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Characterisation and classification of soils from the traditional coffee-growing areas in the Western Ghats of South India

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Abstract : Three pedons were studied and characterised for the soils of the traditional coffee-growing areas in the Western Ghats of South India. Soils were deep to very deep, well drained, dark brown to very dark brown, developed over granite gneiss/weathered granite parent material. The soils were sandy clay loam to clay in texture and subangular blocky in structure. The soils had high organic carbon content, varying from 2.4 to 2.54 per cent in the surface, low in exchangeable bases and low in cation exchange capacity, ranging from 13.90 to 22.62 cmol (+) kg^{-1} of soil,indicating the presence of kaolinitic clays. *The pedons were classified into Ustic Kandihumults, Ustic Palehumults and Ustic Haplohumults* at the subgroup level in the sequence of development.

Key words: *Coffeegrowing soils, Forest Soils, Soil characterisation, Western Ghats*

Introduction

The Western Ghats landscape in India is dominated by forests and plantations. The total area under the Western Ghats is approximately 129,037 km², out of which about 87,307 km² is covered by forests. According to the Forest Survey of India, the area under forest cover in the Western Ghats has increased marginally in recent years. But this includes an increase in area under plantations such as coffee, tea, pepper, coconut, areca, cashew, cocoa, and mango, which are included in the definition of forests (Ravindranath and Murthy, 2015).Coffeeplantations form one of the most common cultivated ecosystems in the Western Ghats, asthey are grown mostly in association with trees to provide shade and other environmental and economic benefits.

Coffee, an important plantation crop, is mainly confined to the hills of South India,with Karnataka, Kerala, and Tamil Nadu forming the major traditional coffee growing regions. Karnataka is the largest producer of coffee, accounting for about 70 per cent of total coffee production and 60 per cent of the area under coffee in India. Among the plantation crops, coffee has made a significant contribution to the Indian economy during the past five decades. The favourable conditions for successful coffee cultivation include well-distributed annual rainfall of 2000-3000 mm, with a dry spell of 2-3 months, moderate to high humidity, and deep to very deep soils with a moderately heavy texture and high base saturation, along with adequate organic carbon content (Muller, 1966).

Characterisation of soils involves the study of their morphological, physical, and chemical properties. The development of soils depends on various factors, and soils vary greatly in their nature and extent of development. Studies on the physical and chemical properties of soil indicate the effects of land use changes and management on soil development (Alvarez and Alvarez 2000). Soil organic carbon content is considered the most valuable indicator of land quality in coffee production systems (Anil Kumar and Shalima Devi,, 2009). To understand the development of soils in coffee-growing areas of the Western Ghats and to classify them according to the Soil Taxonomy (USDA), three representative pedons from coffee plantations in traditional coffee-growing areas of the Western Ghats were characterised by studying morphological, physical, and chemical parameters.

Materials and Methods

The pedons *viz*. P1: CCRI / Balehonnur / Chikmagalur; P2: Mananthawady/Wayanad Forest; and P3: Shanthanpara/ Idukki were exposed and studied for their morphological characteristics. These pedons were situated at an elevation ranging from 770 to 1204 m above mean sea level, with slopes varying from 3 to 5 per cent to 15 to 25 per cent, and were well drained. All studied pedons were developed from weathered granite and granite-gneiss parent materials **(**Table 1)**.**

Soil samples were collected from horizons, air-dried, crushed and passed through a 2 mm sieve. Soil samples were analysed using standard procedures for soil morphological, physical, and chemical parameters. The particle size analysis was done by the International pipette method (Piper 1950), and soil pH (1:2.5 soil water ratio) was measured as outlined by Jackson (1973). Soil organic carbon was estimated by the dry combustion method. Exchangeable bases and cation exchange capacity were determined by the ammonium acetate method (Jackson, 1973). These soils were classified according to the USDA soil taxonomy (Soil Survey Staff, 2014).

Results and Discussion

Morphological characteristics

Relevant morphological features and textural characteristics of the pedons are presented in Table 2. The pedons were very deep except P3, where the depth was up to 140 cm, and below it was weathered rock. The distinctness of the soil boundary varied from abruptto gradual. The hue (soil colour) of Munsell colour chart notation ranged from5 YR to 10 YR, value 3 and chroma from 2 to 3 at the surface. Soil colour of the pedons varied from dark reddish brown to dark brown in the surface and yellowish red to strong brown in the lower horizons. This may have resulted from a decrease in organic matter and intense leaching of bases, leading to the accumulation of sesquioxides and further oxidation. The variations in soil colour result from the chemical and mineralogical composition, coupled with texture and topographic position (Walia and Rao, 1997).The surface structure varied from weak to moderate, with a medium sub-angular blocky structure. The dominant structure was moderate, medium, sub-angular blocky. The surface horizon of pedon 3 recorded a weak fine granular structure.

Physical characteristics

The soil texture varied from sandy clay loam to clay among the pedons (Table 2).This variation could be a result of different soil formation processes, including in situ weathering and the illuviation of clay (Geetha and Naidu2013). The clay content at the surface varied from 26.05 in Chikmagalur to 42.41 in Wayanad. Idukki pedon recorded a clay content of 38.16 per cent.

In P3, there was an increase in the clay content with depth from 38.16 per cent at the surface horizon (0-20 cm) to 60.82 per cent at the sub-surface horizon (83-122cm). In P2, the clay content increased from 42.41 to 53.23 per cent.The increase in clay content with depth could be due to the dispersion of clay at the surface and the illuviation or translocation of clay from the surface to the subsurface (Sarkar et al., 2002; Srinivasan et al., 2013). The decrease in clay content at the deeper layers in the profiles may be due to the influence of parent materialand less active pedogenic processes. A decrease in sand content was observed in the pedons with a concomitant increase in clay content. The process of illuviation has also affected the vertical distribution of sand and silt content (Nagendra and Patil2015). Sand was the major mechanical fraction, which indicates the nature of the parent material (Srinivasan et al, 2013; Chandra Sekhar et al., 2017). The bulk density of pedons ranged from 1.04 to 1.29 Mg m^{-3}.

Table 1: Locations and site characteristics of the studied pedons

Pedon No./Name	Latitude (N)	Longitude (E)	Elevation (m)	Physiography	Slope (%)	Ground water table (m)	Drainage	Erosion	Parent material
P1: Chikmagalur Coffee Plantation	13° 21'40.0"	75°25'38.5"	827	Eastern hills (Malanad) of Western Ghats; Hilly terrain, Moderately sloping	5-10	>50	Well drained	Moderate	Weathered Granite
P2: Wayanad Coffee Plantation	11° 44'03.1"	75°51'00.0"	779	Nilgiris hills of Western Ghats ; Evergreen Forest; Highland, Steeply1 sloping	15-25	25-50	Well drained	Slight	Weathered Granite
P3: Idukki Coffee Plantation	09° 56'42.5"	77°13'11.3"	864	Kumili hills of Western Ghats; Hill side slope; Gently sloping	3-5	10-25	Well drained	Moderate	Granite gneiss; Weathered rock

Table 2: Morphological and physical characteristics of soils

Depth (cm)	Horizon	Moist Colour	Boundary	Structure			Consistence				Total			Coarse fragments: (Volume %)	Stones and Boulders (Volume %)	Fine earth texture USDA	Bulk Density (Mg m^{-3})
				S	G	T	D	M	S	P	Sand (2.0-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)				
Pedon 1: Chikmagalur: Clayey, Kaolinitic, isohyperthermic Ustic Kandihumults																	
0-11	A	10 YR 3/ 3	gs	M	2	sbk		fr	ss	sp	48.37	25.580	26.054	2.39	-	scl	1.29
11-31	B1	10 YR 4/4	gs	M	2	sbk		fr	s	p	44.95	26.327	28.720	0.80	-	cl	1.30
31-54	Bt1	7.5 YR 4/4	gs	M	2	sbk		fr	s	p	41.23	23.974	34.795	31.85	-	cl	1.41
54-86	Bt2	5 YR 4/6	gs	M	2	sbk		fr	s	p	42.58	21.773	35.645	27.87	20	cl	1.45
86-123	Bt3	5 YR 6/6	gs	M	2	sbk		fr	s	p	31.13	30.849	38.021	3.58	-	cl	1.31
123-156	Bt4	5 YR 5/6	gs	M	2	sbk		fr	s	p	23.86	38.782	37.360	1.99	-	cl	1.37
Pedon 2: Wayanad:Clayey, kaolinitic, isohyperthermic Ustic Haplohumults																	
0-20	Ap	5 YR 3/2	cs	M	2	sbk		fr	ss	sp	36.44	21.15	42.41	1.99	-	c	1.04
20-52	Bt1	7.5 YR 3/4	gs	M	2	sbk		fr	s	p	26.88	20.56	52.55	1.59	-	c	0.97
52-84	Bt2	7.5 YR 3/2	gs	M	1	sbk		fr	s	p	25.40	21.37	53.23	0.80	-	c	1.07
84-120	Bt3	7.5 YR 4/4	gs	M	2	sbk		fr	s	p	31.64	18.47	49.89	19.90	-	c	1.37
120-160	Bt4	7.5 YR 5/8		M	1	sbk		fr	s	p	41.86	16.13	42.01	0.40	30	c	1.20

(Expansion of abbreviations: A: Surface horizon, Ap: Plough layer, Bt: Illuvial clay horizon YR: Yellowish red colour hue, scl: Sandy clay loam, sc: Sandy clay, cl: Clay loam, c: Clay)

Chemical Characteristics

Soil pH varied from slightly acidic to strongly acidic (Table 3). The pH varied from 5.1 to 6.2 among the pedons, which may be attributed to the intensive leaching of bases associated with the heavy rainfall in the area (Kharche et al., 2000). The acidic parent material could also contribute to the acidic reaction of the soils. Soils derived from granite gneiss parent materials were slightly acidic to near-neutral in reaction (Shivaprasad et al., 1998).

Surface horizon recorded higher organic carbon in all three pedons studied. P1, (Chikmagalur) recorded an organic carbon content of 2.40 per cent in its surface horizon of 0-11 cm depth.P2 (Wayanad) recorded 2.44 per cent, and Pedon 3 (Idukki) recorded 2.54 per cent. In all the profiles, a gradual reduction in soil organic carbon with depth was observed, which may be attributed to the leaching environment prevalent in the area, as all the soils are well-drained.This also results from slow organic matter decomposition at higher altitudes, where temperature is low and rainfall is high (Sys et al. 1993; Kharche et al. 1999; Shalima Devi and Anil Kumar 2009).

Exchangeable Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} were higher in surface horizons than the sub-surface horizons. They were generally very low in all the pedons. This may be due to the leaching of bases from the root zone caused by high rainfall (Kharche et al., 2000). The liming carried out in the coffee plantation replenishes the Ca^{2+} and Mg^{2+} content in these soils.

Cation exchange capacity (CEC) ranged from 10.44 to 14.36cmol (+) $kg^{-1}$of soil. Low cation exchange capacity values despite high clay content indicate the dominance of low activity clays, particularly 1:1 type clay minerals,*i.e.,* Kaolinite (Walia and Chamuah, 1988; Kharche et al., 2000). In all the pedons, the CEC was higher at the surface due to the higher organic matter present at the surface. There was a reduction in CEC with depth in all the pedons. The dominance of low activity clays along with the accumulation of sesquioxides and hydrated and hydroxylated forms of iron and aluminium in these soils, leaching of bases, and an increase in iron and aluminium acidity also contribute to the reduction of CEC in the lower layers. The effective CEC (CEC_e) varied from 4.97 to 10.35 on the surface. The CEC_e was lower than the CEC in all the pedons. This may be due to the development of pH-dependent negative charges on the exchange complex (Patil and Dasog1999). The CEC at the surface by sum of cations varied from 13.90 to 22.62 cmol (+) kg^{-1} of soil.The CECper kg clay was higher (>0.25) at the surface horizon in all the pedons. This may be attributed to the higher organic carbon content. The CEC per kg clay was less than 0.25 throughout the solum, indicating the presence of low activity clay. The $BaCl_2$-TEA extractable acidity varied from 9.50 to16.70cmol (+) kg^{-1} soil among the pedons.

Ultisols are the soils that have an argillic or kandic horizon with low base saturation. All the studied pedonsbelonged to the order Ultisols and had ustic soil moisture regime and isohyperthermic soil temperature regime. In a ustic soil moisture regime, when the soil temperature is >22 °C, the soil moisture control section is dry in some or all parts for 90 or more cumulative days in normal years.The pedon P1 was classified as *Ustic Kandihumults* according to the USDA soil taxonomy. At the great group taxon, P3 belongs to *Kandihumults* due to the presence of kandic horizon, absence of root limiting layer within 150 cm of soil and no significant decrease in clay content from the maximum reached in the kandic horizon. At the subgroup level, it belongs to *Ustic Kandihumults* due to the presence of ustic moisture regime. The pedon P2 was classified as *Ustic Haplohumults*. Haplohumults are humults characterised by an argillic horizon and a lithic contact within 150 cm of the mineral soil surface, or with a clay decrease of 20 per cent or more with increasing depth. The pedon P3 was classified as *Ustic Palehumults*. They have an argillic horizon (no kandic horizon), more than 0.9 per cent organic carbon in the upper 15 cm of the argillic horizon and a clay distribution in which the percentage of clay does not decrease from its maximum by as much as 20 per cent within a depth of 150 cm from the mineral soil surface. They do not have any root limiting layer within the same depth interval.

Table 3: Chemical characteristics of soils

Depth (cm)	OC (%)	pH 1:2.5 H_2O	Exchangeable bases					Extractable acidity			CEC			Base saturation (%)		Ratio CEC/ Clay
			Ca	Mg	K	Na	Total	$BaCl_2$-TEA	1.0 *N* KCl H^+	1.0 *N* KCl Al^{3+}	NH_4OAc (pH 7.0)	Sum of cations[1]	ECEC[2]	CEC[3] rn. 7.0	CEC[4] 8.2	
			cmol (+) kg^{-1} soil													
Pedon 1: Chikmagalur: Clayey, Kaolinitic, isohyperthermic Ustic Kandihumults																
0-11	2.40	6.2	7.77	2.21	0.33	0.04	10.35	9.50	0.30	0.00	10.44	19.85	10.35	99	52	0.40
11-31	1.63	6.2	5.79	2.19	0.39	0.04	8.41	9.00	0.35	0.00	8.55	17.41	8.41	98	48	0.30
31-54	1.00	6.1	2.63	2.41	0.47	0.02	5.53	5.50	0.35	0.00	5.85	11.03	5.53	95	50	0.17
54-86	0.36	5.9	1.73	0.59	0.44	0.04	2.80	4.00	0.18	0.00	4.07	6.80	2.80	69	41	0.11
86-123	0.30	6.1	2.13	0.68	0.39	0.04	3.23	5.50	0.23	0.00	4.07	8.73	3.23	79	37	0.11
123-156	0.26	6.4	2.15	0.83	0.27	0.07	3.32	13.50	0.43	0.00	4.95	16.82	3.32	67	20	0.13
Pedon 2: Wayanad: Clayey, kaolinitic, isohyperthermic Ustic Haplohumults																
0-20	2.44	5.5	3.55	0.50	0.32	0.04	4.40	9.50	0.29	0.58	14.36	13.90	4.97	31	32	0.34
20-52	1.96	5.4	2.33	0.41	0.19	0.07	3.00	7.35	0.27	0.95	11.74	10.35	3.95	26	29	0.22
52-84	1.52	5.1	1.88	0.27	0.12	0.05	2.32	13.50	0.29	2.38	9.85	15.82	4.70	24	15	0.19
84-120	1.07	5.0	1.70	0.23	0.12	0.05	1.24	17.50	0.26	1.93	7.95	18.74	3.17	16	7	0.16
120-160	0.67	5.2	1.43	0.46	0.11	0.05	2.05	10.00	0.22	0.48	7.95	12.05	2.52	26	17	0.19
Pedon 3: Idukki: Clayey, kaolinitic, isohyperthermic Ustic Palehumults																
0-20	2.54	5.1	4.13	1.37	0.26	0.16	5.92	16.70	0.42	0.43	13.13	22.62	6.34	45	26	0.34
20-51	1.16	5.0	1.67	0.72	0.17	0.03	2.58	15.20	0.43	1.85	9.51	17.78	4.43	27	15	0.20
51-83	0.90	5.2	2.48	1.42	0.10	0.03	4.03	16.70	0.40	0.78	10.58	20.73	4.81	38	19	0.21
83-122	0.81	5.5	3.43	1.76	0.10	0.03	5.32	15.70	0.22	0.43	10.58	21.02	5.75	50	25	0.17
122-140	0.59	5.4	1.64	1.10	0.06	0.05	2.84	13.70	0.29	0.68	8.82	16.54	3.52	32	17	0.16

[1]Summation of total of exchangeable bases plus $BaCl_2$-TEA extractable acidity

[2]Summation of total exchangeable bases plus 1.0 *N* KCl exchangeable Al^{3+}

[3] [Total exchangeable bases /CEC by NH_4OAc] × 100

[4] [Total exchangeable bases /CEC by sum of cations] × 100

Conclusion

The three coffee-growing soils studied from the Western Ghats were deep to very deep, well drained, dark brown to very dark brown, developed over granite gneiss/weathered granite parent material. The soils were sandy clay loam to clay loam in texture and subangular blocky in structure. Soils were slightly to strongly acidic, exhibiting lower pH and more $BaCl_2$ extractable acidity. Soils were rich in organic carbon content, recording slightly higher content in the surface soils. Soils recorded low exchangeable bases and cation exchange capacity, indicating the presence of low-activity clays and thereby kaolinitic mineralogy. *The soils were classified into Ustic Kandihumults, Ustic Palehumults,* and *Ustic Haplohumultsat* the subgroup level in the sequence of development.

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