SINET: Ethiop. J. Sci., 23(1):35–51, 2000

ISSN: 0379–2897

CHARACTERISTICS AND CLASSIFICATION OF SOILS OF GORA DAGET FOREST, SOUTH WELO HIGHLANDS, ETHIOPIA

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ABSTRACT: The soils of the slopes of the South Welo highlands have been either intensively cultivated or overgrazed and eroded. As a result there are few sites where undisturbed soils exist for use as a reference against which the impacts of land use can be evaluated. The Gora Daget forest on a very steep slope located close to Dessie town provides one of these rare opportunities for the type of investigation. Three pairs of representative soil profiles that formed under this indigenous mixed juniperous forest were investigated to establish the soil characteristics and identify the grouping within the FAO/UNESCO classification system. The depths of the soils ranged from less than 30 cm to slightly more than a meter. The solum in all soil types showed very little horizon differentiation and comprised of only Ah horizon, where it is shallower, and Ah and AC horizons where it is deeper. The Ah colour is invariably dark brown (10YR2/2) while the AC is black (10YR2/1). The crumb structure and the loam texture typifying the surface soils changes very little with depth. The main minerals constituting the clay fraction were mica, morderite and sepiolite while those comprising the skeletal fraction were pyroxenes, anorthoclase, plagioclase, morderite, quartz, and magnetite. The organic carbon and total nitrogen are generally high but available phosphorus is low. The pH is within a range suitable to most plants while both the CEC and base saturation values registered for the soils were high. The A-horizons were mollic and the soil units were identified as Mollic Leptosols and Mollic Phaeozems. All of the soils showed transitional characteristics with Andosols necessitating their third-level categorization as Andi-mollic Leptosols and Andi-mollic Phaeozems.

Key words/phrases: Ethiopia, Gora Daget forest, soils, Welo highlands

INTRODUCTION

Mixed juniperous forests were estimated to account for more than 50 per cent of the original forest cover of the South Welo highlands (DPED, 1993). These forests are assumed to have covered most of the volcanic ridges and mountain slopes at elevations of 2300 to 3100 meters. Remnant stands currently observed in the zone suggest that the forests were largely composed of trees such as *Juniperous procera, Olea europaea, Nuxia congesta, Rhus vulgaris* (Mengistu Gonsamo, 1998). Other tree species that may have constituted the forests include *Accacia abyssinica, Ekebergia capensis, Erythrina brucei* and *Maytenus obscura*. The predominant shrubs were apparently *Erica arborea, Berberiis holstii, Myrsine africana* and *Maytenus senegalensis*.

These natural forests are now on the verge of complete disappearance because of extensive crop cultivation and cattle grazing. Currently the total area under these types of natural forests does not exceed 4500 ha or 0.2 per cent of the total area of the zone (DPED, 1993). These remnant stands are confined to very isolated, remote and rugged terrain and steep slopes (with gradient of more than 60%) where crop cultivation is impractical and grazing is very difficult (Mesfin Tadesse, 1993). In most of the South Welo highlands there are few sites where undisturbed soils exist for use as reference against which the impacts of land use on soil properties can be evaluated. In many places the soils have been severely eroded leaving behind landscapes comprising of Lithic Leptosols and barren rock outcrops. The few soil studies reported for the highlands focus only on these disturbed soilscapes (Paris, 1985; Weigel, 1986; Belay Tegene, 1995; 1997).

Information on virgin forest soils is indispensable for establishing the characteristics of the soils that once covered the now barren slopes of most of the Welo highlands. Understanding the types, limitations and potentials of these soils is also of paramount importance for the utilization and proper management of the soil resources of the highlands. The Gora Daget forest, located close to Dessie town (Fig. 1) provides a very rare opportunity for this type of investigation. The area comprises typical mixed juniperous forest and virgin soils which escaped destruction because of its location on a very steep valley side slope (gradient of more than 70%) and strict protection by the Government. This paper documents the findings of an investigation carried out on the soils of this indigenous forest.

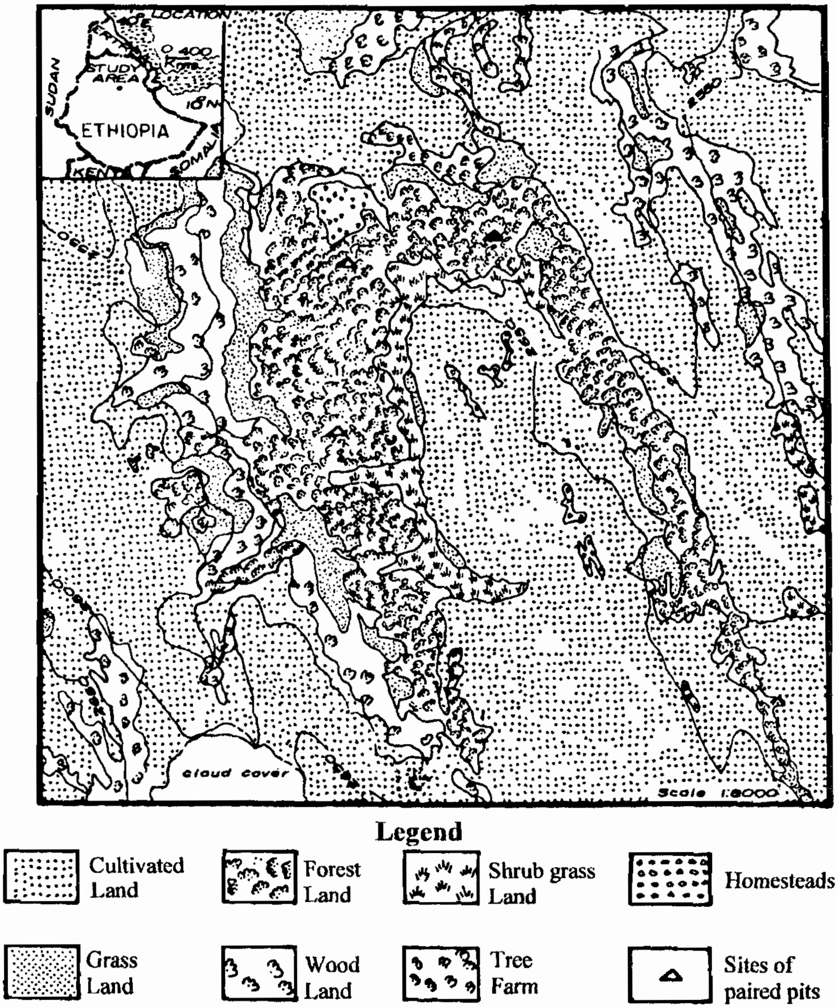

Fig. 1. Location and land use map of Gora Daget forest and its environs.

MATERIALS AND METHODS

Description of the study site

The Gora Daget forest lies at about 11°14′ 30″ N and 39′30 E at altitude of 2450 to 2650 m a.s.l., in the South Welo highlands, about 10 km north of Dessie town and 2 km NNW of Boru Sillassie village. The forest stand bounded as it is by the Bekeksa stream in the east and north, and the Misir Qitta stream in the west, covers an area of more than 60 ha along the steep valley side slopes of an interfluve ridge. The lower limits of the forest are on all sides of the V-shaped stream channels while the upper limit is the cultivated broad interfluve ridge crest. The surface occupied by the forest is marked by micro-terracettes formed on general slope gradients of 80 to 100 per cent. The geological formation of the region as a whole comprises of volcanic rocks of the Magdala group of the Upper Miocene to Pleistocene and comprises of rhyolites, trachytes, tuffs, ignimbrite and basalts (Ministry of Mines, 1973).

Rainfall records at Boru Meda, located at an elevation of 2720 m, about 2 km to the west of the study site shows mean annual rainfall of 1236 mm (Table 1). The mean annual temperature of 15° C, registered for altitude of 2540 m a.s.l., in Dessie town, and the rainfall data for Boru Meda suggest that the study site falls within the moderately cool to cool sub-tropical summer rainfall zone of the FAO/UNESCO (1990) climatic classification scheme.

Table 1. Records of rainfall made for Boru Meda and temperature for Dessie.

	J	F	M	A	M	J	J	A	S	O	N	D	Ann.
RF (mm)	31	35	84	123	108	39	315	292	148	24	20	17	1236
T (° C)	14	15	14	16	16	17	17	16	15	14	13	13	15

Source: National Meteorological Service.

Methods and procedures

The predominant plants constituting Gora Daget forest were identified in two phases. First the local names of the plants found in the vicinity of the sites where pits were opened were recorded. Then the scientific names corresponding to the local names were identified based on plant identification done in a forest about 3 km from the site (Mengistu Gonsamo, 1998).

The soils of the forest were investigated in three paired pits opened on representative slopes of the study site. Profile descriptions were made to depths of up to the parent material following the FAO Guidelines (FAO, 1990). The morphological and physical characteristics described were colour, texture, structure, consistence, bulk density, nature of horizon boundary, root distribution, etc. Soil bulk density was determined based on weight of 100 cm^3 core samples. Texture and chemical analysis were performed in the National Soil Testing Laboratory of the Ministry of Agriculture. Particle size distribution was determined using hydrometer after removing the organic matter and dispersing the soil with hydrogen peroxide and sodium hexa-metaphosphate solutions, respectively (Black *et al.*, 1965). The USDA particle size classification was employed to define percentages of sand (2.0-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm) (Soil Survey Staff, 1969). The revised legend of the Soil Map of the World (FAO/UNESCO, 1990) was used in the identification of soil units.

Soil pH was measured in a 1:2.5 soil-water suspension with standard glass electrode. Organic carbon was tested following Walkley and Black's method (Black *et al.*, 1965). Available phosphorous and total nitrogen were determined following Olsen's method and the standard Kjeldahl procedure, respectively, while the ammonium acetate method was employed to determine separately the cation exchange capacity (CEC) and exchangeable bases (Black *et al.*, 1965). Percentage base saturation was calculated against CEC.

Acid oxalate extractable Al (Alo) and Fe (Feo) were estimated on clear extracts after the soil fraction was shaken for four hours in the dark with 0.2 M ammonium oxalate-oxalic acid solution at pH 3.0. Estimation of Alo and Feo was made by Atomic Absorption Spectroscopy using N_2O-C_2H_2 and air-C_2H_2 flames (Blackmore *et al.*, 1981). P-retention capacity was estimated on the basis of the phosphate withdrawn after equilibrating the soil sample with a phosphate solution (Blackmore *et al.*, 1981).

The mineralogical composition of the soil was determined in selected samples using X-ray diffractometer (SCINTAG model X1). Firstly, analysis was conducted on the whole soil after powder mounts were prepared crushing the soil in agatha mortar. Secondly, the analysis on the clay (<2 micrometer) and the fine silt fraction (<16 micrometer) were conducted after removing the organic matter and carbonate and dispersing the samples in distilled water. The clay fraction was separated from the larger particles by sedimentation and subsequent drying of the portion that remained in suspension. Analysis of the clay fraction was carried out both before and after glycolation (*i.e.*, saturation of the soil with ethelene glycol for 24 hrs at room temperature) on samples whose particles were oriented according to the basal cleavage plane. The main features of the X-ray diffractograms used in the identification of mineral species and their relative abundance were peak height and width.

RESULTS AND DISCUSSION

Species composition of Gora Daget forest

The plant community constituting the Gora Daget forest was found to comprise of mixed forest dominated by *Juniperous procera, Olea europaea* L. (ssp. custpidata), and *Acacia abyssinica*. Other tree species that constituted the forest were *Bersama abyssinica* Fresen, *Rhus glutinosa* A. Rich ssp. *abyssinica* (Oliv.) Gilb A., *Dougalis abyssinica* Fresen, *Dovyalis abyssinica* (A. Rich) Warb, and *Nuxia congesta* R. Br. ex Fresen. The shrub layer comprised of *Rosa abyssinica* R. Br., *Carissa edulis* (Forsk.) Vahl, *Domabeya torrida* (G.F. Gmel) P. Bamps, *Clutia abyssinica, Pterolobium stellatum* (Forsk) Brenan, *Myrsine africana* L., *Maytenus senegalensis* (Lam) Exell, *Rumex nervosus* Vahl, *Asparagus falctus* L. var ternifolius (Bak) Jessop, *Sida tenuicarpa* Volleson, *Pavetta oliverana* Hiern and *Berberis hosltii* (Engl.) (Table 2). The forest was also marked by a thick carpet of herbaceous plants comprising of *Kalanchoe deficiens* (Forsk) Asch and Schwein, *Plectranthus rupests* (Hochst) Baker, *Polygala rupicola* A. Rich, *Echinops longisetus* A. Rich, and *Panicum pusillum* Hook. Lichens and mosses were also commonly observed.

Table 2. Major plant species identified in the Gora Daget forest.

Local name	Scientific name	Local name	Scientific name
Tid	*Juniperous procera*	Kerchemo	*Myrsine africana*
Woira	*Olea europaea*	Attatt	*Maytenus senegalensis*
Girar	*Acacia abyssinica*	Embuacho	*Rumex nervosus*
Azamir	*Bersama abyssinica*	Yeset kisit	*Asparagus falctus*
Embis	*Rhus glutinosa*	Chifrig	*Sida tenuicarpa*
Koshim	*Dovyalis abyssinica*	Kefeto	*Pavetta oliverana*
Askuar	*Nuxia congesta*	Busike	*Kalanchoe deficiens*
Kega	*Rosa abyssinica*	Boter	*Plectranthus rupests*
Agam	*Carissa edulis*	Kibe Golgul	*Polygala rupicola*
Wulkif	*Domabeya torrida*	Kolo	*Echinops longisetus*
Fiyel Fej	*Clutia abyssinica*	Yekok Sar	*Panicum pusillum*
Kentaf	*Pterolobium stellatum*		

Morphological and physical characteristics of the soils

Despite the very steep slopes, some of the soils were surprisingly deep and extend to depths of more than one meter while the rest are shallower -- some of them are not more than 30 cm deep (PR-1, PR-4, and PR-5). Some of the soils (PR-5, PR-6) have weathered entirely from slope deposits although most of them have formed on residual materials derived from the parent rock. The soils formed on residuum normally end abruptly in the slightly weathered greyish (2.5Y 5/1 to 5Y 5/1) parent rock, and hence form sharp lithic contact. None of the bedrock underlying the soils is weathered into saprolite as commonly observed elsewhere in the Welo highlands (Belay Tegene, 1997), apparently because of their steep slopes. All the soils are marked by dense network of roots throughout their depths because of the thick plant growth. The roots extend into the bedrock through the cracks and fissures and it is this root system that anchors the soils to the steep slopes and protects them from wasting and erosion.

The soil profiles reveal little differentiation and hence comprise of only Ah horizons where they are shallow, and Ah and AC horizons where they are deeper (Table 3). The Ah horizon soil colour is invariably dark brown

(10YR2/2) while the transitional AC horizon is black (10YR2/1). The crumb structure observed throughout the solum and which is typical of all virgin soils result from the high organic matter content and absence of mechanical disturbance. The generally low soil bulk density [0.82 to 1.08 $Mg(m)^{-3}$] reflects the influences of the high organic matter and porous soil structure.

Table 3. Texture, organic carbon, total nitrogen and available phosphorus in representative soils of Gora Daget.

Depth (cm)	Horizon	Texture (%)			Text. Class	O.C. (%)	Tot. N (%)	C/N	Avail. P[$mg(kg)^{-1}$]
		Sand	Silt	Clay					
Profile Nibo-PR-2: Andi-Haplic Phaeozem									
0-21	Ah1	41	36	23	L	4.39	0.33	13	3.70
21-53	Ah2	45	32	23	L	3.38	0.30	11	1.84
Profile Nibo-PR-3: Andi-Haplic Phaeozem									
0-21	Ah1	39	38	23	L	3.57	0.31	12	4.31
21-43	Ah2	43	34	23	L	3.70	0.32	12	2.15
43-88	AC	39	36	25	L	2.90	0.26	11	1.41
Profile Nibo-PR-6: Andi-Haplic Phaeozem									
0-16	Ah1	33	44	23	L	4.25	0.34	13	2.06
16-43	Ah2	37	40	23	L	4.38	0.36	12	1.84
43-108	AC	35	40	25	L	3.30	0.29	12	1.50
Profile Nibo-PR-1: Andi-Mollic Leptosol									
0-21/23	Ah	41	42	17	L	4.80	0.33	15	2.67
Profile Nibo-PR-4: Andi-Mollic Leptosol									
0-17/25	Ah	49	36	15	L	4.01	0.33	12	2.21
Profile Nibo-PR-5: Andi-Mollic Leptosol									
0-22	Ah	33	48	19	L	7.38	0.52	14	2.88
22-27/33	AC	39	40	21	L	3.28	0.28	12	1.36

The soils were marked by loam texture that changes very little with depth (Table 3). Sand and silt combined account for 75 to 77 per cent of the soil fraction. The shallower soils are generally gravelly loam while the deeper ones assume such gravelly texture only with depth. Field estimates show that in some of the soils gravel accounts for about 20 to 30 per cent of the soil material. Some of the lower portions of the soils are also marked by considerable presence of stones having diameters of 6 to 15 cm. Profile PR-6 has a lower part constituting a thick AC horizon comprising of 30% gravel and 20% stone content. The combination of low clay contents, high silt/clay ratio and considerable stone and gravel suggest that the soils are generally less weathered and young. These soils are also characterized by strong to moderate, fine to medium granular (crumb) structure, and friable, non-sticky and non-plastic consistence. The texture and the structure impart excellent permeability and lesser erodibility on the soils.

Chemical and biochemical properties

The chemical and biochemical characteristics of the soils described in the Gora Daget forest are summarized in Tables 3, 4 and 5. One of the impressive features is the high percentage organic carbon (3.57 to 7.38%) registered throughout the soils. Certainly, the large supply of plant detritus and dense network of roots contribute much of the organic matter incorporated in the soils. The soils are also marked by high contents of total nitrogen (0.31 to 0.52%) but very low levels of available phosphorus [2.06 to 4.31 $mg(kg)^{-1}$]. The C/N ratios of between 11 and 15 suggest that the organic matter exist in well-humified state.

The pH throughout the soil profiles ranges from 6.4 to 7.0 providing a favourable condition for plant growth. The percentage base saturation in the soils was generally high and ranged from 59 to 92 per cent. The cation exchange capacity (CEC) was between 60 to 80 cmol (+)/kg soil (205 to 424 cmol (+)/kg clay). The presence of amorphous products of weathering is clearly reflected in the 0.58 to 1.18% acid oxalate extractable iron (Feo) recorded for the soils. According to Blank and Fosberg (1989) oxalate extractable iron is a measure of ferrihydrite and amorphous products of recent weathering. The sum of acid oxalate extractable aluminum (Alo) and 1/2 acid oxalate extractable iron (Feo), which ranged from 0.72 to 1.18 per cent, also suggests the presence of some allophane and allophanic constituents. The soils also had considerable P-fixation rate. The low exchangeable potassium percentages (EPP) in these soils may be attributed to leaching and/or fixation by the micaceous materials.

Table 4. pH, exchangeable basic cations, cation exchange capacity and base saturation in representative soils of Gora Daget.

Depth (cm)	pH H_2O 1:2.5	Exchangeable Basic Cations (cmol(+)/kg soil) Na	K	Ca	Mg	Sum	CEC [cmol(+)/kg] Soil	Clay	Base satura. (%)
Profile Nibo-PR-2: Andi-Haplic Phaeozem									
0-21	6.5	0.33	0.73	40.39	9.32	50.77	67.98	230	75
21-53	7.0	0.25	0.24	43.53	10.99	55.01	75.11	276	73
Profile Nibo-PR-3: Andi-Haplic Phaeozem									
0-21	6.5	0.16	0.22	37.70	7.27	45.34	59.51	205	76
21-43	6.7	0.25	0.16	37.40	7.53	45.34	60.61	210	74
43-88	6.4	0.33	0.13	38.29	8.85	47.59	80.32	281	59
Profile Nibo-PR-6: Andi-Haplic Phaeozem									
0-16	6.6	0.25	0.30	42.75	8.40	51.70	69.42	238	74
16-43	6.6	0.33	0.27	42.37	9.04	52.01	72.93	251	71
43-108	6.4	0.51	0.24	41.44	10.93	53.12	74.65	253	71
Profile Nibo-PR-1: Andi-Mollic Leptosol									
0-21/23	6.6	0.16	0.84	39.57	9.92	50.50	65.73	289	77
Profile Nibo-PR-4: Andi-Mollic Leptosol									
0-17/25	6.6	0.32	0.45	36.68	8.01	45.47	77.40	424	59
Profile Nibo-PR-5: Andi-Mollic Leptosol									
0-22	6.6	0.42	0.69	55.34	10.14	66.59	72.26	246	92
22-27/33	6.5	0.42	0.25	47.09	11.53	59.29	73.14	295	81

Table 5. Bulk density, P-retention, and percentage acid oxalate soluble aluminium (Alo) and iron (Feo) of soils of Gora Daget forest.

Depth (cm)	Bulk density (Mgm^{-3})	P-retention (%)	Alo (%)	Feo (%)
Profile Nibo-PR-2: Andi-Haplic Phaeozem				
0-21	0.95	37.48	0.49	0.75
21-53	0.82	47.50	0.52	0.69
Profile Nibo-PR-3: Andi-Haplic Phaeozem				
0-21	1.08	40.00	0.57	0.66
21-43	0.82	35.00	0.41	0.61
43-88	0.98	38.75	0.44	0.58
Profile Nibo-PR-6: Andi-Haplic Phaeozem				
0-16	0.84	48.76	0.47	1.18
16-43	0.83	51.28	0.58	1.14
43-108	-	50.00	0.64	1.07
Profile Nibo-PR-1: Andi-Mollic Leptosol				
0-21/23	1.03	-	0.56	0.73
Profile Nibo-PR-4: Andi-Mollic Leptosol				
0-17/25	1.05	37.50	0.40	0.80
Profile Nibo-PR-5: Andi-Mollic Leptosol				
0-22	0.85	48.00	0.48	0.76
22-27/33	0.86	53.76	0.71	0.55

Soil mineralogy

The minerals identified through X-ray diffraction of the whole soil included sand and silt-sze pyroxenes, anorthoclase, plagioclase, morderite, quartz, and magnetite and various types of clay-size minerals (Table 6). The constituents of the fine silt fraction are not much different from those of the whole soil fraction (Table 7). The soil mineralogy also showed not much variation among the three pairs of soil profiles. The considerable presence of the skeletal minerals such as pyroxenes, anorthoclase and plagioclase, which are inherited from the basalt indicates the less weathered nature and the young age of the soils.

The most predominant clay mineral was chlorite but some mica, morderite, and sepiolite were also identified in the fraction (Table 8; see also Figures 2–4). Much of the chlorite appears to be pedogenic, although some of it might have been inherited from the mafic igneous rocks (Jackson, 1976). The high background of the diffractograms, observed in the patterns of the samples, provide additional evidence for the presence of a considerable amount of amorphous minerals.

Table 6. Relative abundance of minerals identified in whole soils (<2 mm) of Gora Daget forest using X-ray diffractometer.

Profile no.	Depth (cm)	Clay mineral	Pyrox.	Plag.	Anort.	Mord.	Quart.	Mag.
Boru-PR-2	21-53	***	**	**	**	*	**	*
Boru-PR-5	22-27/33	***	*	*	*	****	*	*
Boru-PR-6	16-43	***	****	*	***	*	*	*

Table 7. Relative abundance of minerals identified in the fine silt fraction (<16 micron) of Gora Daget forest soils using X-ray diffractometer.

Profile no.	Depth (cm)	Chlorite	Mica	Anorthoclase	Morderite
Boru-PR-2	21-53	**	*	***	**
Boru-PR-5	22-27/33	**	*	**	***
Boru-PR-6	16-43	**	*	****	*

Table 8. Relative abundance of minerals identified in the clay fraction (<2 micron) of Gora Daget forest soils using X-ray diffractometer.

Profile no.	Depth (cm)	Chlorite	Mica	Sepiolite	Morderite
Boru-PR-2	21-53	*		*	
Boru-PR-5	22-27/33	*	*		*
Boru-PR-6	16-43	*			

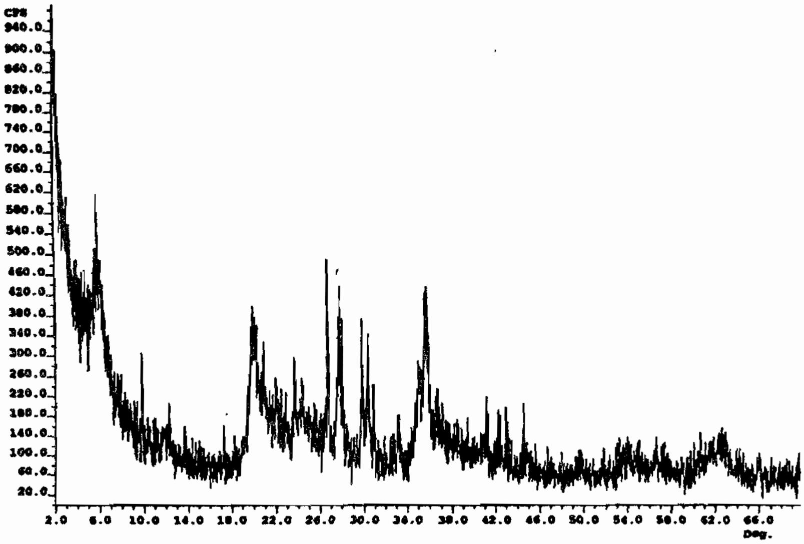

Fig. 2. **X-ray diffractorgram of clay fraction sampled from profiles Boru-Pr-2 (21–53 cm).**

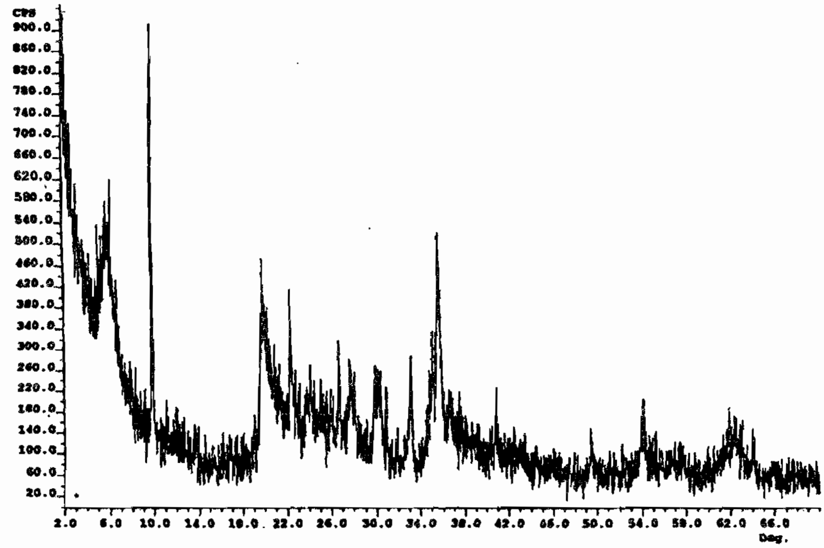

Fig. 3. **X-ray diffractorgram of clay fraction sampled from profile Boru-Pr-5 (22-27/33 cm).**

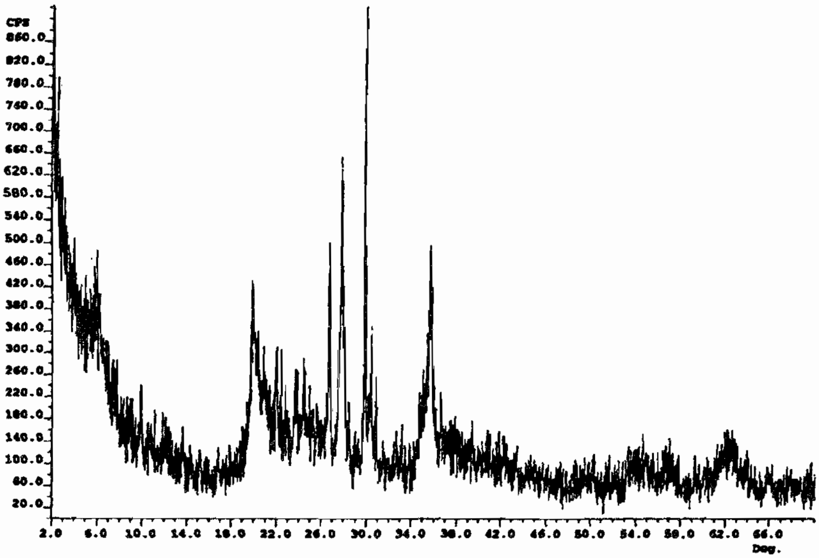

Fig. 4. X-ray diffractorgram of clay fraction sampled from profile Boru-PR-6 (16-43 cm).

Soil genesis and classification

The Ah horizons examined in the Gora Daget forest qualify as mollic A horizons because of their (i) sufficiently strong structure and peds that are neither hard nor massive; (ii) moist chroma and value of less than 3.5; the value of the soil being more than one unit darker than that of the bedrock; (iii) base saturation of more than 50 per cent; (iv) organic C of more than 0.6 and less than 8 per cent; and (v) thickness of more than 10 cm. However, the soils were separated into two groups on the basis of their depth differences. By definition soils that are underlain by coherent rock at less than 30 cm, are grouped under Leptosols (FAO/UNESCO, 1990). Thus, profiles PR-1, PR-4 and PR-5 constitute Mollic Leptosols while those with depths more than 30 cm, *i.e.*, PR-2, PR-3 and PR-6 qualify for Haplic Phaeozems. The latter are marked by mollic A horizons that are much deeper than those of the Leptosols. Both of the soil units have transitional characteristics with Mollic Andosols and it was necessary to employ a third level category to separate them from other Mollic Leptosols and Haplic Phaeozems. Accordingly, the two soils were identified as Andi-mollic Leptosols and Andi-haplic Phaeozems.

The transitional characteristics were in the main inferred from the:

- whole soil bulk density of 0.82 to 1.05 $Mg(m)^{-3}$
- sand fraction of 33 to 49 per cent and silt fraction of 32 to 48 per cent
- measured CEC of 59.51 to 80.32 cmol(+)/kg soil and calculated CEC of 205 to 424 cmol(+)/kg clay. The high CEC is attributed to the amorphous clay minerals such as allophane and allophanic clay
- acid oxalate extractable aluminium (Alo) and 1/2 acid oxalate extractable iron (Feo) of more than 0.40 per cent.

A number of factors were responsible for the genesis of these soils in the Gora Daget forest. The shallow profiles and their young age are primarily attributed to the steep slopes and the highland climate. The steep slope encourages down-slope movement of the more weathered surface soils and keep them young and shallow. The mollic A horizons are results of considerable addition of organic matter and its incorporation into the soil through the process of 'melanization'. The high organic matter is maintained because of the large supply of plant residues, the dense shrub and herbaceous plants, the dense network of roots and the low rate of decomposition due to cold conditions. Where temperature is low and considerable allophanic clay is present humus forms stable organo-mineral complexes and lead to accumulation of organic matter (Boudot *et al.*, 1986). The distinctly darker subsoil colour provides a strong evidence for illuviation cutans that result from translocation of complexes of colloidal organic substances with inorganic colloids such as allophane and imogolite, as observed by E. Frei in the Simien Mountains in the north (Frei, 1978).

CONCLUSIONS

The soil profiles examined in the Gora Daget forest were mostly less than one meter deep and comprised of only thick dark A-horizons that are in some cases underlain by thin AC layers. Almost all the studied soils had loam texture and moderate to strong and fine to medium crumb structure. In all cases organic carbon and total nitrogen contents were high. The high organic carbon and nitrogen contents are attributed to the large supply of plant detritus, the low temperature and the deficiency of phosphorus. Most of the soil properties suggest that the soils are invariably young and this is attributed primarily to the steep slopes which encourage removal of the more weathered materials. The mollic A horizons, the considerable amounts of weatherable minerals and the shallow depths on the one hand, and the absence of other diagnostic horizons and properties on the other, clearly indicate that the soils fall under Mollic Leptosols and Haplic Phaeozems at the second level of grouping. However, their transitional characteristics with Andosols also suggest their identification as Andi-mollic Leptosols and Andi-haplic Phaeozems at the third level of classification. It is believed that until recently these soils had constituted the predominant soils of most of the currently barren steep slopes (gradient >60 per cent) of Welo highlands.

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