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Comparative study of soils under rubber (*Hevea brasiliensis*) and forest with reference to ion exchange and pedogenic components

Keywords: *Hevea brasiliensis*, ion exchange attributes, pedogenic components, natural forest, soils

The available evidences (Miles, 1985; Mathan and Kannan, 1993) suggest that vegetation has a pronounced effect on many soil properties. Changes in dynamic soil properties invariably occur when natural forests are transformed in to tree plantations. Nevertheless, rubber tree stands most closely resemble the natural forest ecosystem, as the advantage of flush of nutrients is realised when the tree roots are capable of capturing and recycling the nutrients (Puspharajah, 1984). The biomass potential of a mature *Hevea* ecosystem, as well as its tree nutrient bank status, can attain levels similar to that of the more luxuriant humid tropical evergreen forest systems (Sivandyan and Moris, 1992). Ironically, these trees can recycle a proportion of the captured nutrients back to the soil, and pump nutrients from the subsoil that otherwise may have been leached from the rooting zone. It is therefore, the favourable effects of trees on soils may be related to the long period.

The ion exchange properties, which is mostly instrumental in controlling the fertility, was not given much attention, especially in plantation agriculture. The oxides and hydrous oxides of iron and aluminium are important constituents of the highly weathered soils of tropical and subtropical regions (Schwertmann and Taylor, 1989). Sesquioxides and hydrous oxides of iron and aluminium are some of the terminal products of weathering of rocks and minerals, occur in several pedogenic forms *viz.*, structural components of silicate clays and coatings or films on clay particles. Among these oxides, iron oxides are the most abundant oxides in most soils and are sensitive indicators of pedogenic environments. These compounds are of great agronomic significance because of their highly reactive nature which enables them to exert tremendous influence on both physical and chemical soil properties. Soil properties such as anion sorption, surface charge, specific surface area and aggregate formation may be significantly modified by presence of amorphous form of the oxides. On the other hand the profile distribution of the various forms of these pedogenic oxides (Fe amd Al) has been used as a criterion in interpreting soil formation processes (Nayak *et al.*, 2002). The present study aimed at studying the soils under rubber, being cultivated over a long period of 80-90 years with reference to ion exchange attributes and pedogenic components, relative to the natural forest ecosystem.

Site description

The study area lies between 76°20' to 76° 55' E and 11 9' to 9° 33' N, which covers four major different agro-climatic zones representing the traditional rubber growing belt in Kerala, India. The available records indicate that in these sites rubber is being cultivated as a third consecutive cycle. The sites for collection of soil profiles identified at Nilambur, Chemoni, Vithura and Mundakayam both in rubber plantation and adjacent natural forest ecosystems of similar physiography. Forests in Nilambur and Chemoni were deciduous type and that of Vithura and Mundakayam were evergreen (Table 1). The areas have an annual rainfall ranging from 2000-3500 mm and the average maximum and minimum temperature are 28.0°C and 24.5°C, respectively. The soils under study are formed from basement complex rocks, chiefly hypersthein bearing gneisses and granulites belonging to charnokites group (ICAR report, 1999).

Table 1. General characteristics of study site

Location	Type of forest	Altitude (m msl)	Slope (%)	Water table (m)	Rainfall (cm)
Nilambur	Moist deciduous	90	8-15	>10	30-35
Chemoni	Moist deciduous	100	8-15	>10	25-35
Vithura	Wet evergreen	140	8-20	5-10	20-30
Mundakayam	Wet evergreen	250	8-20	>10	30-35

Soil sampling and laboratory analysis

Soil samples of each diagnostic horizon were collected from eight profiles representing each location. The samples were air-dried, pulverized and passed through a 2 mm sieve before analysis. Texture was determined by the pipette sedimentation procedure as described by Page (1992). Soil pH was measured in water at a soil : water (w/v) ratio of 1:2.5. The organic carbon was determined by chromic acid wet digestion method (Walkley and Black, 1934) and exchangeable cations were determined according to Page (1992). Results of important physico-chemical properties of the soils are presented in table 2. Total elemental analysis (silica, sesquioxide, Fe_2O_3 and Al_2O_3) of soil samples were done by Na_2CO_3 fusion method. Iron (Fe) and aluminium (Al) were extracted with sodium pyrophosphate (Fe_p and Al_p) (Loepert and Inskeep, 1996), ammonium oxalate (Fe_{ox}) (McKeagne and Day, 1966) and dithionite-citrate-bicarbonate (Fe_{dcb}) (Mehra and Jackson, 1960). Iron in all the extracts was determined colorimetrically (Jackson, 1958) while aluminium was determined by using aluminon method (Hsu, 1964).

Ion exchange soil attributes

The distribution of CEC's of the soils along the depth of both rubber and forest profiles (Table 3) in all the sites follows almost the same trend. The CEC's of the soils were low and were, in general higher in the surface layers as compared with the sub-soils. The CEC's of the surface horizons in rubber profile varied from 5.36 to 12.50 cmol(p+)/kg where Chemoni-rubber soils registered higher CEC values compared to other profiles. Low values of CEC's in the subsoils may be attributed to the pH-dependent exchange sites occupied by either hydrogen ions or hydroxy aluminium ions at low pH. Moreover, the nutrient and organic matter accumulation in the upper horizons is the results of nutrient cycling by biomass. Therefore, both in rubber and native forest system, mull-like moder humus might have formed in the surface horizons that might be the contributory factor for high values CEC. Nevertheless, the CEC's of forest soils considerably higher than rubber growing soils, which may be attributed to the relatively high organic matter accumulation. In general, exchangeable cations both in rubber and forest soils were low, which is characteristics of soils formed under conditions of high rainfall, temperature prevalent in the region and intense leaching. Similar results have also been reported by Krishnakumar (1989) and Satisha and Badrinath (1994) for rubber growing soils of Kerala and Western Ghats forest soils

Table 2. Some important physico-chemical properties of soils under rubber and adjacent forest

Horizon	Depth (cm)	pH	OC (%)	Clay (%)	Texture	Horizon	Depth (cm)	pH	OC (%)	Clay (%)	Texture
		Rubber						*Forest*			
Nilambur											
Apl	0-19	4.4	1.68	42	sc	Ap	0-18	4.6	1.99	27	scl
A2	19-35	4.5	1.13	41	sc	Bt1	18-34	4.7	1.26	40	sc
Bw1	35-57	4.4	0.73	39	sc	Bt2	34-57	4.7	0.89	46	sc
Bw2	57-100	4.3	0.67	34	scl	Bt3	57-100	4.6	0.87	41	sc
BC	100-129	4.2	0.52	33	scl	B1	100-132	4.9	0.73	45	sc
Chemoni											
Ap	0-14	4.9	2.33	28	scl	Ap	0-11	5.0	3.96	32	scl
A2	14-24	4.9	1.33	35	sc	A2	11-33	5.0	2.26	35	sc
Aw1	24-38	4.1	1.06	44	sc	Bw1	33-64	5.0	1.62	38	sc
Aw2	38-52	4.5	0.99	41	c	Bw2	67-100	4.8	1.56	32	scl
Aw3	52-76	4.5	0.67	33	scl	BC	100-130	5.1	1.42	30	scl
BC1	76-100	4.5	0.55	29	scl						
Vithura											
Ap	0-26	4.9	2.22	37	sc	A	0-22	5.0	2.22	37	scl
Bt1	26-51	4.8	1.15	48	sc	Bt1	22-40	5.0	1.15	48	sc
Bt2	51-76	4.7	0.97	48	sc	Bt2	40-59	4.8	0.97	48	sc
Bt3	76-100	4.6	0.89	42	sc	Bt3	59-80	4.6	0.89	42	sc
Bt4	100-124	4.7	0.81	48	sc	Bt4	80-100	4.7	0.81	48	sc
Mundakayam											
Ap	0-9	4.7	1.83	39	sc	A1	0-11	5.2	2.61	25	scl
A2	9-32	4.7	1.36	39	sc	A2	11-24	6.0	1.60	29	scl
A3	32-51	4.8	1.07	39	sc	Bt1	24-45	5.6	1.28	51	c
Bt1	51-73	4.9	0.96	51	sc	Bt2	45-69	5.2	0.75	33	cl
Bt2	73-100	4.9	0.67	44	c	Bt3	69-100	5.0	0.49	14	cl
Bt3	100-124	4.9	0.75	51	c						

pH-(soil/water ratio = 1:2.5); OC-Organic carbon;

Table 3. Ion exchange attributes of soils under rubber and adjacent forest

Depth (cm)	Exchangeable cation (cmol(p+) kg^{-1})			CEC	BS (%)	Depth (cm)	Exchangeable cation (cmol(p+) kg^{-1})			CEC	BS (%)
	Ca^{2-}	Mg^{2-} *Rubber*	K^{-}				Ca^{2-}	Mg^{2-} *Forest*	K^{-}		
Nilambur											
0-19	1.23	0.48	0.27	6.07	36	0-18	2.54	0.62	0.69	10.70	41
19-35	0.51	0.18	0.23	5.36	21	18-34	1.31	0.52	0.69	8.57	32
35-57	0.28	0.12	0.13	3.93	19	34-57	0.62	0.64	0.57	10.00	21
57-100	0.38	0.17	0.11	2.71	32	57-100	0.96	0.73	0.25	3.57	61
100-129	0.28	0.43	0.11	4.99	22	100-132	0.91	0.76	0.20	3.93	59
Chemoni											
0-14	1.08	0.31	0.59	12.50	19	0-11	4.91	1.10	0.62	12.85	53
14-24	0.86	0.32	0.19	10.70	13	11-33	2.64	0.92	0.26	18.57	16
24-38	0.74	0.30	0.19	9.80	14	33-64	0.84	0.19	0.23	11.07	14
38-52	1.19	0.98	0.21	6.07	20	67-100	0.72	0.31	0.24	6.98	20
52-76	1.00	0.64	0.29	5.36	17	100-130	0.78	0.43	0.24	7.68	23
76-100	1.11	0.40	0.29	5.36	14						
Vithura											
0-26	1.50	0.37	0.25	11.78	10	0-22	1.50	0.37	0.25	11.78	10
26-51	0.62	0.21	0.17	11.07	13	22-40	0.62	0.21	0.17	11.07	13
51-76	0.51	0.18	0.13	8.93	12	40-59	0.51	0.18	0.13	8.93	12
76-100	0.22	0.19	0.15	4.39	15	59-80	0.22	0.19	0.15	4.39	15
100-124	0.26	0.20	0.13	3.81	13	80-100	0.26	0.20	0.13	3.81	13
Mundakayam											
0-9	0.97	0.28	0.63	7.72	25	0-11	2.75	0.45	1.05	9.09	55
9-32	0.35	0.14	0.32	6.77	12	11-24	1.38	0.45	0.59	7.83	30
32-51	0.72	0.16	0.34	5.80	24	24-45	1.11	0.45	0.76	7.51	34
51-73	0.73	0.33	0.29	5.60	27	45-69	0.84	0.45	0.59	4.68	43
73-100	0.71	0.45	0.42	4.72	32	69-100	0.49	0.28	0.42	6.52	20
100-124	0.70	0.41	0.29	5.25	35						

CEC-Cation exchange capacity(cmol(p+)/kg); BS-Base saturation.

Table 4. Pedogenic components of the soils

Depth (cm)	SiO_2 (%)	R_2O_3 (%) *Rubber*	Fe_2O_3(%)	Al_2O_3 (%)	Depth (cm)	SiO_2 (%)	R_2O_3 (%) *Forest*	Fe_2O_3 (%)	Al_2O_3 (%)
Nilambur									
0-19	53.0	23.0	8.8	14.2	0-18	43.3	14.0	5.6	18.4
19-35	46.7	26.0	8.8	17.2	18-34	50.4	20.0	6.4	13.6
35-57	48.1	28.0	8.0	20.0	34-57	46.7	20.0	7.6	12.4
57-100	48.2	30.0	9.8	20.2	57-100	56.2	22.0	8.2	13.8
100-129	54.5	29.0	9.4	19.6	100-132	53.4	24.0	8.4	15.2
Chemoni									
0-14	40.9	26.0	9.4	16.6	0-11	48.5	21.0	6.2	17.8
14-24	41.2	28.0	9.4	18.6	11-33	42.8	22.0	6.4	15.6
24-38	53.2	31.0	9.0	22.0	33-64	53.8	21.0	6.6	14.4
38-52	49.1	33.0	9.2	23.8	67-100	48.8	24.0	7.0	17.0
52-76	46.8	36.0	9.0	27.0	100-130	51.4	25.0	6.0	19.0
76-100	54.3	33.0	9.0	24.0					
Vithura									
0-26	50.5	24.0	7.0	17.0	0-22	64.4	25.0	7.4	17.6
26-51	54.7	24.0	7.6	19.6	22-40	40.9	31.0	8.0	23.0
51-76	44.3	27.0	8.0	19.0	40-59	57.7	30.0	8.0	22.0
76-100	55.3	23.0	7.0	16.0	59-80	56.1	26.0	6.2	19.8
100-124	46.3	25.0	7.8	17.1	80-100	42.5	24.0	5.8	18.2
Mundakayam									
0-9	54.3	29.0	10.0	19.0	0-11	50.1	27.0	7.6	19.4
9-32	43.0	27.0	9.0	18.0	11-24	64.3	28.0	9.2	18.8
32-51	40.1	28.0	9.2	18.8	24-45	64.5	26.0	9.4	16.8
51-73	47.7	30.0	10.2	19.8	45-69	56.4	29.0	9.4	19.6
73-100	54.9	30.0	11.0	22.0	69-100	53.2	26.0	5.6	20.4
100-124	44.8	33.0	11.0	22.5					

of Karnataka, respectively. Percent base saturation in rubber cultivated soils was considerably low, ranging from 13 to 36 per cent and the values decreased with depth. Base saturation of soils under rubber was significantly lower compared to forest soils, which could have arisen from the associated differences in intensity of leaching. The decrease of the base saturation with depth indicates about the maturity of these woodland biosequences (Gangopadhyay *et al.*, 1987). Thus, redistribution of exchangeable Ca and Mg ions within an ecosystem, is perhaps very much dependent on microclimatic condition and vegetation, as stated by Satisha *et al.* (1998). Since rubber plantations of third cycle, it can be inferred that considerable depletion of cations might have taken place due to the storage of these cationic nutrients in the trunk and their complete loss from the rubber ecosystem during the logging operations at the end of each planting cycle, probably the menace of leaching of bases is offset by the efficacy of the rubber tree as a superb biocycling agent as long as Ca^{2+} is concerned (Karthikakuttyamma *et al.*, 2002).

Pedogenic components of the soils

Silica was the major constituent of the soils and its content varied from 40.1 to 55.3 per cent in rubber cultivated soils and 40.9 to 64.5 per cent in forest soils (Table 4). Next to silica, the sesquioxide dominates the constituents of soil mass in which alumina occurs as a major fraction. The sesquioxide content of the soils under rubber varied from 23.0 to 36.0 per cent and in forest soil profiles, the content varied from 14.0 to 31.0 per cent. Depth-wise increasing trend in the distribution pattern of R_2O_3, Al_2O_3 and Fe_2O_3 in all the profiles of both rubber and forest lands indicate migration of fine clay to lower layers. The sesquioxide, Al_2O_3 and Fe_2O_3 content of the soils under rubber was significantly higher compared to those of forest, which is an indication of the tendency of laterisation process in monoculture as compared to natural forest. All the soil pedons under rubber had lower SiO_2/R_2O_3, SiO_2/Fe_2O_3 and SiO_2/Al_2O_3 molar ratios compared to forest soil profiles, further confirms that laterisation process and thereby induration occurs faster (Byju and Varghese, 2001). Organic matter-sesquioxide complexes in B horizons are generally precipitated at specific carbon/sesquioxide ratios (Buurman, 1985). Such complexes are soluble in water at low metal contents and become insoluble once a critical metal content is surpassed. Therefore, in the present investigation, the differences in components and the intensity may be attributed to the variation in complexation of metals by organic matter.

The different forms of Fe and Al in the soils are

Table 5. Iron and aluminium extractables of the soils in pyrophosphate (Fe_p, Al_p), ammonium-oxalate (Fe_{ox}) and dithionite-citrate-bicarbonate (Fe_{dcb})

Depth	Fe_p(%)	Al_p(%)	Fe_{ox}(%) *Rubber*	Fe_{dcb}(%)	Fe_{ox} / Fe_{dcb}	Depth	Fe_p(%)	Al_p(%)	Fe_{ox}(%) *Forest*	Fe_{dcb}(%)	Fe_{ox} / Fe_{dcb}
Nilambur											
0-19	6.16	7.38	2.22	3.20	0.69	0-18	3.92	9.57	1.60	3.72	0.43
19-35	6.16	8.94	2.41	3.33	0.72	18-34	4.48	7.07	1.90	2.50	0.76
35-57	5.60	10.40	2.58	4.71	0.55	34-57	5.32	6.45	1.61	2.73	0.59
57-100	6.86	10.50	1.90	2.20	0.86	57-100	5.74	7.18	1.53	3.00	0.51
100-129	6.58	10.19	1.90	2.50	0.76	100-132	5.88	7.90	1.60	2.33	0.69
Chemoni											
0-14	6.58	8.63	2.03	1.60	1.27	0-11	4.34	9.26	1.90	2.30	0.83
14-24	6.58	9.67	2.00	3.67	0.54	11-33	4.48	8.11	1.90	2.30	0.83
24-38	6.30	11.44	1.50	4.70	0.32	33-64	4.62	7.49	2.21	3.00	0.74
38-52	6.44	12.38	1.30	2.53	0.51	67-100	4.90	8.84	1.60	1.91	0.84
52-76	6.30	14.04	1.06	5.58	0.19	100-130	4.20	9.88	1.04	1.52	0.68
76-100	6.30	12.48	1.23	2.60	0.47						
Vithura											
0-26	4.90	8.84	1.10	1.90	0.58	0-22	5.18	9.15	2.50	5.30	0.47
26-51	5.32	10.19	1.40	4.70	0.30	22-40	5.60	11.96	2.50	2.30	1.09
51-76	4.16	9.88	1.33	2.71	0.49	40-59	5.60	11.44	2.50	2.10	1.19
76-100	4.90	8.32	1.52	2.20	0.69	59-80	4.34	10.30	2.50	1.92	1.30
100-124	5.46	8.89	1.00	2.50	0.40	80-100	4.06	9.46	1.43	0.80	1.79
Mundakayam											
0-9	7.00	9.88	2.42	5.00	0.48	0-9	5.32	10.09	2.50	5.30	0.47
9-32	6.30	9.36	2.50	1.93	1.30	9-32	6.44	9.78	2.50	2.63	0.95
32-51	6.44	9.78	2.30	10.00	0.23	32-51	6.58	8.74	2.50	1.90	1.32
51-73	7.14	10.30	1.72	7.42	0.23	51-73	6.58	10.19	2.50	1.90	1.32
73-100	7.70	11.40	2.23	9.00	0.25	73-100	3.92	10.61	1.00	0.80	1.25
100-124	7.70	11.70	2.18	9.90	0.22	100-124	5.32	10.09	2.50	5.30	0.47

presented in Table 5. The contents of Fe_p in soils under rubber were higher compared to forest soils. The forms of Fe followed the sequence $Fe_p < Fe_{dcd} < Fe_{ox}$ for both rubber cultivated and forest soils. It is generally assumed that Fe_p gives an estimate of Fe bound to well decomposed organic matter (Bascomb 1968), while Fe_{ox} estimates poorly crystalline Fe oxides and Fe_{dcb} estimates the total amount of Fe oxides (Cornell and Schwertmann, 1996). Al_p was consistently higher in soils under rubber than in forest soils and in general, contents were increased along the depth of the profiles. This indicates that Al is present in organically bound forms and is sparingly associated to goethite, which is a major well-crystalline iron oxide identified in hard laterites (Parfitt and Childs, 1988). The contents of Fe_p in soils under rubber were higher compared to forest soils. The presence of relatively high contents of Fe_p in rubber plantation soils could be regarded as an indication of advanced stage of weathering than those of native forest. These results corroborated the fact that as weathering intensity increases, leaching of the cations and silica increases correspondingly and consequently the amount of hydrous oxides of Fe increases (Maro et al. 1993). Fe_{ox}, which is an indication of the active iron and Fe_{dcb} content in soils under rubber varied from 1.10 to 2.58 per cent and 1.93 to 10.00 per cent, respectively. The ratio between Fe_{ox} and Fe_{dcb} in soils under rubber ranged from 0.19 to 1.30 while that for forest soils, varied from 0.47 to 1.79. The ratio Fe_{ox}/Fe_{dcb} (activity ratio) is often used as a relative measure of the degree of ageing or crystallinity of free iron oxides. The higher values of Fe_{ox}/Fe_{dcb} in forest soils compared to rubber growing soils indicate their relative enrichment with amorphous iron oxides than crystalline ones. Lower amorphous forms of iron as compared to crystalline forms, was also reported by Eshett (1991) for rubber growing soils of southern Nigeria. The presence of high contents of Fe_{dcb} further confirms that rubber cultivated soils are more weathered than forest soils. The high Fe_{ox}/Fe_{dcb} ratios found in forest soils could further reflect the presence of organic matter that impedes formation of crystalline iron oxides as suggested by Bascomb (1968). This is verified by the relatively high ratios between Fe_p and Fe_{dcb}, which ranged from 1.97 to 2.24 as determined in forest soils.

References

Bascomb, C.L. 1968. Distribution of pyrophosphate-extractable iron and organic carbon in soils of various group. *Journal of Soil Science* **19**:251-268.

Buurman, P. 1985. Carbon/sesquioxide ratios in organic complexes and the transition albic-spodic horizon. *Journal of Soil Science* **36**:255-260.

Byju, G. and Varghese, T. 2001. Impact of cassave and rubber on laterisation process in a selected laterite terrain from Kerala. *Journal of the Indian Society of Soil Science* **49**(3):476-478.

Cornell, R.M. and Schwertmann, U. 1996. The iron oxides: Structure, properties, reactions, occurrence and uses, Wehheim, New York, USA.

Eshett, E.T. 1991. General properties and iron and aluminium status of selected rubber growing soils of southern Nigeria. *Indian Journal of Natural Rubber Research* **4** (1):8-15.

Gangopadhyay, S.K., Nath, S. and Banerjee, S.K. 1987. Nature and properties of some introduced tea (*Tectona grandis*) growing soils of North-West Bengal. *Indian Forester* **113**:65-72.

Hsu, P.H. 1964. Effect of initial pH, phosphate, and silicate on the determination of aluminium with aluminon. *Soil Science* **96**:230-238.

ICAR report. 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.

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

Karthikakuttyamma, M., Satisha, G.C., Suresh, P.R. and Aiyer, R.S. 2002. Biomass production and nutrient budgeting in *Hevea brasilensis*. *Natural Rubber Research* **17**(2):108-114.

Krishnakumar, A.K. 1989. *Soil under Hevea in India: A physical, chemical and mineralogical study with reference to soil moisture cation influence on yield of Hevea brasiliensis.* Ph.D Thesis, Indian Institute of Technology, Kharagpur, West Bengal, India.

Loeppert, R.H. and Inskeep, W.P. 1996. Iron. In: Sparks, D.L. *et al.* (eds) *Methods of Soil Analysis.* Part 3. Chemical Methods, American Society of Agronomy, Madison, Wisconsin, USA. pp. 639-664.

Maro, R.S., Chamshama, S.A.O., Nsolomo, V.R. and Maliondo, S.M. 1993. Soil chemical characteristics in a natural forest and a *Cupressus lustanica* plantation at West Kilomanjaro, Northern Tanzania. *Journal of Tropical Forest Science* **5**(4):465-472.

Mathan, K.K. and Kannan, N. 1993. Physico-chemical properties of pedons under the influence of different vegetations in Kodaikanal hills of Tamilnadu. *Madras Agricultural Journal* **80**(10):581-585.

McKeague, J.A. and Day, J.H. 1966. Dithionite and oxalate extractable iron and aluminium as aids in differentiating various classes of soil. *Canadian Journal of Soil Sciences* **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.

Miles, J. 1985. The pedogenic effects of different species and vegetation types and the implications of succession. *Journal of Soil Science* **36**:571-584.

Nayak, D.C., Sarkar, D. and Das, K. 2002. Forms and distributions of pedogenic iron, aluminium and manganese in some benchmark soils. *Journal of the Indian Society of Soil Science* **50**(1):89-93.

Page, A.L. 1992. *Methods of Soil Analysis*, ASA and SSSA Publishers, Madison, WI. 321p.

Parfitt, R.L. and Childs, C.W. 1988. Estimation of forms of Fe and Al: A review, and analysis of contrasting soils by dissolution and Moessbauer methods. *Australian Journal of Soil Research* **26**:121-144.

Pusparajah, E. 1984. *Nutrient availability of acid soils in the tropical following clearing and cultivation with plantation crops.* In: Proc. Int. Workshop on Soils, Australian Council for International Agricultural Research, Canberra, Australia, pp. 47-51.

Satisha, G.C. and Badrinath. 1994. Characterisation of soils of Western Ghats in Dakshina Kannada District, Karnataka. *Agropedology* **4** : 45-48.

Satisha, G.C., Pal, T.K., Dey, S.K. and Annamma Varghese, Y. 1998. Characteristics, genesis and classifiction of soils under *Hevea* in Mizoram, North-East India. *Indian Journal of Natural Rubber Research* **11**(1&2) : 38-45.

Schwertmann, U. and Taylor, R.N. 1989. pp. 379-438. In: *Minerals in Soil Environments* J.B. Dixon and S.B. Weed, (Eds.) Soil Sci. Soc. Am. Madison, USA.

Sivanadyan, K. and Moris, N. 1992. Consequence of transforming tropical rain forests to *Hevea* Plantations. *The Planter* **68** (800) : 547-567.

Walkley, A. and Black, C.A. 1934. An examination of the Dagtareff method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Science* 37:29-39.

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