Discussion on the Garhwal Himalaya Pedogenesis

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Abstract : *Ten soil profiles occurring on 3350-4200 m altitude in a catena of Garhwal Himalaya, Uttar Pradesh were studied. The soils at the highest latitude (3950-4200 m) are classified as Leptosols and Regosols; at the middle (3550-3775 m) as Cambisols; and at the lowest (3350-3390 m) as Podzols. Their physico-chemical properties, soil forming processes and classification are described.*

The scientific information of the soils ocurring on Garhwal Himalayas of Uttar Pradesh is very limited. It is, therefore, pertinent to study these soils for their fundamental properties, such as pedogenesis, classification, and other related physico-chemical behaviour in order to develop sustainable land use plan.

MATERIALS AND METHODS

Ten soil profiles at an altitude of 3350-4200 m were studied in Garhwal Himalaya, Uttar Pradesh, located between N. Latitude 30°50' to 30°54' and E.longitude 78°44' to 78°50'. The area is drained by the Din Gad river a tributory of the river Bhagirathi.

The relief is a typical glacial alpine with morainal deposits of different age. The well drained parent materials (weathering products of gneiss-schist) has facilitated the leaching of entire carbonates and development of acidity in the profile. At 3950-4200 m altitude, the bottom soil horizon (25-33 cm depth) has traces of carbonates. A common characteristic of the soil forming processes in this region is taking place under strong and very strong acid conditions and under lateral rather than vertical substance movement. But it is possible for a 'presoil' partluvation* to have taken place, resulting in a 'preliminary' profile texture differentiation.

RESULTS AND DISCUSSION

Soils in the region are grouped into three categories.

Soils on 3550-3775 m Altitude Zone

Soil profiles characterizing 3550-3775 m altitude zone are formed on lateral moraines as follows: GH-3/20 (at 3775 m), GH-1 (at 3700 m) and GH-10 (at 3625 m) under herbaceous vegetation

* Migration of silt-clay suspension

TABLE 1. Texture and some chemical properties

Depth (cm)	Size distribution particles (mm) %									humus %	Total N %	C N	pH KCl.	pH H_2O	Total P %
	loss > (%)	1	1-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	0.001	0.01						
GH-3/20															
0-4	3.2	0.0	14.2	36.3	28.7	8.5	2.3	1.8	22.6	11.58	0.660	10.18	4.15	4.65	0.427
4-16	2.2	0.0	19.5	24.6	24.5	12.1	6.2	10.8	29.1	6.69	0.365	10.61	3.75	4.30	0.308
16-30	3.6	11.7	45.9	14.1	10.5	4.3	2.9	7.0	14.2	3.39	0.142	13.85	4.10	4.50	
30-55	3.7	0.0	48.9	24.4	10.9	3.2	2.5	6.4	12.1	2.11	0.068	18.00	4.20	4.60	
GH-4/21															
0-6	3.1	0.0	4.4	46.5	25.8	6.9	2.7	10.6	20.2	13.95	0.830	9.75	4.05	4.40	0.462
6-21	2.9	0.0	13.1	48.5	14.6	8.3	3.9	8.7	20.9	8.43	0.673	7.26	3.90	4.30	0.398
21-38	1.2	11.2	24.1	35.2	15.5	4.5	3.3	5.0	12.8	2.05	0.111	10.71	4.15	4.50	
38-50	2.5	16.4	44.2	20.5	9.4	2.5	0.9	3.6	7.0	1.15	0.048	12.08	4.20	4.50	
GH-6/22															
0-7	3.6	0.0	6.0	47.5	21.3	6.8	2.8	12.0	21.6	18.65	0.672	16.10	4.20	4.70	0.247
7-16	3.0	0.0	8.8	19.1	27.1	15.0	12.3	14.7	42.0	8.96	0.326	15.94	3.30	4.05	
16-42	2.5	0.0	12.7	43.6	17.0	5.0	3.9	15.3	24.2	10.79	0.275	22.76	3.85	4.10	
42-60	6.1	0.0	0.6	48.9	23.1	6.8	3.1	11.4	21.3	4.61	0.173	15.45	4.05	4.35	

TABLE 2. Iron Groups

Depth (cm)	Total (%)	Free (Mehra-Jackson)		Combined		Amorphous Tamm		Crystalline			Comb.e Amor. Fe		Fe (elem	
		1*	2	1	2	1	2	1	2		Free Fe	Crystal Fe		Organic C
GH-3 20														
0-4	6.61	2.24	33.89	4.37	66.11	1.30	19.67	0.94	14.22		1.95	1.38		0.21
4-16	6.39	2.71	42.41	3.68	57.59	2.23	34.90	0.48	7.51		1.36	4.65		0.46
16-30	5.71	2.11	36.95	3.60	63.05	1.31	22.94	0.80	14.01		1.71	1.64		0.72
30-55	5.53	1.83	33.09	3.70	66.91	1.02	18.44	0.81	14.65		2.02	1.26		1.03
GH-4 21														
0-6	6.41	3.11	48.52	3.30	51.48	1.94	30.27	1.17	18.25		1.06	1.67		0.23
6-21	8.18	3.52	43.03	4.66	56.97	2.90	35.45	0.62	7.58		1.32	4.68		0.46
21-38	5.32	2.02	87.97	3.30	62.03	1.33	25.00	0.69	12.97		1.63	1.93		1.16
38-50	4.34	1.46	33.64	2.88	66.36	0.83	19.12	0.63	14.52		1.97	1.32		1.50
GH-6 22														
0-7	4.04	2.02	50.00	2.02	50.00	1.46	35.89	0.57	14.11		1.00	2.54		0.11
7-16	5.03	2.43	48.31	2.60	51.69	2.16	42.74	0.28	5.57		1.07	7.68		0.30
16-42	9.94	7.22	72.64	2.72	27.36	7.22	72.64	0.00	0.00		0.38	--		0.72
42-60	5.52	1.78	32.25	3.74	67.75	1.30	23.55	0.48	8.70		2.10	2.71		0.45

*1 - % of tempered (at 900° C) soil; 2 - % of total Fe_2O_3

and GH-4/21 (at 3550 m) under transition from herbaceous to forest vegetation. The general description of these profiles is as follows:

GH-3/20; Ad** - Ab - a/bCF - CD;

GH-1 : Ad - Ab - a/bCf - CD;

GH-10; Ad - AB - a/bCf - CD; and

GH-4/21; Ad - AB (a)/BCf - CD

The top horizon Ad is 4-6 cm thick with dry colours of 10 YR 3/2, 5 and 3/3; crumb structure, weak degree of aggregation and 30-70 per cent roots. The next Ab or AB horizon is 12-25 cm thick, 10 Y 4/3, 5, 2 and 4, 5/4, medium crumb structure, moderate degree of aggregation and 20-50 per cent of roots. The next (with common symbol a/bCf) horizon is 14-27 cm thick, 10 YR 5/4 and 5, 5/6 of colour, structureless, gravelly with 5-10 per cent of roots. The bottom horizon (CD) has 10 YR, 5/4 and 6/5 colour and with 40-50 per cent coarse and fine gravel. The whole thickness of the profile is 30-40 cm. There are mica particles throughout, decreasing with depth. The profile is of loamy sand texture (Table 1). The clay content decreases gradually with depth, but the medium and the fine silt fractions (0.10 - 0.005 mm and 0.005 - 0.001 mm) have their maxima in the second horizon, i.e. there is differentiation due to ("presoil" and/or as a result of the pedogenesis) partluvation. Free and amorphous iron content of the second horizon show highest values (Table 2). It seems that there exists a mutual relationship in this horizon between the medium and fine silt fractions and the free and amorphous iron which is a result of weathering and pedogenesis and is morphologically manifested in the change of colour, structure, consistence, etc. Therefore it may be assumed that these soils have a cambic horizon in their profiles. The crystalline iron is always less than the amorphous one, and the combined iron-always more than the free one.

The organic matter content of the soil profile decreases gradually with depth (Table 1, 2, 4). During the growing season the organic matter mineralization and humification pass under relatively high biological activity conditions (C/N being 9.8-10.2 for the top horizon). The humus is oligothrophous mull and changes with depth to mull moder (GH-4/21) and moder (GH-4/20), which is obviously related to the altitude. The content of total nitrogen corresponds to the humus content. The pH values are low and very low in the top horizon, and increase slightly with depth, but still remain low. The contents of both the forms of aluminium increase with depth in GH-3/20, but in the lower (with regard to altitude) profile they accumulate slightly in the middle part of the profile. This difference in distribution of the aluminium is probably related to altitude. At the lower altitude, there are better expressions of weathering processes and the formation cambic horizon. This also explains the fact that

** Mineral humus accumulative horizon formed under herbaceous (esp. meadow) vegetation and containing at least 50 per cent (by volume) of live roots

TABLE 3. Aluminium and manganese content

Depth (cm)	Aluminium (%)					Manganese (mg/kg)				
	Total	Mehra-Jackson		Tamm		Total	Mehra-Jackson		Tamm	
		1*	2	1			1	2	1	2
GH-3/20										
0-4	13.30	0.58	4.36	0.68	5.11	984	599	60.87	534	54.27
4-16	12.09	0.85	7.03	0.88	7.28	547	331	60.51	172	31.44
16-30	10.15	1.11	10.94	1.19	11.72	511	112	36.01	73	23.47
30-55	10.32	1.22	11.82	1.19	11.53	317	131	41.32	106	33.44
GH-4/21										
0-6	8.94	0.91	10.18	0.70	7.83	395	267	67.59	203	51.39
6-21	10.94	1.02	9.32	0.91	8.32	699	546	78.11	355	50.79
21-38	10.34	0.98	9.48	0.78	7.54	439	121	27.56	71	16.17
38-50	9.82	0.66	6.72	0.62	6.31	344	166	33.72	72	20.93
GH-6/22										
0-7	8.95	0.75	8.38	0.87	9.72	265	234	88.30	173	65.28
7-16	11.03	0.68	6.17	0.76	6.89	224	75	33.48	22	9.82
16-42	4.48	3.65	81.47	4.26	95.10	228	144	63.16	80	35.09
42-60	8.12	2.75	33.87	2.89	35.59	387	367	94.83	319	82.43

*1 (% of tempered at 900° C),2- (% of total content).

the colour of third horizon of GH-4/21 is lighter and brighter than the same one of GH-3/20. It seems that in the two bottom horizons of these soil profiles the reduction conditions occur periodically, which determine the better manganese solubility and mobility. Because of this the total manganese content and its degree of extraction according to the Mehra-Jackson's method is lower (Table 3). According to the FAO (1986) these soils may be referred to as Umbric Cambisols.

Soils on 3950-4200 m Altitude Zone

It is characterised by the GH-8 (4200 m) and GH-2 (3950 m) profiles formed on lateral moraines, under herbaceous vegetation. The general description of these profiles is as follows:

GH-8: Ad - aCF - a/Cd - Cd;

GH-2: Ad - (a) CF- cD

They are relatively shallow (10-26 cm). The colour (moist) of the soil is 10 YR 3/4 and 4/2 with humus content of 5.5-6.4 per cent at upper horizon and decreases abruptly reaching minimum values of 0.2-0.7 per cent in the bottom horizon. The total nitrogen content is also least. The pH values are low and very low, but increase gradually with the depth and attaining carbonates 0.5-0.8 per cent at CD horizon. The humus is of oligotrophous mull-moder type, where there are no carbonates.

These soils have no cambic horizon in their profiles. According to the FAO (1986) GH-2 soil is Eutric Leptosol and

TABLE 4. Chemical Properties

Profile	Depth (cm)	Humus (%)	Total N (%)	C/N ratio	pH KCl	pH H_2O
GH-8	0-8	5.52	not det.		3.7	4.6
	8-16	1.82	"		3.8	4.8
	16-26	1.51	"		4.0	4.9
	26-33	0.20	"		6.0	7.1
GH-2	0-3	0.39	0.270	13.73	4.3	5.2
	3-10	1.30	0.064	11.78	4.4	5.5
	10-25	0.72	0.038	10.99	5.7	6.7
GH-1	0-5	16.40	not det.		3.8	4.4
	5-30	10.70	"		3.7	4.2
	30-45	5.11	"		4.1	4.5
GH-10	0-6	14.15	"		3.9	4.5
	6-18	8.46	"		3.7	4.3
	18-45	3.86	"		4.2	4.7
	45-55	2.14	"		4.3	4.7
GH-9	0-8	18.00	0.778	13.42	4.3	4.7
	8-18	5.03	0.196	14.89	3.7	4.5
	18-33	6.09	0.134	26.36	4.1	4.6
	33-57	5.37	0.138	22.57	4.3	4.6

that of GH-8 is Eutric Regosol. They have been called Eutric because of the lack of carbonates in the parent rock. However, due to acidic and strong acidic conditions they may be referred to as Umbric Leptosols and Dystric Regosols.

Soils on 3350-3900 m Altitude Zone

It is characterizied by GH-6/22 (3390 m) and GH-9 (3350 m) profiles formed on lateral moraines, under forest vegetation. The profile descriptions of GH-6/22 are given in Table 5. These soils have textural differentiation not only in the clay fraction but also in the three silt fractions (0.05-0.01 mm, 0.01-0.005 mm, and 0.005-0.001 mm). In the second horizon. In the third horizon the clay content is slightly higher. The free and amorphous iron contents (Table 1 and 2) increase in the second horizon (there is slight ferrification correlating with the above mentioned texturtal differentiation. They increase abruptly in the third horizon and decrease again considerably in the bC horizon. In the first two horizons the free and the combined iron contents are approximately equal, the crystalline iron being only 6-14 per cent of the total iron. In the third (Bhfe) horizon the free iron sharply prevails over the combined one

TABLE 5. Profile description of GH-6 22

Horizon	Depth (cm)	Gley mottles	Colour	Moisture conditions	Density	Texture	Structure	Roots (%)	Mica particles
Ao/Ad	0-7	None	10YR 4/2	Fresh	Slightly dense	Sandy loam	fine, subangular	50-60	Many
A(g)	7-16	Few 7.5 YR 5/6	10YR 4/4	Slightly moist	Dense	Silt loam	Medium subangular	30	Many
Bhfe	16-42	Very few 7.5 YR 5/7	5YR 4/7	Slightly moist	Very dense	Sandy loam	Fine subangular	15-20	Few
bC	42-60	None	10YR 7/4	Fresh	Very dense	Sandy loam	Structure-less	2-3	Very few (rare)

Note: All horizons contain rare fine gravel; they do not effervesce with 10% HCl and have a clear smooth boundary. Below 60 cm. cracked gneiss-schist show up

(ratio=0.38); the total free iron being amorphous. It may be asserted that both forms of aluminium (Table 3) have an eluvial-illuvial profile distribution. It has high aluminium content in the fourth horizon (as commonly, aluminium "outstrips' iron in their downward movement). The low values of the two manganese forms atleast to very weakly and a weakly expressed gleying process in the second and partially in the third horizon (Table 3).

The humus is of moder type and has also a eluvial-illuvial profile distribution. It is higher (18-19 per cent) in the top, decreases in the second and increases again in the third horizon (Tables 1, 4). The C/N ratio is highest in the third horizon. The total nitrogen content decreases with depth. The pH values are low in the top horizon, become very low in the second one and then rise slightly with depth. These soils have an almost two times less total phosporous than the others. According to FAO (1986) they are Cambic Podzols (without A2 and extractable free Fe. The Fe-organic carbon ratio is 0.7 in third horizon. They have elements of Stagni-Gleyic Podzols (because of the very slightly expressed hydromorphous conditions). Although the morphologic and the analytical characteristics do not express their "layered" nature, the primary neteorogeneity of the parent materials as well as the probable "presoil" partluvation, may have some influence on the podzol process - mainly by making it still more sharply expressed.

CONCLUSION

It may provisionally be assumed that the investigated soils form a catena in which three soil groups may be distinguished. The soils at the highest altitude are grouped as Leptosols and Regosols; at the middle as Cambisols

and at the lowest as Podzols. Our analytical results and the taxonomic references for the first two of the above mentioned groups entirely coincide with the former soil investigations in the regions (Anonymous, 1977; Murthy and Pandey, 1987). We hope that the Podzols whose presence in the "bottom" part of the Cambisol zone is expected and will find their place among the "inclusions" in case of their distribution in patches or in strips. The spodic horizon in the Himalaya 2500-4000 m altitude zone was reported by Dobrovolskii and Guerassimova, (1989). Another significant finding is that the altitude boundary between the Leptosols and Regosols on one side and the Cambisols on the other is (for the investigated region) found to be between 3775 and 3950 m above sea level.

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