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Characteristics and Pedogenic Evolution of N E Himalayan Forest Soils

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The morphological and physico-chemical characteristics as also the nature of humic substances of soils of varying altitudes (750–3530 m) of the North-Eastern Himalayan Region under different vegetations were studied. More layer was formed on the forest floor in the upper hills. Clay translocation was apparent in some of the pedons forming argillic subsurface diagnostic horizons. There was a significant translocation of organic matter in some pedons to the intermediate subsurface and the horizon below. The accumulation of exchangeable cations was maximum in the surface soils of all the pedons and decreases more or less down the profile. There was more or less a uniform distribution of Fe^{3+} along the profile. Within the profile, the content of humic acid decreased with depth with a concomitant increase of fulvic acid. The functional groups of humic and fulvic acids although increased with depth their active participation in the mobilization of either Fe or Al was not noticeable. The climatic and vegetational factors in this area seem to favour some kind of podsolization. But neither morphological features of soil nor analyses of soil components give any definite evidence of such a process.

Key Words: Forest soils, North-Eastern Himalayas, Humus constituents, Pedogenic evolution

Introduction

The undisturbed soil on the surface of earth has a characteristic distribution of undecayed and decaying litter and humus. In considering the important effects of organic matter on the pedogenesis of the soil it should be mentioned that soil formation is closely linked with the action of diverse forms of organic substances on the parent rocks. Impact of organic matter in soil development and horizon differentiation becomes more effective when the movement of organic constituents has taken place with sesquioxide constituents. The extent of downward movement will be decided by the amount of organic matter and its decomposed products, active Fe and Al in the weathering zone, *p*H condition imparting adequate chelate stability and also on the contents of electrolytes in the illuvial zone (Bloomfield 1955, 1957, Wright & Schnitzer 1963, Stevenson 1982).

In the North Eastern Himalayan Region on different altitudes, various types of soils under different vegetations have developed. In the lower hills (300–900 m) the main type of forest is *Shorea-Terminalia-Schima* community. In the middle hills (900–1800 m) although the major portion is under plantation of *Cryptomeria japonica*, the main type of forest is *Castanopsis-Quercus-Alcimandra* community while in the upper hills (1800–2700 m) the main type belongs to *Quercus-Acer-Castanopsis* community. In the alpine region (2700–3600 m) the forests comprise of mainly ever-green conifers (*Abies densa*) admixed with some broad leaved species viz., *Rhododendron* sp. and *Betula alnoids* (Banerjee et al. 1984, 1986). The soils under different plant communities thus constitute a unique material for studying the organic

matter constituents, their nature and characteristics and their possible impact on the pedogenesis of soils.

Materials and Methods

Study sites: Six sites were selected in the North-Eastern Himalayan Region (between 87°59′ & 88°53′E and 26°31′ & 27°13′N, figure 1). They are on forested hills having slopes 5 to 12% within altitude range of 750–3530 m. The parent material is derived from gneisses, sandstones and quartzites with sporadic occurrence of mica. Annual precipitation varies from 2700 to 3500 mm and mean annual maximum and minimum temperatures are 16°C and 4°C, respectively.

The morphological characteristics of the six representative soil profiles from upper, middle and lower forested hill slopes were studied (Soil Survey Staff 1966) and horizonwise soil samples collected.

The profile samples were analysed for *p*H, soil separates (pipette method), CEC (ammonium acetate), exchangeable cations, total carbon and nitrogen using methods outlined by Piper (1950) and Jackson (1958).

Soil samples fused with Na_2CO_3 were analysed for Si, Al, Fe, Ca and Mg (Kanehiro & Sherman 1965). Total Na and K were determined flame photometrically after digestion of soil with HF-$HClO_4$ (Pratt 1965).

Total exchangeable acidity was determined in KCl extracts by titrating with NaOH; exchangeable Al was determined from the same solution by titrating with standard HCl (Mclean 1965). Mobile forms of Fe and Al were determined gravimetrically as per the method described by Dhir (1967). Fe^{3+} was determined in Normal NH_4OAC (*p*H 3) extracts (Jackson 1958).

Soil humic matter was extracted with 0.5 N NaOH (Soil : NaOH = 1 : 20 W/V). Humic acid obtained by repeated dissolution and precipitation in alkali and acid systems was purified with dilute solution of HCl-HF (Banerjee & Mukherjee 1975). The humic acid suspension was then dialysed against distilled water and finally electrodialysed. Fulvic acid was converted into Ba-fulvate and dialysed against distilled water. Ash content of humic and fulvic acids was determined by igniting the samples at 750°C for 3 hr. Carbon was determined by dry combustion and nitrogen by mocro-Kjeldahl methods. Humic and fulvic acid carbon was estimated following the method described by Kononova (1966).

Total acidity of humic and fulvic acids was determined by titrating the acids potentiometrically by standard NaOH solution. The carboxyl acidity was determined by adding calcium acetate solution to the acids and titrating the acetic acid liberated with standard alkali (Kononova 1966).

Results and Discussion

The description of the pedons reveal that the mineral soil of Pedon 5 was the deepest and that of pedon 1 the shallowest, it was more or less the same in all other pedons (table 1). The depth of the forest soils was determined by the actual or potential penetration of the roots which varies from a few centimeters to two to three meters. The root distribution in all the pedons was upto the deepest layer. Occasionally, the region of root distribution was sharply delineated by impermeable bed rock, by ground water or by soil layer containing chemical compounds toxic to roots. In other cases the depth of forest soil was neither constant nor definite; it depends upon the inherent ability of tree species and soil organisms to penetrate geologic strate (Wilde 1958). Perhaps this will be the reason for the difference of the soil depth in different pedons under different vegetation communities.

All the pedons had a number of distinct horizons clearly separated by their composition, colour and structure. They could be grouped into surface organic and organomineral horizons, subsurface eluvial and illuvial horizons and deeper subsurface and subsoil horizons.

Organic horizons in Pedons 3, 4 and 5 in the upper hills under *Quercus-Acer-Castanopsis* community consisted of Oi (litter) and Oa (humus) layers. Their relative thickness reflects the rate of decomposition and can be related to the kind of plant debris. The surface humus in Pedon 6 located in the alpine region was mull-like moder type. It is interesting to note the non-existence of litter layer on the surface (Pedon 6) in such a cool climate (altitude 3530 and more than 5 months under snow). This may be attributed to the fact that fungi are the dominant organisms causing decomposition (unpublished data). Moreover, it has been observed that in summer there is a severe biotic interference.

The horizons were not uniformly coloured. There was commonly a gradation in colour from the junction with the A downward and there were accasional bands of darker colour containing higher amount of organic matter (Pedons 2 and 4) which broke up the continuity of the colours. The colour of the surface mineral soils of Pedons 3 and 5 was brighter (table 1) which might be due to the presence of biotite-muscovite minerals (Annon. 1977). Moreover, iron oxides occur in all colours from the yellow at the one extreme to red at the other. Thus many brown soils contain relatively large amounts of iron oxides in addition to organic matter. The surface soil particularly of Pedon 3 contained highest amount of total Fe_2O_3 (table 3). Singhal and Sharma (1985) observed the bright colour of some soils of North-Western Himalayas containing high amount of organic matter.

The structure of most of the horizon samples was granular to weak subangular blocky. A granular structure characterises horizons with higher proportion of fine organic material. The soils of Pedon 6 were

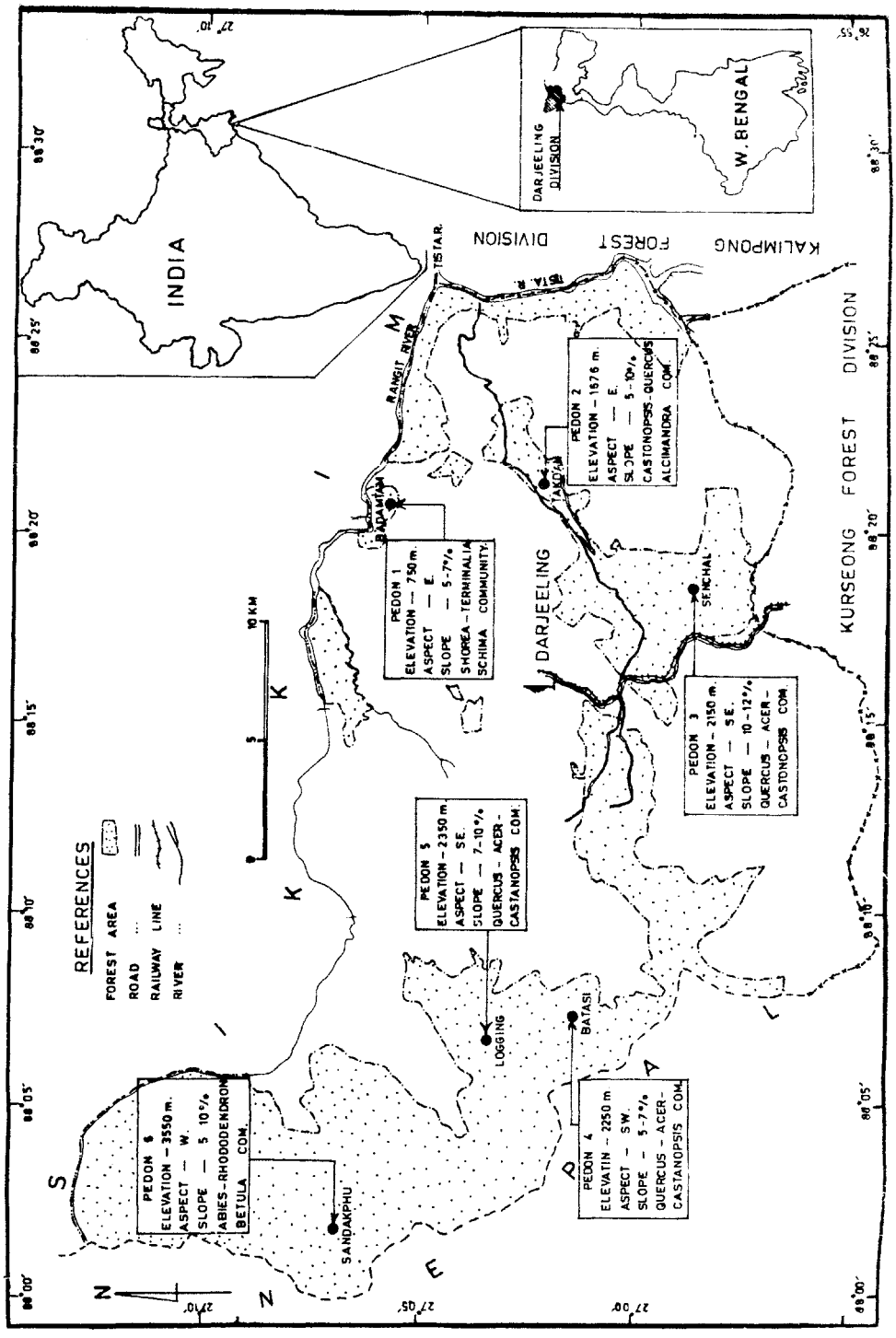

FIG. 1. LOCATION OF PEDONS IN DARJEELING FOREST DIVISION.

Figure 1 Location of pedons in Darjeeling forest division

Table 1 *Morphological characteristics of pedons*

Pedon 1 from eastern slopes of lower hills with 5–7% slope at an elevation of 750m in Badamiam Block, Darjeeling Range and Division.	Pedon 2 from eastern slopes of middle hills with 5–10% slope at an elevation of 1676m in Linding Block, Takdah Range.	Pedon 3 from south-eastern slopes of upper hills with 10–12% slope at an elevation of 2150m in Senchal Range and Block.
A1 (0–4cm) Yellowish brown (10YR 5/6,m) sandy clay loam; moderate medium subangular blocky; hard (dry), friable (moist), sticky (wet); many medium and fine roots; clear way boundary.	**A11 (0–12cm)** Dark yellowish brown (10YR 4/4,m) loam; weak fine subangular blocky; hard (dry), friable (moist), many roots; clear smooth boundary.	**Oi (5–3cm)** Litter comprising leaves and few lichens and mosses.
	A12 (12–25 cm) Very dark greyish brown (10YR 3/2,m) loam; weak fine subangular blocky; loose (dry), friable (moist), many fine mica particles; many roots; gradual smooth boundary.	**Oa (3–0 cm)** Humus layer.
B11 (4–17 cm) Reddish yellow (7.5YR 6/8,m) clay loam; moderate medium subangular blocky; hard (dry), firm (moist), sticky (wet); common medium and fine roots; clear wavy boundary.		**A11 (0–8 cm)** Dark brown (7.5YR 3/4,m) loam; fine granular; very friable (moist), slightly sticky (wet); few fine iron concretions; many roots; clear wavy boundary.
B21t (17–35 cm) Yellowish red (5YR 5/8,m) clay, moderate medium subangular blocky; hard (dry), firm (moist), very sticky (wet); thin dark reddish brown (5YR 3/4) clay skins on peds; few fine and medium roots; clear smooth boundary.	**IIB1 (25–64 cm)** Dark yellowish brown (10YR 4/6,m) clay loam; strong medium subangular blocky; hard (dry), friable (moist), slightly sticky (wet), many fine mica particles; common roots; gradual smooth boundary.	**A12 (8–20 cm)** Yellowish red (5YR 5/6,m) loam; moderate fine subangular blocky; friable (moist), sticky (wet); many fine iron concretions; many roots; clear smooth boundary.
B22t (35–59 cm) Reddish yellow (5YR 6/8,m) clay; moderate medium subangular blocky; hard (dry), firm (moist), very sticky (wet); moderately thick continuous dark reddish browh (5YR 3/4) clay skins on peds; few medium and fine roots; clear smooth boundary.	**IIIB21 (64–82 cm)** Dark yellowish brown (10YR 4/6,m) clay loam; moderate medium subangular blocky; hard (dry), slightly firm (moist), slightly sticky (wet) common fine mica particles; common roots; gradual smooth boundary.	**IIB1 (20–80 cm)** Yellowish brown (10YR 5/6,m) sandy clay loam; moderate medium subangular blocky; friable (moist), sticky and very plastic (wet); few fine iron concretions; many roots; gradual smooth boundary.
B3t (59–100 cm) Reddish yellow (5YR 6/6,m) clay; moderate medium subangular blocky; hard (dry). firm (moist), very sticky (wet); thick continuous clay skins on peds; very few fine roots.	**IV B22 (82–120 cm)** Dark yellowish brown (10YR 4/6,m) clay loam; moderate medium subangular blocky; slightly hard (dry), friable (moist), slightly sticky (wet); few fine iron concretions with few fine mica particles; few roots.	**IIIBC (80–112 cm)** Brownish yellow (10YR 6/6,m) gravelly sandy clay loam; weak fine subangular blocky; friable (moist), sticky and plastic (wet); common fine iron concretions; few roots.

Pedon 4 from south-western slopes of upper hills with 5–7% slopes at an elevation of 2250 m in Batasi Block, Tungloo Range.

Oi (6–2 cm) Litter layer
Oa (2–0 cm) Humus layer

A11 (0–8 cm)

Yellowish brown (10YR 5/4,m) sandy clay loam; moderate medium subangular blocky; very friable (moist), slightly sticky and slightly plastic (wet); abundant roots; many fine crotovenas; clear wavy boundary.

A12 (8–24 cm)

Dark brown (7.5YR 4/2,m) sandy clay loam; moderate medium subangular blocky; friable (moist), slightly sticky and plastic (wet); many roots; few fine crotovenas; clear wavy boundary.

IIB21 (24–34 cm)

Strong brown (7.5YR 4/6,m) loam; moderate fine subangular blocky; friable (moist), slightly sticky and plastic (wet); many roots; gradual smooth boundary.

IIIB22 (34–60 cm)

Strong brown (7.5YR 5/6,m) sandy loam; moderate fine subangular blocky; friable (moist), slightly sticky and plastic (wet); many roots; gradual smooth boundary.

IV B3 (60–115 cm)

Yellowish brown (10YR 5/4,m) sandy clay loam; moderate fine subangular blocky; firm (moist), sticky and plastic (wet); common roots.

Pedon 5 from south-eastern slopes of upper hills with 7–10% slopes at an elevation 2350 m in Kankibong block, Logging Range.

Oi (5–2 cm) Litter layer
Oa (2–0 cm) Humus layer

A11 (0–8 cm)

Dark brown (7.5YR 3/4,m) sandy clay loam; moderate medium subangular blocky; slightly hard (dry), friable (moist); many fine, common medium to coarse roots; clear smooth boundary.

A12 (8–26 cm)

Dark brown (1-YR 4/4,m) sandy loam; weak medium subangular blocky; slightly hard (dry); friable (moist); common fine quartz particles with few iron concretions; many fine and common medium to coarse roots; clear smooth boundary.

II B (26–52 cm)

Dark yellowish brown (10YR 3/6,m) sandy loam; weak medium subangular blocky; friable (moist); many coarse quartz particles with few iron concretions; common roots; gradual smooth boundary.

III C1 (52–126 cm)

Dark yellowish brown (10YR 4/6,m) loamy sand; loose (dry); many fine quartz particles; common roots; clear smooth boundary.

IV C2 (126–145 cm)

Dark yellowish brown (10YR 4/6,m) loamy sand; loose (dry), very friable (moist); few fine quartz particles; few roots; clear smooth boundary.

V C3 (145–163 cm)

Dark yellowish brown (10YR 4/6,m) sandy loam; friable (moist); many fine quartz particles with medium to coarse common; few fine roots.

Pedon 6 from western slopes of upper hills with 5–10% slope at an elevation of 3530 m in Sandakphu Block, Singalila Range.

A1 (0–20 cm)

Very dark brown (10 YR 2/2,m) silt loam; fine granular; very friable (moist), slightly sticky (wet); many fine iron concretions with many fine quartz particles; many roots; clear wavy boundary.

B21t (20–38 cm)

Dark yellowish brown (10YR 3/6,m) clay loam; coarse granular; friable (moist); sticky (wet); discontinuous clay skins on ped surfaces; many fine iron concretions with many fine quartz particles; many roots; clear wavy boundary.

II B22t (38–56 cm)

Dark yellowish brown (10 YR 4/6,m) clay loam; coarse granular; slightly firm (moist), sticky (wet); many distinct clay skins on ped surfaces; many medium to coarse quartz particles with few fine iron concretions; many roots; clear wavy boundary.

III B23t (56–74 cm)

Dark yellowish brown (10YR 4/6,m) clay loam; moderate medium subangular blocky; firm (moist), very sticky (wet); many distinct clay skins on ped surfaces; many medium to fine quartz particles with few iron concretions; few roots; clear wavy boundary.

IV BC (74–120 cm)

Brown (10YR 5/3,m) gravelly sandy loam; single grain; very friable (moist); many medium to coarse quartz particles with many iron concretions; very few roots.

highly melanised. Here, seasonally intense biological activity was sufficient to provide a rapid turnover of organic matter and its admixture with clay to form a fine aggregate structure in the surface and subsurface horizons up to B22t. The disruption of aggregates by the pressure of woody roots may also be contributory to some extent to the formation of granular structure.

The morphological and physico-chemical characteristics of the soils (tables 1 and 2 respectively) display the irregular distribution of organic carbon in some of the Pedons and wide variations in sand to silt ratios with depth in most of the Pedons. Smith and Wilding (1972) suggested the difference of 0.1 or more in the sand to silt ratio between any two adjoining horizons as indicative of lithologic discontinuity. Accordingly such breaks may be observed almost at each horizon boundary in the Pedons of middle and upper hills.

All the Pedon samples were strongly acidic. The ΔpH (difference between pH water and KCl) was fairly wide, suggesting that pH values were not near their zero-point of charge.

Clay content in the surface and intermediate subsurface horizons was highest in Pedon 1. Clay translocation was quite apparent and lessivage was common in lower horizons of Pedons 1 and 6 as evidenced by the presence of the clay skins on the surface of the peds and in the interior of the pores forming argillic subsurface diagnostic horizons. Eswaran and Sys (1979) have pointed out that three sets of processes are involved: dispersion, translocation and accumulation of clay, claiming that only when all the three are optimal, is an argillic horizon formed. In the present case although the factors responsible for the formation of argillic horizons are more or less the same, the non-existence of litter layer in Pedons 1 and 6 permits the percolation of water resulting the illuviation of clay in the deeper horizons which is restricted to other Pedons having a thick mat of litter layer. Except in Pedons 1 and 6 the higher values of clays in some subsurface horizons are not due to translocation but original *in situ*.

Organic matter content was highest in the surface of Pedon 6. It showed decreasing trend in Pedons 1, 3, 5 and 6 and significant translocation in Pedons 2 and 4 to the intermediate subsurface and the horizon below (table 2). The surface soils of Pedons 1 and 2 of lower and middle hills have comparatively lower organic matter (table 2) as compared to Pedons from western and south-western slopes of higher hills. This variation may be due to the altitude and aspect and also to the vegetation community. The plant materials, the chief source of organic matter, generally contain the same groups of substances (waxes, fats, resins, carbohydrates, lignins, proteins etc.). But the proportions of these substances in different plants are extremely variable, which together with the environmental factors materially affect the humification rate and in turn bring about variations in the form, quantity and distribution of organic matter in the soil. Trend of distribution of N followed the pattern similar to that of organic carbon.

CEC bore more or less linear relationship with the distribution trend of clay as well as organic matter. The accumulation of exchangeable cations was maximum in the surface soils of all the pedons and decreased more or less down the profile. Under *Quercus-Acer-Castanopsis* community the content of total exchangeable bases in the surface was highest in Pedon 3 (table 2) followed by Pedon 4 and Pedon 5. But when all the pedons are considered the content of exchangeable bases in the surface of Pedon 1 under *Shorea-Terminalia-Schima* community was the second highest. Pedon 3 had the maximum exchangeable Ca^{2+} at the surface and Pedon 2 the least. Exchangeable Mg^{2+} followed almost the same trend as Ca^{2+}. Depth distribution of Al^{3+} did not follow any definite trend but among the surface soils it was highest in Pedon 3. The contribution of Al to total acidity would be less than the KCl extractable Al would indicate (MClean 1965), and possibly this is the reason for the discrepancy in CEC and exchangeable cations and exchange acidity values in the present study.

There was more or less a uniform distribution of Fe^{3+} along the profiles (table 3), although in some pedons slightly higher values were obtained in the subsurface horizons. This indicates that there is neither translocation of Fe^{3-} nor interaction of iron with organic constituents resulting illuviation and immobilization in the lower layers.

The extracted humic matter (expressed as C per cent), except in Pedon 2 and Pedon 4, was higher in surface horizons irrespective of altitudinal variations (table 5). Within the profile, the total humic matter content as well as humic acid decreased with depth with a concomitant increase in the content of fulvic acid. Perhaps, the brown humic acid fraction (low molecular weight) was leached down and precipitated in the lower horizons of pedons 2 and 4 which needs verification. With a few exceptions, the HA_c/FA_c was less than unity in all the soil samples of all the profiles, which suggests that mobility of fulvic acid tended to predominate. This is a common feature in high altitude forest soils (Nath et al. 1983, Pal et al. 1984). There was no appreciable translocation of humus in these pedons. However, highly acidic condition and high rainfall might have accentuated the mobility of fulvic acid.

The increasing trend of total acidity as well as carboxyl acidity of both humic and fulvic acids with

Table 2 *Physico-chemical characteristics of the soils*

Horizon	Particle size analysis (%)			*p*H (1:2.5)		Organic carbon(1%)	Total N(%)	C.E.C (me/100g)	Exch. bases (me/100g)			
	Sand	Silt	Clay	Water	KCl				Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Pedon 1 (Eastern slopes of lower hill)												
A1	52.4	17.2	30.4	4.5	3.5	2.93	0.265	24.2	6.35	3.70	0.54	0.05
B11	32.5	23.1	44.4	4.6	3.2	1.41	0.136	14.1	3.69	1.85	0.23	0.04
B21t	27.0	26.6	46.4	4.3	2.8	1.00	0.099	12.6	1.87	0.45	0.11	0.02
B22t	13.6	31.6	54.8	4.5	2.8	0.62	0.067	17.7	1.66	0.57	0.20	0.02
B3t	22.2	32.2	45.6	4.8	3.0	0.50	0.052	17.1	1.44	1.00	0.12	0.03
Pedon 2 (Eastern slopes of middle hill)												
A11	51.7	22.7	25.6	3.8	3.0	2.22	0.211	21.6	0.18	0.03	0.24	0.11
A12	62.0	21.0	16.9	3.9	3.0	3.51	0.316	26.4	0.20	0.03	0.41	0.11
IIB1	49.6	22.6	27.8	4.0	3.2	1.53	0.158	20.5	0.11	0.01	0.15	0.09
IIIB21	39.6	30.0	30.4	4.3	3.5	0.93	0.103	17.7	0.08	0.05	0.14	0.07
IV B22	46.6	26.4	27.0	4.5	3.8	0.78	0.084	21.5	0.20	0.04	0.14	0.09
Pedon 3 (South-eastern slopes of upper hills)												
A11	64.8	15.8	19.4	4.2	3.4	7.21	0.514	35.2	10.70	5.00	0.47	0.17
A12	51.9	31.2	16.9	4.0	3.1	3.63	0.302	26.3	0.70	0.50	0.18	0.10
IIB1	64.7	13.4	21.9	4.6	3.5	1.13	0.115	15.7	0.80	0.50	0.12	0.14
III Bc	58.5	19.3	22.2	5.1	4.1	0.26	0.028	11.5	0.40	0.40	0.13	0.10
Pedon 4 (South-Western slopes of upper hills)												
A11	54.0	23.2	22.8	4.2	3.5	2.64	0.221	17.7	3.25	0.44	0.31	0.09
A12	48.0	28.8	23.2	4.5	3.5	4.65	0.391	24.4	2.76	0.49	0.43	0.19
IIB 21	39.2	49.2	11.6	4.0	3.7	2.70	0.249	18.5	1.34	0.35	0.23	0.10
IIIB 22	72.8	13.6	13.6	4.0	3.6	1.92	0.198	16.3	1.11	1.12	0.27	0.17
IV B3	55.2	23.6	21.2	4.2	3.7	1.08	0.124	12.9	1.25	0.16	0.27	0.29
Pedon 5 (South-eastern slopes of upper hills)												
A11	46.0	27.2	26.8	4.5	3.6	6.52	0.452	32.1	2.26	0.76	0.51	0.04
A12	54.4	27.2	18.4	4.0	3.4	4.14	0.296	25.2	0.68	0.11	0.23	0.03
IIB	69.5	20.0	10.4	4.0	3.9	3.64	0.273	22.9	0.19	0.11	0.9	0.04
IIC1	82.4	12.4	5.2	4.4	3.9	1.67	0.152	15.9	0.38	0.14	0.09	0.06
IV C2	74.8	18.4	6.8	4.6	3.7	2.02	0.096	18.2	0.95	0.52	0.10	0.10
VC3	62.4	20.2	17.2	4.5	3.6	0.83	0.082	20.3	1.15	0.35	0.16	0.07
Pedon 6 (Western slopes of upper hills)												
A1	42.6	35.8	21.6	3.9	3.1	8.33	0.325	38.4	0.93	0.45	1.02	0.02
B21t	44.0	25.8	30.2	3.8	2.9	5.39	0.318	27.8	0.45	0.33	1.06	0.02
IIB22t	48.9	21.5	29.6	4.2	3.0	3.07	0.217	18.7	0.37	0.25	1.01	0.01
IIIB23t	56.4	12.8	30.8	4.7	3.9	1.16	0.098	10.7	0.33	0.17	0.98	0.02
IVBC	78.7	8.5	12.8	5.3	4.5	0.28	0.037	7.8	0.37	0.10	0.82	0.03

Table 3 *Chemical characteristics of the soils*

Horizon	Mobile form (%)		Exch. cations (me/100g)			Total (%)						
	Fe_2O_3	Al_2O_3	H^+	Al^{3+}	Fe^{3+}	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
					Pedon 1 (Eastern slopes of lower hills)							
A1	0.189	2.712	1.24	1.24	0.65	68.6	4.82	19.68	0.54	0.41	1.71	0.05
B11	0.194	2.694	1.24	2.89	0.75	66.2	2.32	23.93	0.85	0.34	1.78	0.06
B21t	0.166	2.669	1.03	3.72	0.51	67.2	2.86	20.39	0.57	0.47	1.82	0.06
B22t	0.177	2.657	1.45	3.10	0.49	64.1	1.70	22.75	0.50	0.37	1.21	0.03
B3t	0.186	2.355	1.24	3.10	0.58	71.2	7.05	10.78	0.26	0.24	1.01	0.03
					Pedon 2 (Eastern slopes of middle hills)							
A11	0.885	3.283	n.d.	n.d.	1.51	62.4	6.25	13.26	0.07	0.19	0.84	0.07
A12	0.743	3.077	„	„	1.42	62.3	5.44	7.83	0.05	0.09	0.70	0.06
IIB1	0.878	5.330	„	„	1.65	59.4	7.12	10.35	0.02	0.26	0.69	0.06
IIIB21	0.764	3.864	„	„	1.62	56.2	7.28	12.27	0.05	0.42	0.82	0.08
IVB22	0.671	3.417	„	„	1.85	58.9	9.00	13.00	0.05	0.40	0.87	0.06
					Pedon 3 (South-eastern slopes of upper hills)							
A11	0.700	3.210	1.45	10.13	1.72	61.5	8.07	12.45	0.60	0.31	1.05	n.d.
A12	1.080	4.810	0.93	9.71	2.02	59.7	10.86	15.04	1.00	0.33	1.25	„
IIB1	0.640	4.810	0.56	11.65	1.95	61.8	10.59	17.31	1.50	0.41	1.54	„
IIBC	0.450	1.920	0.72	2.62	1.62	64.5	9.47	17.55	1.47	0.43	1.58	„
					Pedon 4 (South-western slopes of upper hills)							
A11	0.429	0.379	0.95	2.67	1.45	62.1	6.70	16.12	0.61	0.62	1.67	0.02
A12	0.471	2.049	1.19	3.44	1.32	59.2	6.43	13.90	0.82	0.46	1.74	0.13
IIB21	0.514	0.926	1.05	4.58	1.38	59.4	6.61	13.64	0.80	0.74	1.61	0.13
IIIB22	0.547	1.875	1.04	4.39	1.62	61.7	6.79	24.77	1.10	0.83	1.70	0.13
IVB3	0.243	1.193	0.60	3.63	1.52	61.8	6.69	19.50	0.80	0.57	1.32	0.02
					Pedon 5 (South-eastern slopes of upper hills)							
A11	0.529	0.871	1.51	1.91	1.40	54.9	5.27	13.31	0.61	0.51	1.23	0.17
A12	0.821	0.539	1.34	6.30	1.72	57.7	6.25	15.52	0.74	0.62	1.67	0.13
IIB	0.843	4.431	0.98	3.25	1.88	52.9	5.80	22.03	0.59	0.30	1.29	0.13
IIIC1	0.857	1.283	0.37	3.25	1.82	58.7	6.61	20.12	0.87	0.49	1.25	0.12
IVC2	0.757	0.563	1.02	4.01	1.60	57.1	6.61	19.55	0.99	0.69	1.25	0.10
VC3	0.571	0.549	0.66	4.77	1.18	59.9	6.43	19.72	1.50	1.54	0.12	
					Pedon 6 (Western slopes of upper hills)							
A1	0.886	1.286	1.68	8.27	1.65	57.2	5.63	24.37	0.50	0.28	.07	0.09
B21t	0.629	1.553	0.62	9.99	1.42	62.6	6.96	20.29	0.67	0.53	1.10	0.13
IIB22t	0.571	1.373	0.41	6.72	1.08	62.1	6.96	17.54	0.96	0.64	1.13	0.10
IIIB23t	0.557	1.077	0.52	3.96	0.94	72.2	6.34	17.76	0.16	1.02	1.22	0.08
IVBC	0.186	1.422	0.25	2.07	0.28	71.6	5.35	20.52	0.50	1.14	1.38	0.08

Table 4 *Characteristics of humic and fulvic acids (oven dry basis of selected horizons*

Horizon	Ash (%)		Acidity (me/100g)*						Total C(%)		Total N(%)	
			HA			FA						
	HA	FA	Total	Carboxyl	Phenolic	Total	Carboxyl	Phenolic	HA	FA	HA	FA
Pedon 1 Eastern slopes of lower hills)												
A1	3.1	14.2	5.95	2.25	3.70	6.45	3.95	2.50	54.6	46.1	3.8	2.6
B21t	3.2	11.5	5.80	2.35	3.45	6.65	4.15	2.50	55.2	45.8	4.1	2.8
B3t	2.7	11.7	6.20	2.85	3.35	7.00	4.65	2.35	55.8	44.3	4.2	2.1
Pedon 2 (Eastern slopes of middle hills)												
A11	2.6	15.3	5.60	2.45	3.15	6.65	3.85	2.80	55.2	44.8	4.3	2.8
IIB1	2.7	14.1	5.75	2.40	3.35	6.70	3.80	2.90	55.4	45.3	4.1	2.9
IVB22	2.1	12.6	6.25	2.70	3.55	7.15	4.05	3.10	54.9	44.9	4.2	2.4
Pedon 3 (South-eastern slopes of upper hills)												
A11	3.7	15.6	2.80	1.10	1.70	6.25	3.55	2.70	54.8	46.2	3.9	2.1
IIB1	2.9	12.3	2.85	1.25	1.60	6.85	3.80	3.05	55.1	45.2	3.3	1.6
IIIBC	3.1	12.9	3.10	1.20	1.90	7.25	3.95	3.30	55.6	44.1	2.9	1.7
Pedon 4 (South-western slopes of upper hills)												
A11	4.0	12.8	3.80	1.65	2.15	6.95	3.75	3.20	55.4	46.8	3.4	2.1
IIB21	3.3	10.1	4.10	1.80	2.30	7.15	4.00	3.15	55.3	46.2	3.2	1.8
IVB3	3.1	9.6	4.75	2.10	2.65	7.65	4.30	3.35	55.8	44.2	3.3	1.5
Pedon 5 (South-eastern slopes of upper hills)												
A11	3.2	10.3	4.25	2.00	2.25	7.23	4.15	3.08	55.4	45.3	3.2	2.3
IIB	2.3	11.6	4.83	2.50	2.33	7.35	4.20	3.15	55.6	44.6	3.0	1.8
IVC2	2.4	10.9	5.10	2.65	2.45	7.66	4.10	3.56	55.8	45.1	2.6	1.9
Pedon 6 (Western slopes of upper hills)												
A1	3.1	14.2	3.65	1.45	2.20	6.35	3.35	3.00	55.3	46.6	4.3	2.8
IIB22t	2.9	9.5	3.80	1.60	2.20	6.10	3.00	3.10	55.6	44.2	4.0	2.2
IIIB23t	3.4	10.2	4.15	1.75	2.40	6.35	3.00	3.35	55.8	45.3	3.3	2.3
IVBC	22.	11.1	4.20	1.85	2.35	6.95	3.65	3.30	56.1	44 3	3.6	1.6

* Ash free basis

Table 5 *Content and composition of humus in soils*

Horizon	Humus carbon (%)	Humic acid carbon (%) (H A C)	Fulvic acid carbon (%) (F A C)	HA_C/FA_C
		Pedon 1		
A1	1.43	0.50 (34.96)*	0.93 (65.03)**	0.53
B11	1.10	0.43 (39.09)	0.67 (60.90)	0.64
B21t	0.50	0.20 (40.00)	0.30 (60.00)	0.66
B22t	0.23	0.10 (43.48)	0.13 (56.52)	0.77
B3t	0.15	0.06 (40.00)	0.09 (60.00)	0.66
		Pedon 2		
A11	1.00	0.29 (29.00)	0.72 (72.00)	0.40
A12	1.52	0.39 (25.66)	1.13 (74.34)	0.35
IIB1	1.26	0.19 (15.08)	1.03 (81.74)	0.18
IIIB21	0.75	0.20 (26.67)	0.55 (73.33)	0.36
IVB22	0.55	0.21 (38.18)	0.35 (63.63)	0.64
		Pedon 3		
A11	3.06	1.28 (41.83)	1.78 (58.17)	0.72
A12	1.95	0.68 (34.87)	1.27 (65.13)	0.65
IIB1	0.63	0.36 (57.14)	0.27 (42.86)	1.33
IIIBC	0.24	0.05 (20.83)	0.19 (79.17)	0.26
		Pedon 4		
A11	1.36	0.24 (17.64)	1.12 (82.35)	0.22
A12	2.12	0.39 (18.39)	1.73 (81.60)	0.23
IIB21	1.80	0.30 (16.67)	1.50 (83.33)	0.20
IIIB22	1.30	0.20 (15.38)	1.11 (85.38)	0.18
IVB3	0.45	0.09 (20.00)	0.36 (80.00)	0.25
		Pedon 5		
A11	3.67	0.94 (25.61)	2.72 (74.11)	0.34
A12	2.27	0.48 (21.14)	1.79 (78.85)	0.27
IIB	2.48	0.48 (19.35)	2.01 (81.04)	0.24
$IIIC^1$	1.12	0.21 (18.75)	0.91 (81.25)	0.23
IVC_2	0.75	0.20 (28.66)	0.53 (70.67)	0.27
VC_3	0.48	0.05 (10.41)	0.43 (89.58)	0.11
		Pedon 6		
A1	4.44	1.88 (42.34)	2.56 (57.65)	0.73
B21t	3.95	1.44 (36.45)	1.61 (40.75)	0.89
IIB22t	1.94	0.85 (43.81)	1.09 (56.18)	0.78
IIIB23t	0.85	0.30 (35.29)	0.55 (64.70)	0.55
IVBC	0.26	0.09 (34.61)	0.17 (65.38)	0.47

Note: The values in parenthesis indicate HAC and FAC as per cent of total humus carbon

depth obtained in this study (table 4) suggests that low molecular weight fractions of humic and fulvic acids increase with depth (Mukhopadhyay & Banerjee 1985). It indicates that the functional groups of humic and fulvic acids although increase with depth, their active participation in the mobilization of either Fe or Al is not noticeable. No marked variation was observed in the contents of elemental C and N.

Under the prevailing high rainfall and cool climate there was sizeable accumulation of organic matter in the surface horizons, particularly in high hills, and as a consequence of strong acid reaction under these conditions, it is expected that there should be a considerable release of Al and Fe from soil minerals and their interaction with the reactive constituents of humic matter. Contrary to expectation, the soil profiles studied showed no translocation either of Al or Fe as there was more or less uniform distribution of mobile forms of Fe_2O_3 and Al_2O_3 in different horizons of a soil profile. Both silica and sesquioxide contents increased regularly with depth (table 3), particularly in pedons from high hills. This type of soluviation of the sesquioxides though not fully cheluviation, subscribes to the concept of early workers in the North-Western Himalayas (Tamhane & Lote 1955) who preferred to classify these soils as podsols.

The climatic and vegetation factors of the NE Himalayan Region covered by this study seem to favour faint or mild podsolization. However, complete absence of any morphological evidence and more or less uniform distribution of mechanical soil separates, mild mull-like moder layer, distribution of exchangeable cations along the profile and presence of large quantity of mobile sesquioxide and Fe^{3+} in the horizons preclude the occurrence of podsolization. Steep slopes prevent the parent material from interacting with soil forming factors for a sufficiently long time for podsolization to occur. Instead of vertical percolation most of the precipitation is lost as surface run off. Thus, the soils of North-Eastern Himalayan Ranges developed under the climate and vegetation influences as that of podsol, have a unique combination of properties.

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