots; moderately rapid permeability; gradual smooth boundary.
	Bt1	30-70	Red (5YR4/8) clay; dark red (2.5YR3/6) moist; medium subangular blocky; firm; sticky and plastic; plentiful roots; moderate permeability, diffuse wavy boundary.
	Bt2	70-90	Red (10R4/8) clay; dark red (10R3/6) moist; moderate medium subangular blocky structure; moist firm; slow permeability; few roots; diffuse wavy boundary.
	Bt3	90-125	Red (10R4/8) clay; dark red (10R3/6) moist; subangular blocky structure; moist firm; few roots; sticky and plastic; quartz pebbles plenty; diffuse wavy boundary.
	Bt4	125-150	Red (10R4/8) clay; dark red (10R3/6) moist; moderate medium subangular blocky structure; firm; few roots; sticky and plastic; moderate permeability; quartz pebbles plenty.
Profile 2	Ap	0-17	Brown (7.5YR5/4), sandy clay loam; brown (7.5YR4/2) moist, crumb; moist friable; wet slightly sticky and slightly plastic; moderate to rapid permeability; roots abundant; clear smooth boundary.
	A2	17-30	Yellowish red (5YR5/6), sandy clay loam; reddish brown (5YR4/3) moist; weak medium subangular blocky; moist friable; slightly sticky and slightly plastic; abundant roots; moderate permeability; diffuse wavy boundary.
	BA	30-50	Yellowish red (5YR5/8), sandy clay loam; reddish brown (5YR4/4) moist; medium weak subangular blocky; moist friable; slightly sticky and slightly plastic; roots plentiful; moderate permeability; diffuse wavy boundary.
	Bt1	50-90	Yellowish red (5YR5/8), clay loam; red (2.5YR4/6) moist; subangular blocky; slightly sticky; few roots; slow permeability; diffuse boundary.
	Bt2	90-150	Reddish yellow (5YR6/8), clay loam; red (2.5YR4/8) moist; subangular blocky; moist firm; sticky and plastic; few roots; slow permeability.
Profile 3	Ap	0-13	Dark reddish brown (5YR3/4), clay; dark reddish brown (5YR3/2) moist; crumb; moist friable; slightly sticky and plastic; abundant roots; rapid permeability; diffuse wavy boundary.
	A2	13-25	Dark reddish brown (5YR3/3), clay; dark reddish brown (5YR3/4) moist; crumb; friable; slightly sticky; abundant roots; rapid permeability; diffuse wavy boundary.
	BA	25-40	Reddish brown (5YR4/4), clay; dark reddish brown (5YR3/3) moist; weak subangular blocky; friable; slightly sticky; plentiful roots; moderately rapid permeability; diffuse wavy boundary.
	Bt1	40-73	Red (2.5YR4/8), clay; dark red (2.5YR4/6) moist; weak subangular blocky; friable; slightly sticky and plastic; plentiful roots; moderately rapid permeability; diffuse wavy boundary.
	Bt2	73-94	Red (2.5YR5/8), clay loam; yellowish red (5YR4/8) moist; subangular blocky; firm; plentiful roots; moderate slow permeability; diffuse wavy boundary.
	Bt3	94-150	Red (2.5YR4/6), clay; reddish brown (5YR4/4) moist; very coarse subangular blocky; firm; sticky (wet); few roots; moderate slow permeability.
Profile 4	Ap	0-13	Dark reddish brown (5YR3/4), clay; dark reddish brown (5YR3/2) moist; crumb; friable; slightly sticky; roots abundant; rapid permeability; diffuse boundary.
	A2	13-35	Reddish brown (5YR4/4), clay; dark reddish brown (5YR3/3) moist; weak subangular blocky; friable; wet sticky and plastic; roots plentiful; moderately rapid permeability; diffuse smooth boundary.
	Bt1	35-65	Yellowish red (5YR4/6) clay; dark reddish grey (5YR4/2) moist; subangular blocky; firm sticky when wet; plentiful roots; moderately slow permeability; abrupt smooth boundary.
	Bt2	65-125	Dark red (2.5YR3/6), clay; subangular blocky-massive; moist very firm; wet sticky and plastic; few roots; moderately slow permeability; diffuse wavy boundary.
	BC	125-150	Red (2.5YR4/6) moist; clay, massive; firm; sticky; few roots; moderately slow permeability.
Profile 5	Ap	0-10	Brown (7.5YR5/4), sandy clay loam; dark reddish brown (5YR3/3) moist; crumb; very friable; wet slightly sticky and plastic; abundant roots; rapid permeability; diffuse smooth boundary.
	A2	10-30	Reddish brown (5YR4/4), clay; reddish brown (5YR4/3) moist; crumb; friable; wet slightly sticky and plastic; abundant roots; moderately rapid permeability; gradual wavy boundary.
	Bt1	30-75	Red (2.5YR5/8) moist; clay; medium subangular blocky; firm; slightly sticky and plastic; roots plentiful; moderate permeability; clear smooth boundary.
	Bt2	75-150	Reddish yellow (5YR6/6), clay; red (2.5YR5/6) moist; subangular blocky; firm; wet sticky and plastic; roots few; moderately slow permeability; diffuse boundary.

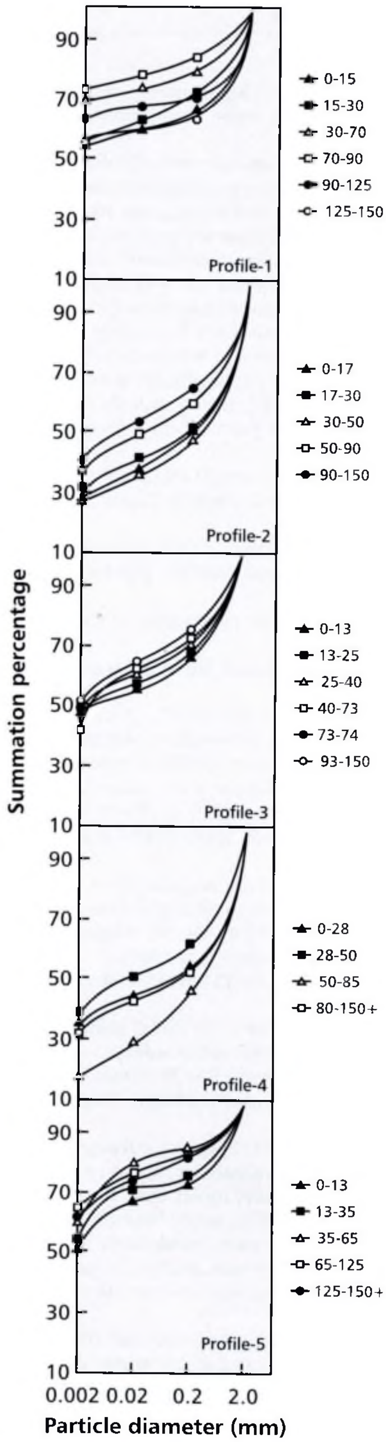

Fig. 1. Summation curves of soil texture

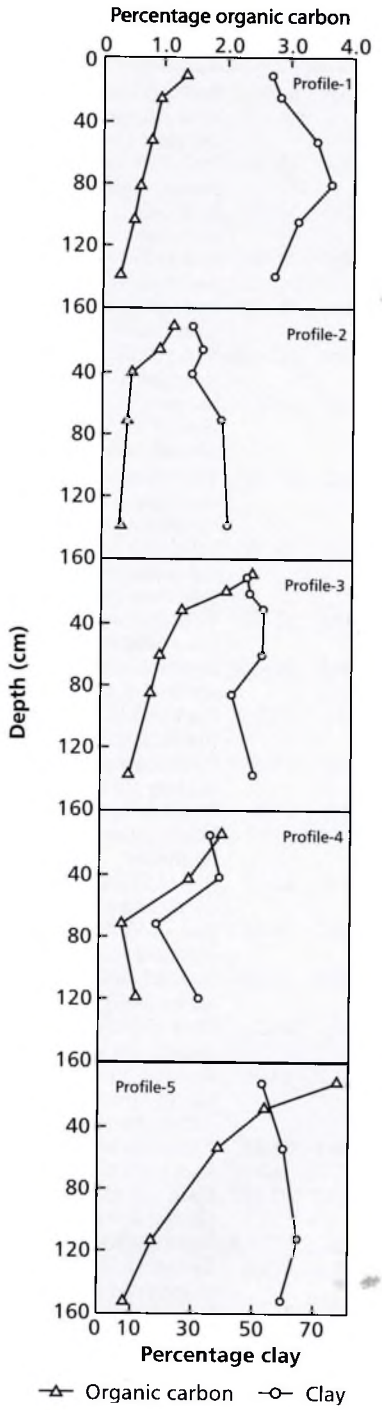

Fig. 2. Distribution of organic carbon and clay in soil profiles

be attributed to the clay migration by illuviation. The rate of illuviation of clay may depend upon altitude, climate and parent material. The mobilisation, migration and subsequent immobilisation of clay colloid in tropical soils is a major pedogenic process with implications on horizon differentiation (Satisha *et al.*, 1998). The low clay content in the surface horizon could be attributed to the removal of clay by erosion and /or surface runoff. In general, the ratio of silt to clay was slightly higher in the A horizons of the profiles and decreased with depth. The ratio of clay to clay + silt showed a slight increase from surface downwards in the illuvial horizons suggesting a higher degree of weathering and clay translocation from the surface layers. Satisha *et al.* (1998) observed similar results for rubber growing soils of Mizoram.

In the profiles studied, the bulk density values varied from region to region to the extent their textural composition varied. The general distribution of the bulk density showed a decrease down the profile. This points to a good state of aggregation of soil. The higher values of bulk density encountered in the surface layers of the profiles can be due to the higher sand content. Veihmeyer and Hendrickson (1948) have reported the threshold bulk density values for clay textured soils as 1.46 to 1.65 Mg/m^3. The bulk density values obtained in the present study were lower than the threshold values suggesting that it does not affect the growth of *Hevea*. Particle density had no definite trend in its distribution along the profile. Total porosity was found to increase down the profile (Table 2) and surface (Table 3) samples. A significant negative correlation was obtained between bulk density and total porosity in all the profiles except the profile from Goa where it was negative but non-significant (Table 4). A positive correlation existed in the four profiles between clay and total porosity, which was significant in the profile from Karnataka. These observations are in agreement with those of Satisha and Badrinath (1994) for forest soils of the Western Ghat in Karnataka.

Clay mineralogy

Moisture retention and release, and the exchange properties of soils are the important physico-chemical factors governing the yield of latex in *Hevea* and hence information on the clay mineral makeup which has a profound influence on the physical chemistry of soil colloids becomes necessary. The moisture retention characteristics of soils under *Hevea* have already been reported (Krishnakumar *et al.*, 1990). The X-ray diffractograms of the profile clay samples (Fig. 3) bring out that the dominant clay mineral in all the soils under study was well crystallized kaolinite indicated by its well defined (001) spacing (around 7.1 °A) and subsequent (002) spacing. The mineral next in abundance was illite. The diffuse nature of the peak suggests that the mineral was degraded. The content of degraded illite showed variation between the profiles. Degradation was more pronounced in the profile from Goa and it was the least in that from Calicut. Illite and other K-bearing minerals control to a large extent the potassium supplying capacity of soil. Since potassium is of utmost importance to the nutrition of *Hevea*, its ease of release and availability has to be interpreted in terms of the clay minerals present. A small quantity of the smectitic group has been identified in the profile from Kanyakumari region. Magnesium ionic environment as indicated by the physico-chemical analysis justifies the formation of smectite for which magnesium is a prerequisite. Differential thermal analysis of the samples giving off low temperature endotherm supports the XRD analysis and confirms the presence of 2:1 expanding lattice mineral (Fig. 4). Dehydroxylation reaction in the region of 520-525°C suggests a mixture of kaolinite and 2:1 type mineral. Simi-

Table 2. **Mechanical composition, single value constants and soil moisture retention characteristics of profile samples**

Horizon	Depth (cm)	Particle size distribution (%)				Texture	Ratio		Bulk density	Particle density	Total porosity	Water retention (m³/m³) at	
		Coarse sand	Fine sand	Silt	Clay*		Silt/clay	Clay/ clay+silt	(Mg/m³)	(Mg/m³)	(%)	0.033 Mpa	1.5 Mpa
Profile 1. Kanyakumari region (Bethany Estate, Kulashekaram)													
Ap	0 - 15	32.0	9.0	5.3	53.7	c	0.10	0.91	1.28	2.45	47.76	24.30	16.83
A2	15 - 30	25.9	10.6	7.6	55.9	c	0.14	0.88	1.21	2.41	49.79	24.55	17.61
Bt1	30 - 70	19.9	6.3	4.7	69.1	c	0.07	0.94	1.20	2.40	50.00	28.96	21.37
Bt2	70 - 90	14.6	7.3	4.7	73.4	c	0.06	0.94	1.15	2.42	52.48	34.41	23.17
Bt3	90 - 125	27.7	5.1	4.9	62.3	c	0.08	0.93	1.11	2.48	55.24	33.29	24.00
Bt4	125 - 150	35.8	4.7	4.4	55.1	c	0.08	0.93	1.20	2.56	53.13	25.63	17.50
Profile 2. Calicut region (Kinalur Estate, Thamarassery)													
Ap	0 - 17	46.8	16.2	9.2	27.8	scl	0.33	0.75	1.35	2.65	48.47	19.50	11.93
A2	17 - 30	47.0	12.3	10.2	30.5	scl	0.33	0.75	1.34	2.60	47.46	20.69	12.40
BA	30 - 50	50.7	13.3	8.6	27.4	scl	0.31	0.76	1.30	2.65	50.94	20.65	9.12
Bt1	50 - 90	39.1	11.1	12.3	37.5	cl	0.33	0.75	1.20	2.60	53.85	26.32	14.47
Bt2	90 - 150	35.2	11.7	13.8	39.5	cl	0.35	0.74	1.25	2.61	52.11	29.88	17.00
Profile 3. Central Kerala (Central Experiment Station, Chethackal)													
Ap	0 - 13	29.6	16.1	9.2	45.1	c	0.20	0.83	1.25	2.50	50.00	30.64	20.17
A2	13 - 25	30.0	14.8	8.8	46.4	c	0.19	0.84	1.20	2.50	52.00	27.74	18.20
BA	25 - 40	25.6	12.6	11.1	50.7	c	0.22	0.82	1.21	2.48	51.21	28.60	20.40
Bt1	40 - 73	28.0	12.3	9.6	50.1	c	0.19	0.84	1.24	2.49	50.20	29.92	20.13
Bt2	73 - 94	25.6	13.2	20.4	40.8	cl	0.50	0.67	1.21	2.50	51.60	33.42	22.98
Bt3	94 - 150	24.2	12.6	14.6	48.6	c	0.30	0.77	1.10	2.51	56.18	33.16	22.99
Profile 4. Goa (Canacona)													
Ap	0 - 13	21.5	11.7	15.2	51.6	c	0.29	0.77	1.25	2.60	50.94	37.83	24.92
A2	13 - 35	20.5	8.7	17.1	53.7	c	0.32	0.76	1.26	2.59	51.35	40.30	26.70
Bt1	35 - 65	11.2	9.5	19.4	59.9	c	0.32	0.76	1.30	2.58	51.56	40.07	26.92
Bt2	65 - 125	14.5	8.9	12.2	64.4	c	0.19	0.84	1.25	2.50	52.00	35.32	25.45
BC	125+	17.3	9.5	13.4	59.4	c	0.22	0.82	1.29	2.46	50.41	32.76	24.07
Profile 5. Karnataka (Koduchar Plantations, Puttur)													
Ap	0 - 10	38.3	12.9	11.8	37.0	scl	0.32	0.76	1.33	2.58	49.60	26.22	18.14
A2	10 - 30	22.4	12.9	14.2	50.5	c	0.28	0.78	1.26	2.56	50.78	31.64	22.50
Bt1	30 - 75	12.6	11.7	14.7	61.0	c	0.24	0.81	1.23	2.54	51.97	38.48	24.00
Bt2	75 - 150	17.5	8.5	16.8	57.2	c	0.29	0.77	1.28	2.51	49.00	37.62	24.99

c : clay, scl : sandy clay loam, cl : clay loam.

lar mineral species in the soil clays of the laterite and red soils of Kerala have been reported by Datta and Das (1974). The nature of XRD indicates that there is no crystalline clay in the 30-75 cm layer of the profile from Calicut. Besides containing well crystallized kaolinite, a well defined peak around 4.85°A suggests the presence of gibbsite in the 0-15 and 125-150 cm layers of the profile from Calicut and in all the layers from the profile from Central Kerala. The chemical analysis has also revealed an appreciable quantity of amorphous clay in the rubber growing region. These soils had kaolinitic mineralogy. Oxides of iron and gibbsite and illite in degraded form were also present to a lesser extent.

Physico-chemical properties

The data on pH, CEC of soils and the exchangeable cations are presented in Table 5 and 6. In general, pH does not show any definite pattern in the profiles. A decrease followed by an increase in the lowest layer

Table 3. **Mechanical composition, single value constants and soil moisture retention characteristics of surface samples**

Location	Depth (cm)	Particle size distribution (%) Coarse sand	Fine sand	Silt	Clay clay+silt	Texture	Bulk density (Mg/m^3)	Particle density (Mg/m^3)	Total porosity (%)	Water retention (m^3/m^3) at 0.033 Mpa	1.5 Mpa
Kanyakumari	0-30	35.6	8.7	7.4	46.0	c	1.28	2.58	50.36	26.30	18.12
	0-30	41.3	10.5	4.2	41.5	sc	1.24	2.45	49.39	26.00	17.15
	0-30	44.7	7.2	2.1	44.0	sc	1.25	2.40	46.94	24.93	16.32
Calicut	0-30	43.8	17.1	10.6	26.3	scl	1.28	2.57	53.75	22.51	12.95
	0-30	41.0	10.9	13.3	32.7	scl	1.32	2.65	50.19	20.85	11.93
	0-30	42.9	15.9	9.2	29.4	scl	1.34	2.49	46.18	18.85	12.05
Central Kerala	0-30	40.8	12.1	10.0	33.0.	scl	1.25	2.50	50.00	28.60	18.12
	0-30	31.6	13.8	9.8	40.2	c	1.18	2.46	52.03	29.25	19.65
	0-30	40.8	9.2	10.4	34.2	scl	1.29	2.48	48.39	28.85	17.32
Goa	0-30	12.8	4.9	18.9	58.7	c	1.25	2.62	52.29	36.25	23.15
	0-30	17.1	5.5	9.2	61.5	c	1.30	2.65	50.94	35.43	24.25
	0-30	22.6	9.8	10.9	50.1	c	1.32	2.55	48.24	34.12	20.90
Karnataka	0-30	18.4	10.7	14.0	51.7	c	1.31	2.55	48.62	26.21	18.25
	0-30	41.7	8.0	3.0	42.0	sc	1.18	2.62	54.96	29.46	17.15
	0-30	22.5	9.5	13.1	52.2	c	1.20	2.59	53.67	27.53	19.25

c : clay, scl : sandy clay loam, sc : sandy clay

Table 4. **Simple correlation of clay and bulk density with some properties of soil profile samples**

Profile number	Bulk density	Moisture retention 0.033 Mpa	1.5 Mpa	Available water	Porosity	Particle density	CEC	Loss on ignition
Clay								
1	-0.571	0.821*	0.818*	0.620	0.287	-0.489	-0.602	0.849*
2	-0.825	0.967**	0.926*	0.599	0.750	-0.611	0.410	-0.731
3	-0.162	-0.490	-0.130	-0.376	-0.110	-0.470	-0.378	-0.557
4	0.111	-0.480	-0.058	-0.668	-0.668	-0.787	-0.768	-0.411
5	-0.831	0.959**	0.933*	0.892*	0.892*	-0.507	-0.62	-0.302
Bulk density								
1	-	-0.860*	-0.856*	-0.492	-0.903*	-0.829	-	-
2	-	-0.822	-0.573	-0.736	-0.987**	0.279	-	-
3	-	-0.438	-0.522	0.426	-0.997**	-0.568	-	-
4	-	0.846	0.631	0.912*	-0.146	0.906*	-	-
5	-	-0.594	-0.144	-0.549	-0.897*	0.323	-	-

* Significant at P<0.05, **Significant at P<0.01

of the profile from Goa and Karnataka could be due to enrichment of electrolytes leached down from the upper soil layers. A slightly higher pH encountered in the surface horizons of the profiles can be attributed to the influence of applied rock phosphate and also to the recycling of bases by the canopy litter and cover crop. The negative Δ pH values indicate the presence of negative charges and therefore a preponderance of variable charged colloids. This suggests the presence of appreciable quantities of silicate clay minerals in these soils with relatively constant surface charge as shown by Bleeker and Sageman (1990). However, the lower values of Δ pH indicated that the pH of these soils was closer to their zero point charge, and indicates the presence of pH-dependent charge minerals. Mineralogical investigation showed that these soils had both permanent charge (layer silicate systems) and variable charge because of the presence of pH-depen-

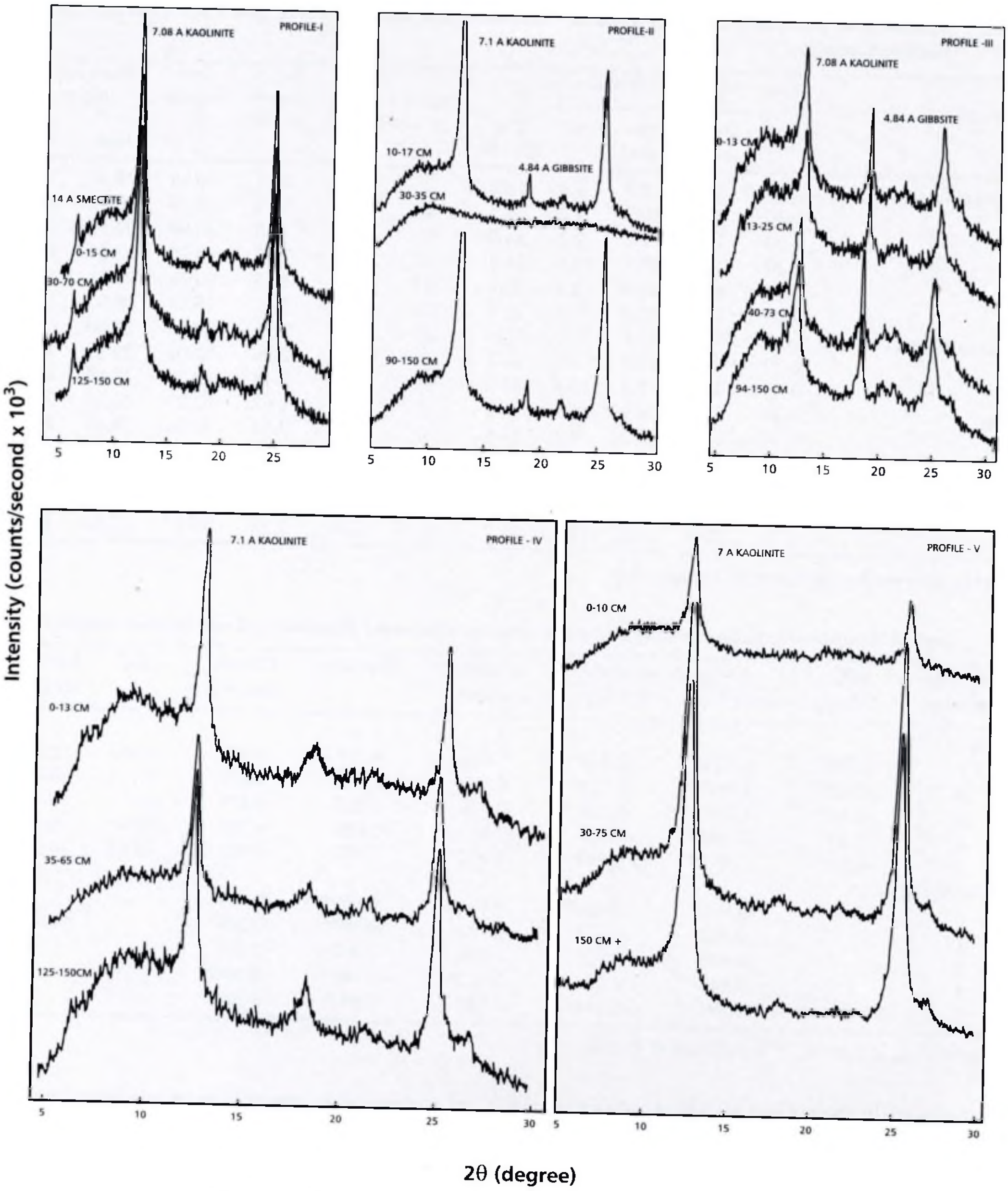

Fig. 3. X-ray diffractograms of oriented clay fraction of soil profiles

dent minerals such as iron and aluminium hydroxides as well as organic matter (Patil and Dasog, 1996). The pH of the surface samples ranged from 4.5 to 5.6 (Table 6). The CEC of a soil is of much consequence in the humid tropics and governs the nutrient dynamics and soil fertility to a great degree. The CEC of the profile samples varied over a wide range from 3.55 to 18.02 cmol (p+)/kg (Table 5). Despite high clay content, CEC showed a decreasing trend with depth. High content of organic matter must have been a

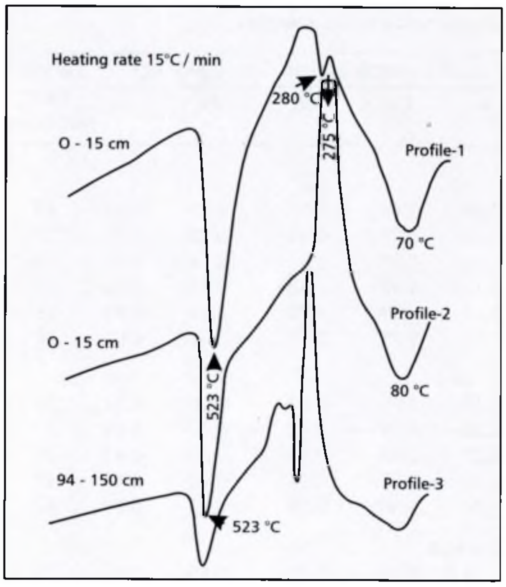

Fig. 4. Differential thermographs of clay fraction of soil profiles

contributory factor for the high values of CEC in the surface soils whereas low values in the sub surface may be attributed to the pH - dependent exchange sites occupied by either hydrogen ions or hydroxy aluminium ions at low pH (Patil and Dasog, 1997). The exchangeable potassium content was the highest in the surface layer in all the profiles except in the profiles from Calicut and Goa. The distribution of exchangeable potassium in the profile showed, in general, a decreasing trend with depth. While the surface enrichment of exchangeable potassium could be due to litter recycling in the organo-mineral surface layers, relatively higher exchangeable potassium percentage of the profiles suggests a potassium rich ionic environment and illitic component in the soil clays. Exchangeable calcium was the dominant cation accounting for 23.78, 26.59, 9.98, 20.65 and 25.22 per cent of the CEC in the profiles from Kanyakumari, Calicut, Central Kerala, Goa and Karnataka, respectively. The mean exchangeable calcium was the highest in the profile from Goa and lowest in that from Central Kerala. The distribution of exchangeable magnesium did not show any definite pattern except in the profile from Goa, where it showed a decrease with depth. In the profile from Goa the exchangeable magnesium accounted 11.35 per cent of the CEC and its contribution in the profile from Karnataka to CEC was 16.73 per cent, the means respectively for these two profiles being 1.33 and 1.32 cmol (p+)/kg. Exchangeable iron was found to vary in the range of 0.02 to 0.20 cmol (p+)/kg in the profile samples, and the mean values in the Profile 1 through 5 were 0.15, 0.13, 0.10, 0.03 and 0.06 cmol (p+)/kg respectively.

Of the exchangeable cations, magnesium was found to be dominant in Profiles 4 and 5. The soils also had a considerable content of aluminium particularly more in the subsurface horizons. Under a soil pH less than 5, presence of a higher proportion of exchangeable Al is a usual feature. The extent to which the resultant drop in the Al/Ca ratio in the soil adversely affects the roots is important. Presence of organic matter is known to reduce the toxic effect of aluminium by chelation. The soils under *Hevea* are generally rich in organic matter and this can, to some degree, offset the deleterious effect of aluminium. Taking into account its native habitat, the rubber tree itself may be adaptable to a certain level of aluminium tolerance. The large amount of calcium added by way of rock phosphate might also bring about a favourable disposition of calcium to aluminium. However, further study is needed to ascertain if aluminium-toxic subsoil could be a chemical barrier to *Hevea* root development.

Deficiency of micronutrients is seldom encountered in mature *Hevea* trees though zinc deficiency is noticed in the nursery and immature phases. Excess availability of manganese has been reported to affect the uptake of magnesium and growth of *Hevea*. Exchangeable manganese in the profile from

Table 5. **Physico-chemical properties of soil profile samples**

Horizon	Depth (cm)	pH H_2O	pH 1N KCl	Organic Carbon (%)	CEC (cmol (p+)/kg)	Exchangeable cations (cmol(p+)/kg) K	Ca	Mg	Fe	Al	Per cent base saturation
Profile 1. Kanyakumari (Bethany Estate, Kulashekaram)											
Ap	0 - 15	4.6	3.8	1.39	11.83	0.24	3.48	1.37	0.13	0.91	43
A2	15 - 30	4.8	4.0	0.92	8.56	0.13	1.77	0.95	0.13	1.71	21
Bt1	30 - 70	4.7	3.9	0.82	9.09	0.12	1.87	1.65	0.14	1.00	40
Bt2	70 - 90	4.5	4.0	0.61	8.63	0.11	1.87	1.80	0.13	0.96	39
Bt3	90 -125	4.6	3.9	0.53	9.10	0.19	1.87	1.70	0.14	0.93	41
Bt4	125 -150	4.6	4.1	0.30	8.01	0.16	1.75	1.18	0.22	1.00	39
Profile 2. Calicut (Kinalur Estate, Thamarassery)											
Ap	0 - 17	4.9	3.8	1.54	4.73	0.21	1.08	0.24	0.20	0.54	32
A2	17 - 30	4.9	4.2	0.87	3.91	0.18	0.79	0.22	0.17	0.69	30
BA	30 - 50	4.8	4.1	0.43	3.68	0.27	0.68	0.33	0.16	0.44	35
Bt1	50 - 90	4.8	4.1	0.41	3.55	0.16	1.28	0.16	0.10	0.45	45
Bt2	90 -150	4.8	4.1	0.32	4.64	0.20	1.60	0.16	0.03	0.29	42
Profile 3. Central Kerala (Central Experiment Station, Chethackal)											
Ap	0 - 13	4.5	4.0	2.41	7.40	0.34	0.53	0.22	0.18	0.92	15
A2	13 - 25	4.5	3.9	1.97	8.83	0.27	0.45	0.31	0.16	1.14	12
BA	25 - 40	4.5	4.2	1.22	4.62	0.22	0.86	0.41	0.13	1.09	32
Bt1	40 - 73	4.6	4.2	0.93	4.79	0.20	0.90	0.56	0.03	0.86	35
Bt2	73 - 94	4.5	4.2	0.78	4.46	0.17	0.40	0.96	0.04	0.76	28
Bt3	94 -150	4.5	4.0	0.48	4.37	0.19	0.40	0.61	0.03	0.14	28
Profile 4. Goa (Canacona)											
Ap	0 - 13	5.8	4.9	3.8	18.02	0.64	1.87	2.33	0.04	0.02	27
A2	13 - 35	5.8	5.0	2.66	12.6	0.47	1.87	1.18	0.04	0.02	28
Bt1	35 - 65	5.7	4.9	1.89	11.83	0.33	1.91	1.12	0.04	0.01	28
Bt2	65 -125	5.7	5.3	0.91	9.77	0.77	1.87	1.09	0.02	0.03	38
BC	125+	5.9	4.2	0.42	6.39	0.28	1.82	0.93	0.02	0.01	48
Profile 5. Karnataka (Koduchar Plantations, Puttur)											
Ap	0 - 10	5.4	4.5	2.37	9.25	0.72	2.26	2.16	0.07	1.02	56
A2	10 - 30	5.0	4.3	1.78	8.74	0.32	2.25	1.05	0.11	1.08	47
Bt1	30 - 75	4.9	4.0	0.79	7.54	0.20	1.07	0.31	0.06	1.12	21
Bt2	75 -150	5.3	4.6	0.30	7.54	0.26	1.98	1.37	0.02	0.19	30

Goa is fairly high. Though in well-aerated and well-drained tropical soils, manganese toxicity is seldom encountered, high exchangeable manganese in the profile from Goa might pose management problems for rubber. Moreover, excess of available manganese may inhibit nitrogen fixation and growth of legumes. Establishment of a leguminous ground cover is an integral part of management of rubber plantation. Therefore, incidence of manganese toxicity has to be looked into and ameliorative measures adopted. Application of liming substance as provided through the routine application of rock phosphate in rubber plantation, may go a long way in overcoming the toxic effects of manganese. The percent base saturation of soil for the Profiles 1 to 5 were 42, 37, 23, 36 and 46, respectively. Calcium was observed to be the dominant cation in the exchange complex, while the availability and uptake of nutrient cations are highly dependent on their concentration in the soil solution, the nature of adsorption complex and the percentage base saturation govern to a large extent, the ease of their release (Chavan *et al.*, 1995).

Table 6. **pH, C/N ratio and chemical composition (total nutrients) of surface soil samples (0-30cm depth)**

Sample number	pH	Organic carbon (%)	C/N ratio	N	P	K	Ca (%)	Mg	Fe	Al	Zn (ppm)	Mn
Kanyakumari												
1	4.7	0.91	3.6	0.25	0.039	0.512	0.024	0.013	5.68	2.80	80	85
2	5.0	1.02	4.1	0.23	0.038	0.896	0.025	0.020	6.00	2.77	80	100
3	4.7	0.91	4.6	0.20	0.021	0.320	0.020	0.018	6.20	3.60	100	120
Calicut												
4	4.9	0.8	8.9	0.09	0.033	0.691	0.060	0.042	6.12	2.65	390	66
5	4.8	0.85	8.5	0.10	0.035	0.712	0.063	0.035	6.13	2.75	420	90
6	4.8	0.9	10	0.09	0.03	0.660	0.057	0.041	6.40	2.23	360	105
Central Kerala												
7	4.6	1.93	8.4	0.23	0.065	0.851	0.042	0.032	8.60	2.75	130	90
8	4.5	2.18	10.9	0.20	0.042	0.890	0.050	0.030	8.52	2.15	80	100
9	4.5	2.96	14.8	0.20	0.066	0.893	0.039	0.028	7.98	2.15	130	80
Goa												
10	5.5	2.64	8.0	0.33	0.028	0.672	0.038	0.013	10.84	2.28	100	953
11	5.4	3.36	16.0	0.21	0.011	0.568	0.044	0.064	10.64	2.18	130	875
12	5.5	3.45	17.3	0.20	0.009	0.052	0.038	0.060	10.54	2.15	120	1000
Karnataka												
13	5.3	2.58	14.3	0.18	0.039	0.519	0.024	0.013	10.08	2.03	330	422
14	5.3	2.85	16.8	0.17	0.032	0.896	0.028	0.022	10.36	2.14	500	410
15	5.1	1.32	10.2	0.13	0.021	0.32	0.200	0.018	5.36	2.14	480	300

Organic matter status and total nutrient content

The chemical composition (total nutrients) and C/N ratio of the profile samples are given in Table 7. The surface layer of the profiles had the highest organic matter and the distribution showed a decline with depth (Fig. 2). In tropical tree-crop ecosystems and especially in *Hevea*, leaf litter accumulates as a result of periodic leaf fall, providing a form of surface cover over the soil. Thus, high organic matter accumulation in the surface horizon takes place as a result of litter fall as well as the superficial nature of rubber tree roots. The maintenance of luxuriant ground cover, closed canopy and absence of tillage operations further help the build-up. In yet another explanation, Munevar and Wollum (1976) have offered that the interaction of oxides/allophane with organic matter in the tropical soils may render the organic matter relatively resistant to mineralization, and also that extreme P deficiency may inhibit microbial growth, both resulting in a lower mineralization rate. The total nitrogen content in the profile samples varied from 0.04 per cent to 0.35 per cent. Distribution of total nitrogen closely followed the organic carbon distribution, both showing a decreasing trend with depth. In the surface samples the mean total nitrogen content was the highest for samples from Kanyakumari (0.25%) and Goa (0.33 %) and the lowest (0.09 %) for the samples from Calicut region. A positive significant correlation existed between organic carbon and total nitrogen (Table 8).

The C/N ratio of the surface soil around 10 suggests that organic matter has come to a stage of decomposition nearer to humus. A decline in the ratio with depth was observed. The C/N ratio operates somewhat differently in acid soils than in high-base status soils. Carbon tends to be mineralised at a faster rate than nitrogen at low pH values, which decreases the C/N ratio in such soils and results in increase in nitrogen mineralization. Further, nitrogen mineralization can take place at a very low moisture content of the lower depths (tension more than 15 bars) which although unavailable to plants, seems

Table 7. **C/N ratio and chemical compositioin (total nutrients) of profile soil samples**

Horizon	Depth (cm)	C/N ratio	N	P	K	Ca	Mg	Fe	Al	Zn	Mn
						(%)				(ppm)	
Profile 1. Kanyakumari region (Bethany Estate, Kulashekaram)											
Ap	0 - 15	6.90	0.20	0.046	0.56	0.083	0.042	6.10	3.63	875	125
A2	15 - 30	7.00	0.13	0.034	0.60	0.087	0.034	5.91	2.57	575	86
Bt1	30 - 70	8.10	0.10	0.039	0.42	0.035	0.027	6.05	3.24	370	105
Bt2	70 - 90	6.80	0.09	0.030	0.37	0.076	0.047	5.95	2.54	225	145
Bt3	90 -125	7.60	0.07	0.031	0.38	0.042	0.027	6.63	2.52	225	113
Bt4	125 -150	3.60	0.08	0.033	0.43	0.062	0.039	7.00	2.10	500	59
Profile 2. Calicut region (Kinalur Estate, Thamarassery)											
Ap	0 - 17	10.10	0.11	0.033	0.71	0.062	0.047	6.04	2.56	475	66
A2	17 - 30	9.90	0.09	0.030	0.69	0.073	0.047	6.78	2.68	275	68
BA	30 - 50	8.60	0.05	0.031	1.18	0.069	0.045	5.78	1.76	300	69
Bt1	50 - 90	10.00	0.04	0.024	0.60	0.080	0.051	6.50	2.68	225	70
Bt2	90 -150	8.50	0.04	0.023	0.64	0.038	0.048	7.85	2.62	250	117
Profile 3. Central Kerala (Central Experiment Station, Chethackal)											
Ap	0 - 13	9.60	0.25	0.060	0.90	0.052	0.033	8.46	2.55	125	95
A2	13 - 25	10.80	0.18	0.052	0.85	0.031	0.044	9.00	2.14	150	35
BA	25 - 40	9.30	0.13	0.056	0.83	0.042	0.025	9.43	2.64	450	51
Bt1	40 - 73	11.50	0.08	0.058	0.74	0.031	0.032	10.04	2.56	350	66
Bt2	73 - 94	15.40	0.05	0.058	0.64	0.024	0.058	10.24	2.44	300	66
Bt3	94 -150	9.40	0.05	0.065	0.64	0.031	0.030	9.84	2.87	375	90
Profile 4. Goa (Canacona)											
Ap	0 - 13	10.70	0.35	0.093	0.84	0.232	0.047	10.44	1.86	150	1468
A2	13 - 35	11.00	0.24	0.090	0.98	0.048	0.057	10.55	2.56	75	1375
Bt1	35 - 65	9.84	0.19	0.069	1.07	0.055	0.035	10.88	2.31	500	1437
Bt2	65 -125	7.50	0.12	0.065	1.23	0.045	0.039	11.14	2.56	450	703
BC	125 +	6.00	0.07	0.056	1.18	0.038	0.042	10.90	2.63	280	1031
Profile 5. Karnataka (Koduchar Plantations, Puttur)											
Ap	0 - 10	14.70	0.16	0.056	0.71	0.028	0.038	6.78	2.02	200	578
A2	10 - 30	11.70	0.15	0.041	0.83	0.059	0.071	6.43	2.26	475	266
Bt1	30 - 75	6.50	0.12	0.020	0.61	0.018	0.013	7.49	2.53	300	172
Bt2	75 -150	7.50	0.04	0.018	0.79	0.059	0.007	7.06	2.42	200	98

to be available to mineralising microorganisms (Paul, 1984).

Total phosphorus varied in the profile samples from 0.018 to 0.093 per cent (Table 7). Total P content was highest in the surface layers and generally decreased down the profile. The distribution of total potassium in the profile did not show any definite pattern except for the profile from Central Kerala where it decreased with depth. The distribution pattern of total calcium also was similar to that of potassium in not showing any definite trend with the depth. The total magnesium distribution in the profile also was irregular. The content of total iron in the different horizons of the profile did not show any definite distribution pattern. Total zinc in the Profiles 1 to 5 had a mean of

Table 8. **Simple correlation of organic carbon with total and available N and available P and total N with available N**

Profile	Organic carbon to			Total N to
	Total N	Available N	Available P	available N
1	0.940**	0.778	-0.893*	0.895*
2	0.997**	0.896*	0.938*	0.863
3	0.984**	0.933**	0.901*	0.906*
4	0.997**	0.996**	0.996**	0.991**
5	0.926*	0.922*	0.922*	0.879*

* Significant at P<0.05

462, 305, 292, 210 and 285 ppm, respectively. The mean total manganese in the Profiles 1 to 5 was 106, 78, 67, 1203 and 232 ppm, respectively.

Available nutrient status

The available nutrient status of the profile samples is given in Table 9. The available nitrogen content showed a decrease down the profiles. There exists a significant positive correlation (Table 8) between organic carbon and total as well a available nitrogen, suggesting that the organic carbon can be taken as an index of nitrogen status.

The available phosphorus content varied from trace to 1.22 mg/100 g in the profile samples (Table 9). In general, the soils in all the regions were deficient in available phosphorus and showed a decreasing trend with depth. The present results are in conformity with earlier reports (Karthikakuttyamma *et al.*, 1976). Available phosphorus content of soil was positively correlated with total phosphorus except in Profile 3 and it had a positive but statistically non-significant correlation (Table 10) with exchangeable aluminium except in Profile 2 suggesting that Al-P formed a portion of the available phosphorus. A negative correlation between exchangeable iron and available phosphorus

Table 9. **Available nutrients in soil profile samples**

Horizon	Depth (cm)	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
				(mg/100 g)		
Profile 1. Kanyakumari (Bethany Estate, Kulashekaram)						
Ap	0 - 15	25.0	0.91	7.75	45.8	9.24
A2	15 - 30	22.9	0.39	3.75	27.2	10.82
Bt1	30 - 70	18.1	0.09	3.62	36.0	21.28
Bt2	70 - 90	16.0	0.08	2.50	32.2	26.62
Bt3	90 - 125	17.4	0.10	1.25	24.6	21.88
Bt4	125 - 150	18.8	0.09	1.12	17.4	17.39
Profile 2. Calicut (Kinalur Estate, Thamarassery)						
Ap	0 - 17	21.6	0.24	3.12	8.6	3.28
A2	17 - 30	18.1	0.09	1.62	8.6	2.31
BA	30 - 50	14.6	0.03	2.00	8.0	2.07
Bt1	50 - 90	16.5	Trace	1.87	10.2	4.38
Bt2	90 - 150	12.8	Trace	2.25	15.2	4.38
Profile 3. Central Kerala (Central Experiment Station, Chethackal)						
Ap	0 - 13	19.9	0.38	5.87	10.2	4.13
A2	13 - 25	20.9	0.18	4.00	9.2	4.50
BA	25 - 40	16.5	0.17	2.87	15.8	6.93
Bt1	40 - 73	16.4	0.05	2.12	16.4	11.67
Bt2	73 - 94	12.8	Trace	1.87	15.2	5.46
Bt3	94 - 150	11.8	0.07	2.87	6.6	7.30
Profile 4. Goa (Canacona)						
Ap	0 - 13	38.8	0.30	8.12	173.6	19.70
A2	13 - 35	31.5	0.58	7.75	122.8	14.11
Bt1	35 - 65	25.2	0.13	6.75	99.4	19.21
Bt2	65 - 125	15.5	0.13	9.25	80.8	21.40
BC	125+	14.6	0.13	7.75	48.6	15.81
Profile 5. Karnataka (Koduchar Plantations, Puttur)						
Ap	0 - 10	26.9	1.22	7.25	59.0	16.42
A2	10 - 30	23.8	0.89	7.62	25.6	8.76
Bt1	30 - 75	20.2	0.10	3.25	18.0	9.48
Bt2	75 - 150	19.0	0.40	1.62	29.4	15.56

Table 10. **Simple correlation of available phosphorus with chemical properties**

Profile	Total P	Available Ca	Available Mg	Exchangeable Fe	Exchangeable Al	R_2O_3	Free iron oxide
1	0.885*	0.753	-0.736	-0.330	-0.365	0.729	0.862*
2	0.755	-0.446	-0.241	-0.742	0.507	-0.915*	0.926*
3	-0.108	-0.316	-0.804	0.889*	0.397	-0.850*	-0.284
4	0.481	0.532	-0.633	0.503	0.180	-0.404	-0.357
5	0.845	0.670	-0.123	0.533	0.690	-0.576	-0.696

* Significant at $P<0.05$

was observed in the Profiles 1 and 2. A negative correlation was found to exist between R_2O_3 and available phosphorus, except in the profile from Kanyakumari region bringing out that the phosphorus availability is restricted by the sesquioxides. According to Marschner (1986), in acid soils below pH 5.5, an increasing proportion of cation exchange sites of clay minerals are occupied by aluminium where it replaces other cations such as Ca^{2+} and Mg^{2+} and acts as a strong adsorber of phosphorus. In the profile from Kanyakumari region available phosphorus had a negative non-significant correlation with exchangeable aluminium, iron and available magnesium. A positive correlation with available phosphorus and available calcium was also observed. It may be inferred that by raising the level of available calcium as well as total phosphorus, the availability of phosphorus could be improved. Organic carbon also had significant positive correlation (significant for four profiles) with available phosphorus (Table 8). Significant positive relationship of available phosphorus with organic carbon was also observed by Satisha *et al.* (2000) for soils of Mizoram. These observations further suggest that the retention of phosphorus by organic colloids would go a long way in such types of soils.

The available potassium content in the profile samples decreased with depth and varied from 1.12 to 9.37 mg/100 g (Table 10). From the point of nutrition of *Hevea*, the critical level of available potassium content in soil is 5 - 12.5 mg/100 g. As seen from the analytical results of both the surface and profile samples, the soils cannot be rated as sufficient with respect to available potassium content. Soil potassium content is of extreme relevance from the point of view of nutrition of *Hevea*. It has been established that response to applied potassium by *Hevea* depended on the potassium content of soils (Pushparajah, 1977) and that potassium plays a predominant role in the flow of latex and its stability. There was a negative correlation (Table 12) between exchangeable potassium and clay in Profiles 1, 2, 3 and 5. Available potassium had a significant positive relationship with exchangeable potassium in Profile 3 and exchangeable potassium had positive correlation with cation exchange capacity of soil (Table 9). The mineralogical study revealed that the dominant clay mineral is kaolinite followed by degraded illite with admixtures of smectite and gibbsite. The presence of degraded illite calls for attention from the point of view of potassium nutrition since it can fix up and immobilize the soluble potassium (Chamuah, 1987).

In general, there was an increase in available magnesium content with depth indicating leaching and deposition in the lower layers. For the nutrition of *Hevea*, the magnesium content in the profiles from Kanyakumari region, Goa and Karnataka was found to be high. In the profile from Kanyakumari region, a negative correlation (Table 11) existed between available magnesium and available potassium. Similar negative correlations were obtained in the profiles of Central Kerala and Karnataka, the

Table 11. **Simple correlation of available and exchangeable potassium with exchangeable and available cations, CEC and total potassium**

Profile	Exchange-able Mg	Exchange-able K	Exchange-able Ca	Available Ca	Available Mg	Soil Clay	CEC	Total K
Available K								
1	-	0.514	-	0.894*	-0.717	0.760	-	0.679
2	-	0.214	-	0.02	0.196	0.777	-	0.077
3	-	0.975**	-	-0.516	-0.852*	0.681	-	0.716
4	-	0.783	-	-0.176	0.685	-0.170	-	0.234
5	-	0.739	-	0.360	-0.466	0.615	-	-0.296
Exchangeable K								
1	0.111	-	0.799	-	-	0.833*	-0.188	0.314
2	0.879*	-	-0.490	-	-	0.029	-0.417	0.931*
3	-0.857*	-	0.717	-	-	0.732	0.915*	0.840*
4	0.435	-	-0.455	-	-	0.413	0.112	-0.082
5	0.538	-	0.236	-	-	0.443	0.799	-0.035

* Significant at $P<0.05$

former being statistically significant. A balance of Mg/P and Mg/K in the latex is vital and potassium recommendation in the rubber growing regions with high available magnesium status may have to be rescheduled.

Probable pedogenesis of the soils

The cation exchange capacity, clay, SiO_2, sesquioxides, Al_2O_3, their molar ratios and free iron oxide content of the soils are summarised in Table 13. The SiO_2/R_2O_3 ratio ranges from 0.49 to 2.13 in Calicut profile soil samples.

From the nature of the underlying parent rocks, clay mineral assemblage and molar ratios, the following weathering sequence and soil formation process may be deduced. Acidic hydrolytic type of weathering is the most common reaction in these soils as favoured by highly decomposed organic matter and humid tropical climate. Parent rocks of mixed chemical composition as noticed in these soils promoted possibly by initial alkaline hydrolysis, might have released iron and aluminium in the system. Since iron can transform to oxides more readily than aluminium, free iron oxides and sesquioxides occur relatively in higher amounts. Aluminium released out of the hydrolytic decomposition has reacted with silica to form mostly kaolinite and other layer silicates and a part of unreacted aluminium has crystallized out as gibbsite creating a kaolinite-gibbsite system, which is stable in the prevailing acid conditions. Aluminium appearing in the exchange sites indicates an intense tropical weathering; a dominant kaolinitic mineralogy with significant amount of oxides is therefore a logical outcome. Lower SiO_2/R_2O_3 ratios are suggestive of a highly weathered condition of the soils with respect to silica removal. R_2O_3 is dominated by the iron components and this has resulted in a relatively higher SiO_2/Al_2O_3 ratios.

Soil taxonomy

The data generated hitherto on the morphological, physical, chemical and mineralogical aspects have been used to classify the soils. All the soils indicate presence of illuvial horizons, as evidenced by presence of clay skins. For distinguishing Alfisols and Ultisols, base saturation by sum of cations is the differentiating feature. Considering the base saturation and pH, it can be assumed that base saturation by sum of cations at a depth of 180 cm from the top of soil will be less than 35 per cent. Hence all the soils are classified under Ultisols.

The soils get keyed out under

Table 12. **Simple correlation of clay and pH with some chemical properties**

Profile	Available phosphorus	Exchange-iron	Exchange-magnesium	Exchange-aluminium	Exchange-potassium	Exchange-calicium	Available calicium	Available potassium	Available magnesium	Organic carbon
Clay										
1	-0.611	-0.299	-0.189	-0.659	-0.412	0.809	0.237	0.330	0.828*	-
2	-0.620	-0.918*	-0.595	-0.611	0.866	-0.876	0.853	-0.269	0.865	-
3	0.210	0.047	0.002	-0.462	0.711	-0.446	0.054	0.021	0.119	-
4	-0.721	0.653	0.134	0.055	0.220	-0.720	-0.806	0.540	0.416	-
5	-0.870	-0.438	-0.388	-0.946*	-0.954*	-0.703	-0.868	-0.767	-0.170	-
pH										
1	0.138	-0.187	0.802	-0.182	-0.190	-0.663	-0.056	0.154	-0.465	0.262
2	0.834	-0.714	0.828	-0.198	-0.370	0.104	-0.470	0.313	-0.407	0.970**
3	-0.481	-0.648	-0.678	-0.450	0.202	0.215	-0.136	-0.405	0.577	-0.618
4	0.189	-0.263	-0.448	-0.466	-0.535	0.026	-0.169	-0.276	-0.674	-0.097
5	-0.334	-0.647	-0.638	0.265	0.608	0.886*	0.770	-0.293	0.971**	-0.100

* Significant at $P<0.05$; ** Significant at $P<0.01$

Table 13. **Exchange capacity (clay, elemental composition of soils and molar ratios) of profile soil samples**

Horizon	Depth (cm)	‡CEC (clay)	Fe_2O_3 (%)	Al_2O_3 (%)	Sesqui-oxide (%)	Loss on ignition	†Moisture (%)	Free Iron oxide	SiO_2 (%)	SiO_2/R_2O_3	SiO_2/Al_2O
Profile 1. Kanyakumari (Bethany Estate, Kulashekaram)											
Ap	0 - 15	12.54	17.45	13.72	32.37	13.20	1.74	9.60	48.06	1.44	3.50
A2	15 - 30	12.54	16.89	9.71	27.90	12.10	1.65	8.12	54.35	2.01	5.60
Bt1	30 - 70	10.52	17.02	12.24	30.66	14.38	1.73	8.32	50.73	1.65	4.14
Bt2	70 - 90	13.29	18.95	9.59	30.04	15.35	3.89	9.00	48.22	1.61	5.03
Bt3	90 - 125	8.02	18.75	9.52	29.47	13.74	1.66	8.45	54.35	1.84	5.71
Bt4	125 - 150	8.03	20.01	7.91	29.24	13.65	1.66	8.32	53.85	1.84	6.79
Profile 2. Calicut (Kinalur Estate, Thamarassery)											
Ap	0 - 17	9.82	17.27	9.67	28.14	10.05	1.01	9.32	56.80	2.01	5.87
A2	17 - 30	11.29	19.38	10.13	30.61	11.09	1.00	8.22	53.30	1.74	5.26
BA	30 - 50	4.39	16.51	6.65	28.46	11.42	0.88	9.23	56.24	1.98	8.45
Bt1	50 - 90	5.56	18.57	10.13	30.20	11.46	0.74	11.32	54.60	1.81	5.38
Bt2	90 - 150	8.03	22.44	9.90	34.04	19.20	1.52	8.32	43.24	1.27	4.47
Profile 3. Central Kerala (Central Experiment Station, Chethackal)											
Ap	0 - 13	15.30	24.19	9.64	35.03	17.44	3.08	8.32	42.25	1.21	4.38
A2	13 - 25	14.43	25.73	8.09	35.22	17.03	2.51	9.56	46.75	1.33	5.78
BA	25 - 40	11.50	26.97	9.98	38.58	14.74	0.58	8.75	46.81	1.21	4.69
Bt1	40 - 73	8.02	28.70	9.67	39.87	16.22	2.14	9.30	41.77	1.07	4.32
Bt2	73 - 94	5.93	29.28	9.22	39.70	16.63	2.12	8.12	41.55	1.05	4.51
Bt3	94 - 150	5.53	28.13	10.84	40.27	16.85	2.03	10.55	40.10	1.00	3.79
Profile 4. Goa (Canacona)											
Ap	0 - 13	19.88	29.86	7.03	38.19	22.95	4.40	11.23	32.45	0.85	4.62
A2	13 - 35	18.10	30.17	9.67	41.04	20.91	0.35	12.55	32.55	0.80	4.24
Bt1	35 - 65	17.43	31.11	8.73	41.24	28.03	8.04	18.32	21.17	0.51	2.55
Bt2	65 - 125	11.50	31.85	9.67	43.02	15.12	2.09	14.32	38.57	0.90	3.99
BC	125+	9.61	31.16	9.94	42.20	13.78	3.81	11.23	38.21	0.91	4.25
Profile 5. Karnataka (Koduchar Plantations, Puttur)											
Ap	0 - 10	15.88	19.38	7.63	28.11	13.62	1.73	8.32	54.31	0.91	7.36
A2	10 - 30	13.59	18.39	8.54	28.13	16.02	3.97	8.32	49.88	1.77	5.84
Bt1	30 - 75	8.2	21.13	9.56	31.99	13.35	1.47	10.55	51.19	1.60	5.35
Bt2	75 - 150	6.58	20.20	9.15	30.75	11.78	1.00	14.56	54.47	1.77	5.95

‡ Cation exchange capacity (cmol (p+)/kg soil), † oven-dry.

Kanhaplustults, Kandiustults and Kandihumults since the calculated CEC of Kandic or argillic horizon, in major part is less than 16 cmol(p+)/kg clay.

The moisture regime in all the profiles was ustic. Following the keys to soil taxonomy (Soil Survey Staff, 1996), the profiles were classified up to subgroup level as, Rhodic Kanhaplustults (Kanyakumari region), Typic Kandiustults (Calicut region) and Ustic Kandihumults (Central Kerala, Goa and Karnataka.

ACKNOWLEDGEMENT

Authors thank Dr. G.C. Satisha, Soil Chemist, Agronomy/Soils Division, Rubber Research Institute of India, Kottayam, India for critical reading of the manuscript.

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